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The effects of trust on the use of adaptive cruise control

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THE EFFECTS OF TRUST ON THE USE OF ADAPTIVE CRUISE CONTROL

by

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A thesis submitted in partial fulfillment
of the requirements for the
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The University of Iowa

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CERTIFICATE OF APPROVAL

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MASTER'S THESIS

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This is to certify that the Master's thesis of

David Alexander Dickie

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Industrial Engineering at the May 2010 graduation.

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Linda Ng Boyle, Thesis Supervisor

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Peter O'Grady

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Geb Thomas

For Isobel and Alex,
together again

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CHAPTER 1 BACKGROUND ON ADAPTIVE CRUISE CONTROL AND TRUST IN AUTOMATION

Automation has benefited society and, in particular, drivers for many years. Indeed, automated aids can increase the precision and efficiency of a particular task (Sarter & Woods, 1994) and have done so in many domains including aviation and manufacturing. Automation takes a prevalent role in the driving domain and the benefit of some automated aids such as the automobile self-starter is very clear. However, benefits of recently developed automated controllers, such as adaptive cruise control (ACC), may be influenced by individual use. This use may be founded in the level of trust a driver has with the controller. In this study trust and other relevant variables, such as ACC use, were measured through a questionnaire. It is the purpose of this chapter, through a review of the literature, to uncover variables that can influence the benefits of modern automatic controllers. Before the logic of trust - and its constructs - is considered the role of trust in human automation relationships is to be assessed. Prior to justifying the use of a questionnaire, counts of inappropriate use of automation will be described. To begin, the mechanism of ACC will be considered.

Adaptive Cruise Control

Adaptive cruise control (ACC) is an automated, intelligent transport system (ITS) that has been built into commercially available motor vehicles in Japan since 1995 and in the United States since 2001 (Llaneras, 2006; Naranjo, Sotelo, Gonzalez, Garcia, & de Pedro, 2007). Rather than operating the brake and accelerator, a driver supervises the provision of longitudinal control by the ACC system (Marsden, Brackstone, & McDonald, 2001; Young & Stanton, 2004). That is, through referencing a lead vehicle via a radar or laser sensor ACC maintains a constant, user specified headway time. ACC does not interact with other road users or roadside indicators therefore it may be implemented into traffic flows consisting of vehicles with and without ACC (Hoedemaeker & Brookhuis, 1998). The mechanism of ACC may be best described by the "linear follow-the-leader" driving model, where a driver aims to position their vehicle in proportion to the speed of a lead vehicle (Pipes, 1953). The response of ACC to braking situations is approximately ten times greater than that of the human response (0.1s:1s) (Kesting, Treiber, Schönhof, & Helbing, 2007).

The ACC system has a maximum deceleration rate of -2m/s^2 (Weinberger, Winner, & Bubb, 2001) and may not regulate speeds based on stationary vehicles or objects (Naranjo et al., 2007). Moreover, the ACC system will not regulate speeds in stop-and-go traffic (Jenness, Lerner, Mazor, Osberg, & Tefft, 2008), or specifically below 30mph (Marsden et al., 2001), and may not adjust to the topography of curved roads removing the ability to control headway on such road segments. In addition, ACC cannot function properly when obstructed by moisture (e.g., rain, snow) or debris (Rudin-Brown & Parker, 2004). The current limitations of ACC may be addressed by next generation designs that will operate in all speed ranges and stop-and-go traffic (Kesting et al., 2007).

The current ACC system allows drivers to manually override the system by either braking or accelerating (Marsden et al., 2001). These "takeover situations", where ACC limitations are realized, may be missed by drivers (Ohno, 2001; Weinberger et al., 2001) as the system provides few salient warning cues (Seppelt & Lee, 2007). This illustrates why ACC is marketed as a driver convenience rather than as a safety system (Zheng & McDonald, 2005). Indeed, the ACC system has been designed to improve the quality of the driving experience (Marsden et al., 2001) rather than to improve driving safety. Moreover, use of ACC can actually degrade safety through increased reaction times and lane position variability (Rudin-Brown & Parker, 2004).

The implementation of ACC into an increasing number of vehicles may provide a "driving strategy" [rather than a redundant infrastructure] solution for managing rising traffic volumes (Kesting et al., 2007). Moreover, ACC may actually provide a safety benefit by, in reference to a typical driver, maintaining consistently longer headway times (Ohno, 2001) and responding in considerably less time to braking vehicles (Kesting et al., 2007). Although ACC cannot control headway in all situations, only two to three weeks of continued system use are needed to learn the operation of ACC and situations were limitations arise (Weinberger et al., 2001).

Governance of Benefits in Automatic Control

The potential benefits associated with automatic controllers are governed by the users' ability to reclaim control in situations that exceed the systems' operating capacity (J. D. Lee, McGehee, Brown, & Marshall, 2006) and level of trust (J. D. Lee & See, 2004; Parasuraman & Riley, 1997). Many drivers are not aware of all situations that ACC will fail to effectively maintain headway (Dickie & Boyle, 2009; Jenness et al., 2008). The benefits of the system may, therefore, be compromised as these drivers will likely be less enabled to reclaim primary control when required. Trust in automation may be inappropriate on two levels, where overtrust corresponds to trust exceeding the automation aids' capabilities and distrust to trust below that of the systems capabilities (J. D. Lee & See, 2004). Although trust does not entirely arbitrate reliance (J. D. Lee & See, 2004) it often determines the use of automation (Parasuraman & Riley, 1997). Placing too much trust (overtrust) in automation may lead to misuse: use of automation when manual control may be most appropriate. Related to the ability of operators to reclaim primary control, overtrust may also impair the detection and diagnosis of system failures (Sarter, Woods, & Billings, 1997). Disuse occurs when operators reject the use of automation, possibly due to a lack of trust.

Dickie & Boyle (2009) proposed that lower levels of ACC limitation awareness were associated with higher levels of trust and misuse. This was consistent with findings showing that users deemed an automated aid trustworthy even with little knowledge of that aid (Dzindolet, Peterson, Pomranky, Pierce, & Beck, 2003). However, trust is not a binary process (J. D. Lee & See, 2004), operators may have varying levels of trust in a system (somewhere between distrust and overtrust) and there may be distinct behaviors associated with these levels of trust.

Trust in the Use of Automatic Controllers

In a perfect world, automatic devices and computers would replace human planning, control, and problem solving (Bainbridge, 1983). However it is not a perfect world nor is it tenable to suggest that an autonomous system could effectively perform with little or no human involvement (Sarter et al., 1997). Indeed, the contribution of human operators is crucial (Bainbridge, 1983) and alludes to a number of roles: (1) planning, (2) teaching (programming), (3) monitoring (detection and diagnosis of failures), (4) intervening, and (5) learning (Sheridan, 1987). Of interest to this thesis are roles monitoring and intervening (i.e., roles 3 and 4) and how their attainment, pivotal to the existence of ACC benefits (J. D. Lee et al., 2006), may be influenced by trust. Awareness of ACC limitations may be classified as the detection of system failures. The use of ACC in situations that exceed the systems operating capacity (e.g. curved road segments) represents a lack of intervention and the avoidance of such use as indicative of intervention.

Detection and diagnosis of system failures is the most important role of the supervisory controller (Moray, 1986). Trust in a system may impact the detection of failures as people will rely on automation that appears to be reliable in situations that are encountered most often (Sarter et al., 1997). In other words, operators may place their trust in and use the system in all situations even when it is not working effectively. Further, when operators display significant amounts of trust in an automatic controller, they may choose automatic control over manual control (Muir, 1987) and fail to intervene when the system fails (Zuboff, 1988). Alternatively, a lack of trust may eliminate the potential of the automatic controller (Zuboff, 1988). Insufficient trust in automatic controllers may arise from false alarms (Parasuraman & Riley, 1997). For example, drivers will distrust collision avoidance systems if a danger signal is not reliably provided (Bliss & Acton, 2003) resulting in the system being ignored or disabled (Tijerina & Garrott, 1997). Disuse, through lack of trust, was also present in users of automated image detectors, illustrated by their preference for manual image detection even when they were advised that the automated aids' performance was superior to their own (Dzindolet, Pierce, Beck, & Dawe, 2002). As there is little or no evidence to suggest that disuse of ACC would decrease the safety of drivers and bystanders, the main focus of this thesis is to determine the effect of overtrust. Research has shown the influence of overtrust in automation for complex tasks. That is, detection and diagnosis of failures (Sarter et al., 1997) followed by intervention (Zuboff, 1988) are moderated by overtrust. Before divulgence into this research it seems pertinent, since trust is a construct of many elements (Rempel, Holmes, & Zanna, 1985), to define those most meaningful to the purpose of this thesis.

The Logic and Constructs of Trust

To trust an entity or group is to expect that the spoken or unspoken promise of this entity or group can be relied on (Barber, 1983; Rotter, 1971). The constructs of trust have been defined as perceived predictability, dependability, and level of faith (Barber, 1983; J. D. Lee & Moray, 1994; Muir, 1987, 1989; Rempel et al., 1985). Predictability is realized when an entity acts as it has in the past; dependability is reached when an entity conforms to a set standard. Faith, in this instance, is not related to religious beliefs rather it may be formed when an entity successfully provides services not fully understood by a beneficiary (J. D. Lee & Moray, 1994; Muir, 1987; Rempel et al., 1985). For example, people that choose to use automatic income tax software without understanding the underlying process of tax returns in the United States may be said to trust and use via a level of faith in this software. It has been shown that males and females will differ in their trust in technology (Venkatesh, Morris, & Ackerman, 2000). Females will generally be more conservative and may have lower levels of trust in technology than seen in males (Venkatesh et al., 2000). Indeed, males have been shown to have more positive perceptions towards and feel more at ease in the use of assistive computerized technology (Arch & Cummins, 1989; Gefen & Straub, 1997; Shashaani, 1997; Venkatesh et al., 2000; Whitley, 1997).

In this study and based on the literature, trust is defined as the perception that the ACC system will perform predictably and dependably. Trust will develop as drivers perceive the system to perform as they predict and will deepen as they come to depend on their predictions (Muir, 1987). Faith will not be measured as the recruited participants are licensed drivers and, by this prerequisite, will understand the service provided by ACC. Because trust is founded in predictability and dependability, overtrust may lead to inappropriate use of automation. Indeed, humans have a tendency to overweight small samples (Muir, 1987) and therefore operators may trust (overtrust) and use a system based on its predictability and dependability in the most common of situations (Sarter et al., 1997) (ignorant to the fact that the system may not be predictable and dependable in other situations).

Overtrust and the Inappropriate Use of Automation

It is important to recognize that overtrust is not only present in one specific domain but several examples do exist in aviation. For example, while attempting to land, an American Airlines Flight collided with the terrain 33 miles northeast of its destination (Cali, Columbia), killing 159 of the passengers and crew onboard (ACRC, 1996). The flight crew, trusting the automated flight management system (FMS), did not reassume manual control of the airplane even when supervision of the FMS became confusing (ACRC, 1996; Endsley & Strauch, 1997). The flight crews' trust may have been justified based on their prediction that the FMS would land the airplane as it had before and, based on that prediction, depended on the FMS to indeed land the plane. This provides a poignant illustration of how overtrust may lead to misuse, degraded system performance and ultimately catastrophe. Examples from other domains illustrate that the effects of overtrust are not specific to aviation.

Dzindolet et al. (2003) found that users of automated image detectors placed overtrust in these aids to which inappropriate use (misuse) and degraded performance was the consequence. As described earlier, the users with overtrust generally had little knowledge of the automated aid (Dzindolet et al., 2003). Therefore, it seems that overtrust may be associated with limited awareness of an automated systems capabilities and misuse of the system. In a flight simulation task, users displayed high levels of inferred trust and over-relied on automation even in light of advice that the system did not perform without failure (Singh, Molloy, & Parasuraman, 1997). In a simulated process control plant environment, J. D. Lee & Moray (1994) identified some users as preferring automatic control even with prior knowledge and actual experience of system faults. Of particular interest, Dickie & Boyle (2009) allude that drivers with higher levels of trust may be unaware of ACC limitations and fail to intervene in situations where the system cannot effectively maintain headway. Like the data considered in this thesis, the data used by Dickie & Boyle was collected via a questionnaire.

Questionnaires for Data Collection

It is often the case that questionnaires do not provide evenhanded and true reflections of individual perceptions and behaviors (Krosnick, 1999). Participants will generally complete questionnaires in an acquiescent, automatic fashion. That is, they will merely provide answers with little thought (Cialdini, 1985). The cumulative cognitive effort required for participants to provide answers that are as close to reality as possible throughout the questionnaire is substantial (Krosnick, 1999). In other words, when participants begin a questionnaire they are faced with expending a great deal of effort that will only become greater as they continue through the questionnaire. The concerns with questionnaires extend beyond cognitive effort; social bias may significantly impact how participants respond (Randall & Fernandes, 1991). Such an example of social bias is illustrated by underreporting of behaviors and perceptions that are not socially accepted. There is, however apparently absent, reason for the use of questionnaires.

Although participants must expend a great deal of cognitive effort when completing a questionnaire there are many motives for them to do so. Particular to the present thesis, participants may have been motivated by the spirit of altruism (Warwick & Lininger, 1975). This study may provide insights that could make driving with ACC a safer experience for users and bystanders. The potential for such a positive outcome was communicated to participants and this may have motivated a more accurate response. The questionnaire did not require participants to provide information that could be seen as socially unacceptable (e.g., it did not ask for insight into any driving related offences). This suggests that, although there are concerns associated with questionnaire-based research in general, the design of the questionnaire administered as part of this thesis moderates these concerns.

The Use of a Questionnaire in Contrast to Related Research

Much of the recent research concerning ACC is not related to human interaction but rather potential innovations to the system, such as full stop control (Bifulco, Simonelli, & Di Pace, 2008; Naranjo et al., 2007; Vahidi & Eskandarian, 2003; Venhovens, Naab, & Adiprasito, 2000) or the overall effects it may, theoretically, have on traffic systems (Davis, 2007; Kesting et al., 2007). Moreover, this thesis represents an augmentation of the previous human subject field research (e.g. Rudin-Brown & Parker, 2004). The present study design allows assessment of a significantly larger sample that, difficult to replicate in a field study, may be more representative of the ACC user population.

A noteworthy distinction of this thesis is that it will assess participants who perform driving tasks in a variety of different vehicles. This suggests the results may be more representative of the entire population and inherently include individual system and vehicle differences. The potential vehicle disparity within the population is illustrated by many car companies such as DaimlerChrysler, Nissan, BMW, Toyota, and Lexus implementing ACC systems into their vehicles (K. Lee & Peng, 2002). Previous field research (Brookhuis, van Driel, Hof, van Arem, & Hoedemaeker, 2009; Rudin-Brown & Parker, 2004; Weinberger et al., 2001) assessed participants using the same, typically "high-end", vehicle. These studies only allowed participants, who were first-time users, to interact continually with the ACC system for a minimum of ninety minutes (Rudin-Brown & Parker, 2004) and a maximum of four weeks (Weinberger et al., 2001). Responses to the questionnaire administered here indicated that many participants had been using ACC in a variety of vehicles for several years. Finally, as there is no exemplarily manner in which to assess user response to new technology (Van Der Laan, Heino, & De Waard, 1997), any claim for a loss of validity founded in the use of a questionnaire may be suitably challenged.

Chapter 1 Summary

Through a review of the literature, this chapter makes clear the mechanism of ACC and the governance of the potential benefits provided by automatic controllers. Further, it defined the constructs of trust, how this may vary and how it may influence the use of automatic controllers. Overtrust may impair the detection and diagnosis of system failures (Sarter et al., 1997), lead to misuse of automation (Parasuraman & Riley, 1997), and ultimately degrade system performance (Dzindolet et al., 2003; J. D. Lee & Moray, 1994) or even result in the loss of life (ACRC, 1996; Endsley & Strauch, 1997). Distrust in automation may also arise however trust is not a binary process (J. D. Lee & See, 2004). Moreover, it was noted that males may have greater trust in ACC than seen in females. Thus the aims of this thesis are threefold: (1) determine if overtrust, distrust, and intermediate levels of trust in ACC are present; (2) assess the influence of these levels of trust, specifically overtrust, on the use of ACC; (3) determine those most likely to exhibit particular levels of trust in automated control (e.g., males or females; younger or older). Much of the prior research surrounding ACC has been based in field studies however a questionnaire for data collection may augment previous findings via a larger and more representative user sample. The following chapter describes the questionnaire-based method used to obtain the data required to meet the thesis aims.

CHAPTER 2 METHOD

This thesis makes use of data obtained in two separate protocols. This chapter describes the method used in these protocols and how the first (pilot) influenced the second (main) protocol.

Participants

All the participants assessed as part of this thesis were solicited from registered owners of vehicles that could potentially have ACC as a before-market option. The vehicle make, model and year were compiled from data available on automobile manufacturers' websites. The resultant list was then submitted to the Iowa Department of Transportation (Iowa DOT) to be matched to registered vehicle owners in the state of Iowa. In the pilot study, 1000 drivers were sent a questionnaire. These drivers were selected from the list of registered owners were selected using a stratified random sampling procedure (stratified by city of residence).

This pilot study showed that the majority of vehicles with ACC in the state of Iowa were Toyota, Lexus, Audi, and Infiniti vehicles. Therefore only owners of these vehicles were part of the main protocol. In the main study, using the same stratified random sampling technique, an additional 1600 questionnaires were distributed to those who were not previously selected in the pilot.

Distribution

For both the pilot and main study, participants were post-mailed a copy of the questionnaire with a University of Iowa Institutional Review Board (IRB) approved consent letter. Participants were given the option to fill out a paper (3 pages, doubled-sided) or electronic-based questionnaire. The password-protected http address of the electronic questionnaire was provided with the material distributed to potential participants. In the pilot there were a total of 276 questionnaires returned with 82 participants selecting the electronic questionnaire and 194 selecting the post mailed paper version. In the main protocol the addresses of 107 potential participants were not valid and therefore only 1493 potential participants received the questionnaire. The main protocol yielded a total of 514 returned questionnaires with 197 participants selecting the electronic questionnaire and 317 selecting the post-mailed paper version. All participants that completed and returned the questionnaire were compensated with a $10 gift card from a choice of three major retailers.

Administered Questionnaire

The questionnaire, consistent across both protocols aside from the forth mentioned amendments, was designed to understand the perceptions and behaviors of ACC users before and after interaction with the system. The questionnaire was also designed to compliment some of the existing research on ACC users. For that reason, some questions were purposely similar to those posed in previous studies (Jenness et al., 2008). The questionnaire consisted of 17 questions related to driving and ACC use. An additional 6 questions gathered demographic information such as the participants' age, gender, and years driving with ACC. The final set of questions determined gift card compensation preference and solicited interest in participating in future studies.

As it may have only been an option, potential participants did not necessarily have or know about ACC. Therefore, following the initial questions related to demographic characteristics, a short but definite description – not provided in the pilot - was provided to participants in the main protocol (Figure 1). Many of the participants in the pilot protocol confused ACC with conventional cruise control (CCC) or just did not have the system. This further prompted the inclusion of the description in the main protocol so to reduce nonsensical responses and involve the many participants without ACC. The data for participants without ACC are not analyzed as part of this thesis since the main focus was on the perceptions and behaviors of those with ACC. The non-user data will be considered in future studies.

The car you own may have Adaptive Cruise Control (ACC). This is a new technology different from regular cruise control. Regular cruise control is found in most cars and maintains a constant speed without you keeping your foot on the accelerator pedal. Adaptive Cruise Control (ACC) does this as well however it also automatically slows your vehicle down without you pressing your foot on the brake pedal. The ACC laser sensors can detect moving vehicles in front of your own vehicle and, if required, slow your vehicle.

Figure 1: Description of ACC provided to participants

All participants in the main protocol, whether they had used ACC or not, were encouraged to complete eight parts of a Likert-scaled question based on the provided description. This question was designed to capture their potential trust in ACC and how they may use the system (e.g., “I would trust an ACC system”, “If I had ACC I would use it often”). As with most of the Likert-scaled questions, responses were requested on a 5-point scale, ranging from “Strongly Disagree” to “Strongly Agree”. The parts to this question involved non-users in the study and may have also indicated *a priori* perceptions of ACC users (i.e., their predictions of how trustworthy the system is and how they may use it). Following this question, participants were asked to state if they owned or had ever driven a vehicle with ACC. If they responded, "Yes", they were asked to continue with the questionnaire, if they responded, "No", they were directed to the final set of questions. A response of "No" did not disqualify compensation.

Perceptions such as trust and system reliance were measured through a similar Likert scale as before. Participants were asked to rate how often they used ACC under certain conditions (e.g., when on curved road segments or in heavy traffic). Where responses ranged from 1 ("Not at all"), through 3, ("Sometimes") to 5 ("Always"). To determine participant's awareness of the limitations discussed previously, participants were asked to rate how much ACC would help them in situations where limitations were realized (e.g., on curved roads). Responses ranged from 1 ("Not at all") to 5 ("Very Much"), with an additional response of 6 representing "Don't know". The majority of the questions asked were formatted to a Likert scale however a few questions were dichotomous with a response of "Yes" sometimes leading to provocation for further insight (e.g., "If you purchased this same vehicle again, would you want it to have ACC?"; "Was there anything difficult about learning to use ACC?", "If *Yes*, please explain"). The full questionnaire is found in Appendix A.

Questionnaire Response and Data Refinement

In the pilot 27.6% (n=276) of potential participants responded, of these 76 stated that they had driven a vehicle with ACC; 18 were excluded from the analysis as they stated using the system for more than 8 years. ACC had been available in the US for only 8 years at the time of the study (Llaneras, 2006). Hence, the responses of 58 ACC users were initially considered in the pilot analysis. The successful distribution of 1493 questionnaires in the main protocol yielded a response rate of 34 percent (n=514). Of these, 134 participants declared that they had used an ACC system; 2 were excluded from the analysis by the exclusion criteria as before. Therefore, the responses of 132 participants were initially considered in the main analysis.

The inclusion of the ACC description (Figure 1) and previously mentioned restricted sampling procedure (based on vehicle make) in the main protocol had a positive effect (higher response rate; higher percentage of ACC users; less confusion with conventional cruise control) over the outcome of the pilot.

Chapter 2 Summary

This chapter described the data used in this thesis and how they were obtained; a questionnaire was designed and distributed to registered owners of vehicles that potentially had ACC. A pilot protocol was undertaken and a subsequent main protocol benefitted from the data obtained in the pilot. That is, the questionnaire and sampling procedures were revised so to improve the data for consideration in the main analysis. The techniques used to analyze the acquired data are described in the next chapter.

CHAPTER 3 DATA ANALYSIS

This chapter describes the analytic techniques used in this thesis and how these techniques were applied to the acquired data using Statistical Analysis System (SAS) 9.1.3.

Cluster Analysis

A numerical method for uncovering groups (clusters) of homogeneous observations, cluster analysis may be used to make inferences about divisions that naturally exist within any given population of data (Everitt, Landau, & Leese, 2001). Unlike classification, cluster analysis makes no assumptions regarding group size or number (Johnson & Wichern, 2007). In other words, the size and number of groups is not postulated or known prior to the analysis. However, one assumption may be that there is likely to be more than two groups or clusters found. Grouping occurs through the computation of distances between individual observations and among the formed clusters (Johnson & Wichern, 2007). There are various clustering algorithms and distance metrics; complete linkage, a hierarchical method, is the chosen algorithm and Euclidean distance the distance metric.

Clustering may occur in a hierarchical or partitioned (nonhierarchical) manner. The former segregates data in a series of either divisive or agglomerative steps (Everitt et al., 2001). The lesser used (Everitt et al., 2001) divisive method separates individuals from an initial single group made up of all individuals; the agglomerative method starts in the opposite manner by fusing individuals together. The complete linkage algorithm is agglomerative in nature; this is less computationally demanding than any divisive method and is more suitable to the multinomial data used here (Everitt et al., 2001). Over other hierarchical agglomerative methods, such as single-linkage, complete linkage was chosen as it links based on the maximum difference between two points or clusters (Johnson & Wichern, 2007). In other words, similar points at the extreme ends of two different clusters are not joined, maximizing within-cluster homogeneity. Finally, nonhierarchical methods were avoided as the clusters found here, based on levels of trust, were likely to have some sort of hierarchical or overlapping relationship (i.e., being a multinomial process (J. D. Lee & See, 2004), trust would likely range from and within the two previously described extremes of distrust and overtrust). The chosen distance metric, the Euclidean distance, is the most widely used (Everitt et al., 2001) and, appropriate to this thesis, is the most suited to analyses where more than two variables are considered in clustering (Grover & Vriens, 2006). The number of clusters will be plotted against Pseudo F (PSF) statistics so to optimize the clustering solution. Noticeable changes in these statistics (e.g., a sharp rise preceding a peak and subsequent fall) relevant to a particular number of clusters is suggestive of the optimal solution (Everitt et al., 2001). Other methods for determining the number of clusters are available however their success cannot be generalized and there is almost always a sense of subjectivity in the best method and, indeed, the optimal number of clusters (Everitt et al., 2001).

Once the clusters are defined they will be further assessed using other statistical methods, namely, Kruskal-Wallis ANOVA and canonical ANOVA. These analyses will assess differences in variables not included in the cluster analysis, allowing for inferences to be made regarding the influence of particular levels of trust. While the cluster analysis itself will realize aim (1), such inferences will meet the second of the thesis aims: assessing the influence of trust on the use of ACC.

Mathematical Notation of the Chosen Clustering Methods

Complete Linkage Clustering

The following steps (Johnson & Wichern, 2007) were taken in the complete linkage cluster analysis:

1. For *N* objects, start with *N* clusters, each containing a single record with an *N* × *N* symmetric matrix of distances D = $\{d_{ik}\}$.
2. Search the distance matrix for the pair of clusters separated by the smallest distance. Denote the distance between the found clusters *U* and *V* as d_{UV}.
3. Merge the found clusters to create the newly formed cluster *UV*. Update the distance matrix by (a) removing the rows and columns corresponding to clusters *U* and *V* and (b) inserting a row and column giving the distances between cluster (*UV*) and all other clusters.

   The distance between cluster UV and any other cluster W is measured by the Euclidean distance (equation 2) and computed (Johnson & Wichern, 2007) by

$$d_{(UV)W} = \max\{d_{UW}, d_{VW}\} \qquad (1)$$

4. Repeat steps 2 and 3for *N* – 1 times, leaving all objects in a single cluster. Record the identity of clusters that are merged and the distance at which merges occur.

The Euclidean Distance

The Euclidean distance is measured (Everitt et al., 2001) by

$$d_{UV} = \left(\sum_{k=1}^{p}(x_{Uk} - x_{Vk})^2\right)^{\frac{1}{2}} \qquad (2)$$

where x_{Uk} and x_{Vk} are the *k*th variable value of the *p*-dimensional observations for records *U* and *V*, respectively (Everitt et al., 2001).

The Use of a Cluster Analysis

Automation may be overtrusted (Singh et al., 1997) or distrusted (Dzindolet et al., 2002) but it is clearly not a binary process (J. D. Lee & See, 2004). Hence, cluster analysis may reveal the various levels of trust in automation that cannot be revealed otherwise. Cluster analysis has been used previously to reveal variations in teenage driver behavior (Deery & Fildes, 1999; Donmez, Boyle, & Lee, In press), responses to rear-end collision avoidance systems (RECASs) (J. D. Lee, McGehee, Brown, & Reyes, 2002), and among those driving while-intoxicated (DWI) (Ball, Jaffe, Crouse-Artus, Rounsaville, & O'Malley, 2000). The outcome of the cluster analysis conducted by Deery & Fildes (1999) was used to define associations between driving behavior and personality traits. It is the purpose of this thesis to reveal associations between trust in ACC and variables such as system use and limitation awareness.

Constructing the Cluster Analyses

Not all ACC users are aware of the systems' limitations (Jenness et al., 2008). Therefore the pilot analysis attempted to uncover the levels of awareness exhibited by

ACC users. Participants were asked to rate how much they felt that ACC would help them in situations where the maintenance of headway by ACC is often degraded (in reference to stopped vehicles; slow moving traffic; and on curved road segments). The responses to these questions (from 1 “Not at all” to 5 “Very Much” and 6 “Don’t know”) were used to form the pilot cluster analysis. The literature indicted that trust in an automated system may be a strong indicator of behavior and limitation awareness. Many drivers in the pilot analysis were shown to lack awareness of ACC limitations. Therefore, to test if awareness was a consequence of trust, clustering participants via their trust in ACC was the focus of the main analysis.

The cluster analysis from the data in the main protocol attempted to capture the relevant constructs of trust (discussed in Chapter 1) using three questions: (1) level of agreement to trusting ACC based on the provided description; (2) level of agreement to trusting ACC based on actual system use; and (3) level of agreement to relying on the system more since its first use. Question (1) may suggest trust levels based on participants predictions of system performance. This type of trust may also be classified as *a priori* trust (J. D. Lee & Moray, 1994). That is, trust levels before interaction with the system has occurred. Provoking a response based on actual use (2) may illustrate how much participant’s trust the system based on dependability. Determining how reliance on ACC has changed through use (3) may give a further indication to whether or not drivers have changed their trust in the system as they first predict before depending on the systems actions. The described clustering algorithm and distance measure were programmed into SAS using the general cluster analysis procedure (“proc cluster” statement).

Logistic Regression Analysis

Logistic regression analysis predicts the probability of an event occurring (e.g., attended university) based on some explanatory variables (e.g., gender, social class). This type of regression analysis is specific for dependent variables with categorical rather than continuous outcomes. A lot of the time there is only one other outcome to the event of interest. In other words, the dependent variable in many problems is a dichotomy (Allison, 1999) (e.g., attended university or did not).

Binary Logistic Regression

When a response (dependent) variable has two levels (events), the odds of one event may be modeled against the other on the basis of the explanatory variables (Dillon, 1984). That is, the odds of one event occurring is the ratio of the probability (*p*) of occurrence to the probability of no occurrence, denoted by

$$\text{Odds} = \frac{p_i}{1 - p_i} = \frac{\text{probability of event}}{\text{probability of no event}} \qquad (3)$$

The logistic regression model is completed by transforming probabilities to odds (Equation 3), taking the logarithm of the odds and setting the equation equal to the explanatory variables (Allison, 1999; Dillon, 1984), as such

$$\log\left[\frac{p_i}{1 - p_i}\right] = \alpha + \beta_1 x_{i1} + \beta_2 x_{i2} + \ldots + \beta_k x_{ik} \qquad (4)$$

where p_i is the probability that $y_i = 1$ (the event occurs).

The previous literate indicated that trust in ACC was likely extended beyond a binary process. When a dependent variable has more than two levels, a multinomial logistic regression model should be applied (Allison, 1999).

Multinomial Logistic Regression

Rather than writing multiple binary logistic regression models – that would be unworkable as, if true, the combined probabilities would exceed 1 (Allison, 1999) – the multinomial logistic regression model is formulated as

$$\begin{aligned} \log\left[\frac{p_{i1}}{p_{i3}}\right] &= \beta_1[x_i] \\ \log\left[\frac{p_{i2}}{p_{i3}}\right] &= \beta_2[x_i] \\ \log\left[\frac{p_{i1}}{p_{i2}}\right] &= \beta_3[x_i] \end{aligned} \qquad (5)$$

where $[x_i]$ is a vector of the explanatory variables for record *i*. The third equation is redundant in that, as the equations create contrasts between one level and a constant reference level, it may be obtained through a linear combination of the first two (Allison, 1999).

Constructing the Multinomial Logistic Regression Analyses

Multinomial logistic regression models were applied in the pilot and main analyses. In the pilot, the model predicted the likelihood of having a particular level of awareness to the previously mentioned limitations. This, as the dependent variable, had three levels: “aware”; “unsure”; and “unaware” [of ACC limitations]. It was equated to several explanatory variables to complete the model: trust in ACC, intention to use conventional cruise control in the absence of ACC, period of time with access to ACC, tendency to use ACC on curved roads.

In the main analysis, a multinomial logistic regression model was constructed to assess the probability of a participant being classified within a level of trust determined in the cluster analysis. This dependent variable had four levels: one reference (“overtrust”) and three contrast levels (“cautious”, “neutral”, and “distrust”). The explanatory variables were gender, awareness of the inability of ACC to control headway on curved roads, the tendency to use ACC in heavy traffic, and desire to have ACC in future personal vehicles. These explanatory variables were arrived at by a logical process. First, the literature suggested that demographic variables may explain levels of trust. Therefore these were entered into the model and their significance assessed. It was also shown that levels of trust may be associated with varying behavior while using automation and limitation awareness. Measures of behavior and awareness were therefore entered into the model following the determination of significant demographic variables. Nonsignificant variables were removed from the model. The questionnaire measured additional perceptions and behaviors and these were also tested for significance within the model (e.g., desire for ACC in the future). All the explanatory variables entered into the model were classified in binary so to lead to more easily interpretable results (Allison, 1999). The classification process defined the strongest aversion to use or agreement as 1 else as 0 (e.g., responses of 1 [“Not at all”] to the question related to use of ACC on curved road segments were classified as 1 and all other responses [towards “Sometimes” and “Always”] as 0). At least five responses were present in both binary groupings for each explanatory variable so to meet significance testing requirements. It should be noted that measures not entered as explanatory variables were the questions used to define levels of trust (these questions were described in the prior section on cluster analysis). The multinomial analysis was programmed into SAS using the categorical model procedure ("proc catmod" statement).

Constructing the Binary Logistic Regression Analysis

As the main interest of this thesis is overtrust, the clusters discovered in the main analysis were collapsed so to leave two levels of overtrust or other. The dependent variable in the binary logistic regression model therefore consisted of "overtrust" or "did not overtrust".

The binary model was constructed in the same manner as was the multinomial model. The binary analysis was programmed into SAS using the logistic regression model procedure ("proc logistic" statement).

Chapter 3 Summary

The chosen analytic techniques were described and their choice justified. The cluster analysis will uncover levels of trust in ACC, realizing aim (1) of this thesis. These clusters may then be assessed using methods such as Kruskal-Wallis ANOVA to make additional inferences about levels of trust, realizing aim (2). Logistic regression analysis was shown to predict the probability of an event (e.g., membership to a particular cluster) based on some explanatory variables (e.g., ACC use, gender). This will allow for the determination of those most likely to exhibit overtrust and other levels of trust, realizing aim (3). The following chapter describes the results from the data analysis.

CHAPTER 4 RESULTS AND DISCUSSION

The data obtained from each protocol are considered independently. However, as mentioned in the previous chapter, the analysis of the pilot data did influence the basis of the main analysis. This chapter will present and discuss the results from each analysis.

Pilot Analysis

Three participants were excluded from the cluster analysis as they did not respond to one or more of the limitation related questions. Of the remaining 55 participants in the pilot protocol, 63 percent were male and 37 percent female. The mean age of participants was 55.8 years (SD = 16.5 years); they had access to the system for 2.58 years (SD = 1.8 years). The Pseudo F (PSF) statistics suggested that three clusters (PSF = 49. 4) was an appropriate inference from the analysis (2 clusters PSF = 41.6, 4 clusters PSF = 43.5) and were classified as: (1) aware, (2) unaware, and (3) unsure of the limitations of ACC. The median levels of awareness are shown in Table 1. The statistical differences in levels of awareness are illustrated in Figure 2. The cluster labelled unsure (n=18) showed that they were aware of only one of the three ACC limitations. The aware cluster (n=23) was acutely aware of all the limitations. The unaware cluster (n=14) did not recognize any of the ACC system limitations.

The majority (77 percent) of the aware cluster avoided using ACC on curved roads. Fifty-three percent of unaware drivers avoided such use and only 36 percent of unsure drivers did the same. These differences in avoidance of ACC use were significant (χ^2 (2) = 6.22, p = 0.045). None of the unsure drivers avoided using ACC when they “felt tired or otherwise impaired”, 27 percent of unaware drivers avoided such use and 57 percent of the aware drivers did the same (p = 0.035, Fisher’s exact test).

Unsure drivers would use conventional cruise control (CCC) "very often" in the absence of ACC (median = 5 to "How often would you use CCC if you could no longer use ACC", 1 being "Never" and 5 "Very often"). Unaware drivers would use CCC "often" (median = 4), and aware drivers "sometimes" (median = 3). The differences in willingness to use CCC in the absence of ACC were significant ($H(2) = 12.48$, $p = 0.002$).

Table 1: Median awareness levels in pilot

Question	Aware	Unaware	Unsure	H (DF=2)	p value
Stop-and-go	1	5	2	41.71	< 0.0001
Stopped Vehicle	2	5	4	19.37	< 0.0001
Curved road	1	4.5	4	37.13	< 0.0001

Note: 1 being "Not at all" [toward aware] to 5 being "Very much" and 6 being "Don't know" [toward unaware].

Due to the same sample size, findings from the multinomial logistic regression analysis were considered significant at $p < 0.10$. From Table 2 it can be noted that participants were more likely (OR = 5.87) to be unaware, rather than aware of ACC limitations if they had notable levels of trust in the system. Unaware participants were also more likely (OR = 6.55) to use ACC on curved roads. Participants were less likely (OR = 0.53) to be categorized as unaware with longer time periods of access to ACC.

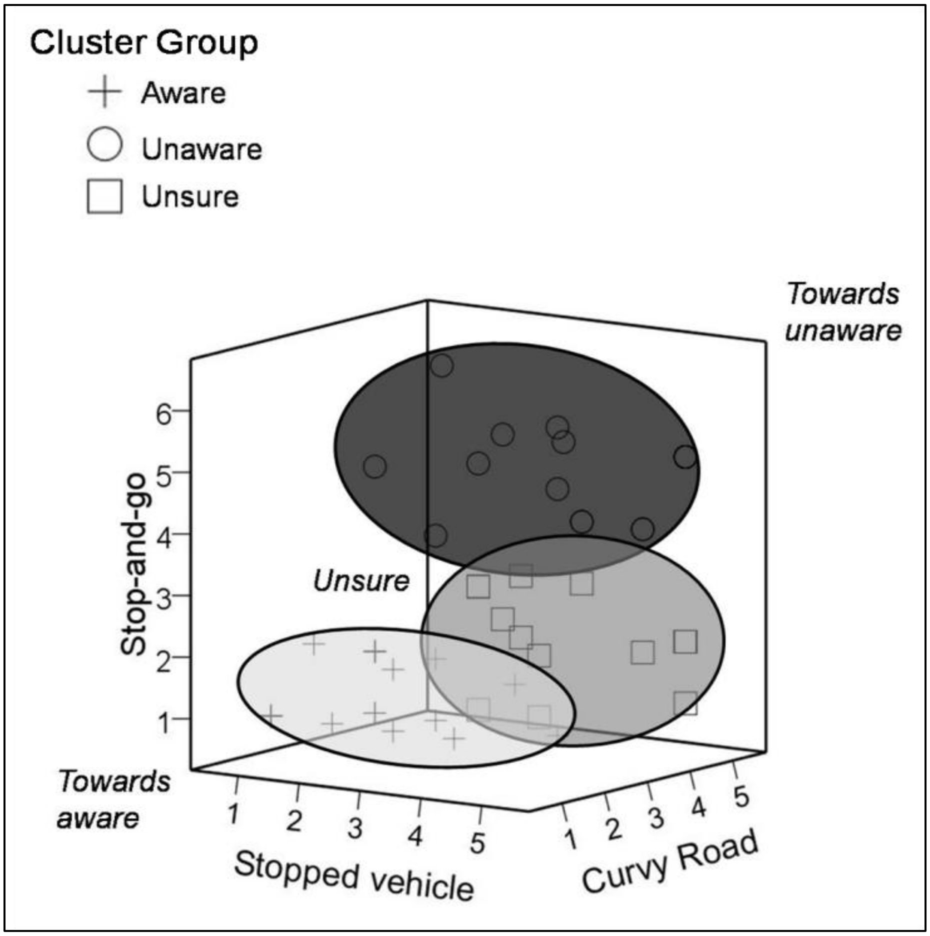

Figure 2: Pilot cluster analysis outcome

Table 2: Predicting classification as unaware when compared to aware

Parameter	Parameter Estimate	Chi-square	Odds ratio	p value
Intercept	-0.52	0.07		0.796
Trust	1.77	2.71	5.87	0.099
Use on curved road	1.88	4.13	6.55	0.042
Period of access	-0.64	4.14	0.53	0.042
-2 Log likelihood at zero				111.91
-2 Log likelihood at convergence				75.98

Table 3 illustrates that participants were more likely to be unsure, rather than aware, of the system limitations if they had notable intention to use CCC in the absence of ACC (OR = 9.11), and if they indicate a willingness to use the system on curved roads (OR = 6.17).

Table 3: Predicting classification as unsure when compared to aware

Parameter	Parameter Estimate	Chi-square	Odds ratio	p value
Intercept	-0.33	0.02		0.871
Use on curved road	1.82	3.12	6.17	0.077
Use CCC	2.21	3.52	9.11	0.061
-2 Log likelihood at zero				111.91
-2 Log likelihood at convergence				75.98

Pilot Analysis Summary

It was taken from the pilot analysis that (1) users of ACC exhibit different levels of awareness regarding the systems' limitations; (2) those lacking awareness of the systems' limitations were most likely to engage in potentially hazardous behavior; (3) the highest levels of trust in ACC were exhibited when awareness of the systems' limitations was lacking. Further to many participants lacking limitation awareness, the literature indicted that trust in an automated system may be a strong indicator of behavior and limitation awareness. To test if awareness was a consequence of trust in ACC, the data in the main analysis was clustered via trust in ACC.

Main Analysis

Fourteen participants were excluded from the main cluster analysis due to missing or nonsensical responses to the questions related to trust. The considered data (n=118) from the main protocol consisted of 66 percent males and 44 percent females. The minimum participant age was 24 and the maximum 83 years (mean = 55.3 years, SD = 14.6 years). Most participants (94 percent) had access to ACC for more than a year (mean = 2.7 years, SD = 1.45 years).

Consistent with the assertion that trust is not a binary process (J. D. Lee & See, 2004) the analysis produced four clusters representing four levels of trust in ACC. The Pseudo F (PSF) statistics supported this finding (3 clusters, PSF = 49.6; 4 clusters, PSF = 70.9; 5 clusters, PSF = 56.4). The outcome of the main cluster analysis is illustrated in Figure 3.

The high levels of trust (Table 4) and apparent lack of awareness (Table 5) of ACC limitations led to cluster 1 (n=65) being characterized as those that tend to "overtrust" (J. D. Lee & See, 2004; Parasuraman & Riley, 1997) the system. Although cluster 2 (n=27) had similar levels of trust, this cluster group actually relied on the system less since their first use and tended toward the inclination that ACC would not work in certain situations. In other words, they tended to be more "cautious" than the overtrust cluster group. The consistently neutral responses of cluster 3 (n=20) led to its classification as "neutral". The low levels of trust displayed by cluster 4 (n=6) alluded to "distrust" (Parasuraman & Riley, 1997). As *a priori* trust increased so did actual use trust increase ($\rho = 0.82$) (i.e. trust levels seemed to be formed in initial interactions as they did not change through time/ use).

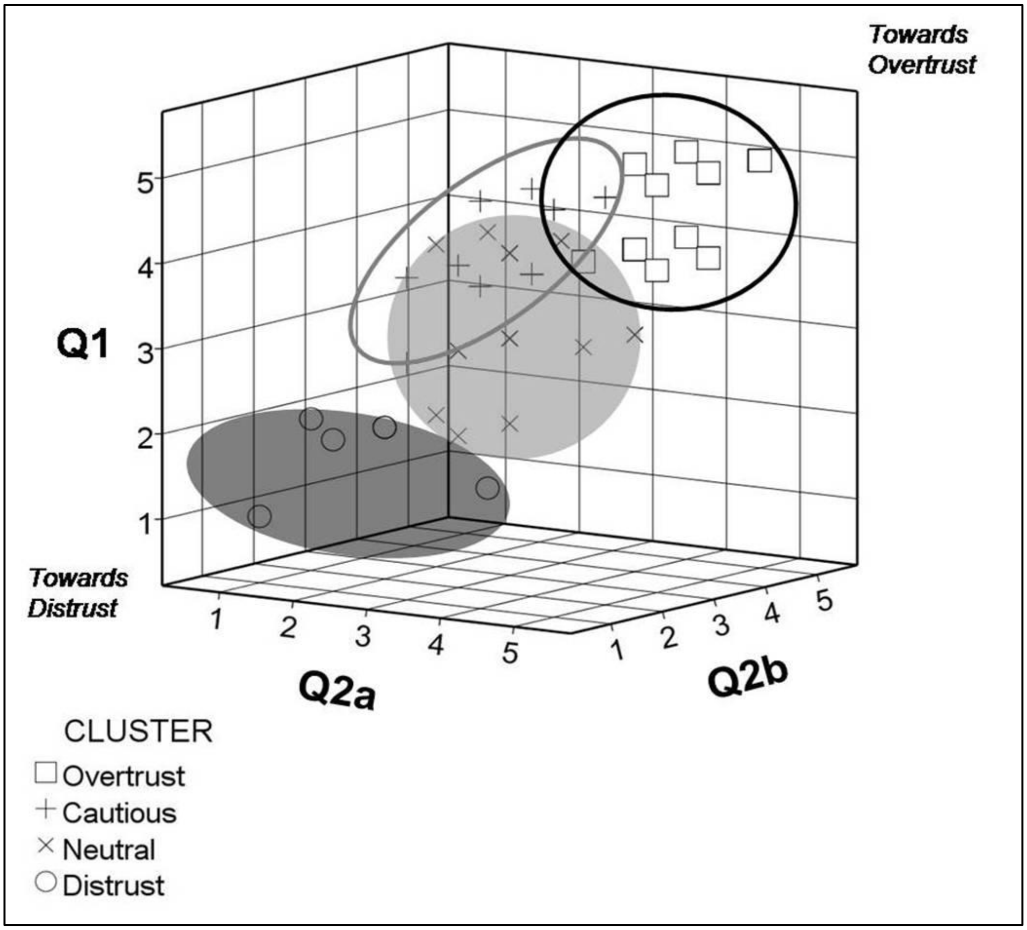

Figure 3: Main cluster analysis outcome

Note (i): Q1 "Based on provided description, please state how much you agree or disagree that you would trust an ACC system; Q2 "Based on your actual use, please state how much that you (a) trust the ACC system (b) rely on ACC more than when you first started using it."

Note (ii): 1 = "Strongly disagree" [towards distrust] and 5 = "Strongly Agree" [towards overtrust]

All four clusters had a similar level of awareness regarding the "Stop-go traffic" limitation. The overtrust cluster, however, consistently displayed the lowest awareness of ACC limitations (Table 5). The cautious and neutral clusters seemed to have an inclination of system limitations while the distrust cluster seemed acutely aware of all the limitations. This is consistent with previous findings (Sarter et al., 1997) and suggests that as trust in ACC increases the potential for detecting and diagnosing failures may decrease.

Table 4: Median trust levels by cluster in main analysis

Question	Overtrust	Cautious	Neutral	Distrust	H (DF=3)	p value
A priori trust	4	4	3	2	50.43	< 0.0001
Actual use trust	4	4	3	2	61.40	< 0.0001
Increased Reliance	4	2	3	2	76.90	< 0.0001

Note: 1 being "Strongly Disagree" [towards distrust] to 5 being "Strongly Agree" [towards overtrust].

Table 5: Median (mean) awareness levels by cluster in the main analysis

Limitation	Overtrust	Cautious	Neutral	Distrust	H (DF=3)	p value
Stop-go traffic	3 (3.03)	2 (2.81)	2.5 (2.45)	1.5 (2.33)	2.40	0.49
Stopped vehicle	4 (3.77)	3.5 (3.03)	3 (2.75)	1.5 (2.17)	10.94	0.0121
Curved road	4 (3.75)	3 (2.96)	3 (3.00)	1.5 (2.17)	11.47	0.0094

Note: 1 being "Not at all" [towards aware] to 5 being "Very Much" and 6 "Don't know" [towards unaware]; mean values are defined within the parenthesis.

Males were overrepresented (72% males, 28% females) in the overtrust cluster. Gender proportions were more evenly distributed in the cautious (56% males, 44% females), neutral (60% males, 40 females), and distrust (67% males, 33% females) clusters. Differences in gender proportions were significant among the clusters (p = 0.05, Fisher's exact test). There were significantly more males within the overtrust cluster ($\chi^2(1) = 12.94$, $p = 0.0003$) however, with no significant differences observed, gender seemed to be more balanced within the other clusters. The overrepresentation of males in the overtrust cluster may be accounted for by considering that males generally have more positive feelings towards assistive computerized technology and are more inclined to use such technology (Arch & Cummins, 1989; Gefen & Straub, 1997; Shashaani, 1997; Venkatesh et al., 2000; Whitley, 1997).

Considering age as a continuous variable found no significant differences among clusters (F (3, 117), $p = 0.30$). Using 65 years to create a dichotomy ($0 < 65$, $1 \geq 65$) yielded no significant differences in age ($p = 0.61$, Fisher's exact test). There were no significant differences in the time with access to ACC; each cluster being close to the mean time (in years) of the entire sample (F (3, 117), $p = 0.62$). The lack of statistical differences in access time may have been due to insufficient power in the sample; if differences do exist between cluster groups then, at a power of 0.8 (alpha=0.05), each would require 142 subjects. Another explanation may be that trust rather than time exposed to a system has guiding influence on awareness of limitations and misuse. For example, the learning period of two to three weeks (Weinberger et al., 2001) did not seem to apply to the overtrust cluster (i.e., like the other clusters, the overtrust cluster had access to ACC for over two years however this cluster still did not seem to understand situations where limitations may arise). However, from the cluster analysis, when trust increased so awareness of ACC limitations decreased.

Ninety-one percent of participants in the overtrust cluster indicated that, if they had the choice to purchase their vehicle again, they would want this vehicle to have ACC.

This is in stark contrast to the distrust cluster where eighty-three percent of participants would not opt for ACC if they had the same choice. The corresponding proportions in the cautious (44% no, 56% yes) and neutral clusters (50% no, 50% yes) were more evenly distributed and the differences among clusters were significant ($p > 0.0001$, Fisher's exact test).

Only nine participants reported difficulties in learning to use ACC and there were no significant differences among clusters relevant to learning difficulties ($p = 0.21$, Fisher's exact test) or safety concerns ($p = 0.17$, Fisher's exact test). When asked if they felt safe using the ACC system, the overtrust and cautious clusters were in most agreement (median = 4, where 1 = "Strongly disagree" and 5 = "Strongly disagree"). The neutral cluster was impartial (median = 3) and the distrust cluster disagreed to feeling safe when using the system (median = 2). These apparent differences were significant ($H(3) = 54.2$, $p < 0.0001$). The overtrust cluster agreed most with the assertion that ACC reduced their stress while driving (median = 4). The other clusters (cautious and neutral median = 3, distrust = 2) were less emphatic in their agreement and these differences were significant ($H(3) = 33.8$, $p < 0.0001$). Statistically significant differences were also observed in how often each cluster used ACC ($H(3) = 25.5$, $p < 0.0001$). The overtrust and cautious clusters agreed that, in general, they used ACC often (median = 4). The neutral cluster neither agreed nor disagreed (median = 3) and the distrust cluster disagreed (median = 2) with this assertion.

The distrust (median = 1.5) and neutral (median = 2) clusters did not use the system in low sunlight conditions (where 1 = "Not at all" to 5 = "Always"). The cautious cluster was neutral (median = 3) in their use and the overtrust cluster more willing to use ACC in low sunlight conditions (median = 4). The observed differences in use during low sunlight conditions were significant among the clusters ($H(3) = 16.6$, $p = 0.0009$). Although the overtrust cluster provided a neutral response (median = 3) to using ACC in heavy but flowing traffic, this represented the greatest willingness to use the system in this condition (cautious median = 2, neutral and distrust = 1). The different levels of use in heavy but flowing traffic were significant (H (3) = 17.0, p = 0.0007). Although ACC may not effectively maintain headway time on curved roads there were significant differences in usage on these road segments (H (3) = 12.4, p = 0.0061). The overtrust cluster used the system sometimes (median = 3), the cautious cluster almost never used the system (median = 2), and the distrust and neutral clusters did not use the system (median = 1) on these road segments. The functionality of ACC may also be limited on roads with lower speed limits however the overtrust cluster still used the system sometimes (median = 3) on these roads. The other clusters did not use the system (median = 1) on these roads and differences among the clusters were significant (H (3) = 12.7, p = 0.0054). When drivers in the overtrust cluster were tired they would still sometimes (median = 3) use the system. The cautious cluster would almost never use the system when tired (median = 2) and the neutral and distrust clusters would not use the system (median = 1). Inclination to use ACC when tired was significantly different among the clusters (H (3) = 9.8, p = 0.02). Consideration of their increased trust in ACC and willingness to use the system when it is potentially hazardous to do so, suggests that participants in the overtrust cluster will frequently choose automatic control over manual control (Muir, 1989), fail to detect and diagnosis failures (Sarter et al., 1997), and lack intervention when necessary (Zuboff, 1988).

In contrast to what their behavior suggests, the overtrust cluster was most assertive (median = 3; compared to disagreement in the other clusters) to the statement of being a safer driver while using ACC (H (3) = 25.7, p < 0.0001). Indeed, of all the clusters, the overtrust cluster felt safest when using ACC, had the lowest perceived stress and indicated the greatest willingness to opt for ACC again if given the choice. Considering these and the other characteristics associated with the overtrust cluster, it suggests that with overtrust comes an idealistic view of automatic control. Further to this, as indicated by the assertiveness to the safer driver statement, overtrust may also create an idealistic view of the entire automation-user system. This view suggests that their specific use of the ACC system improves safety whereas the results from the analysis suggest the opposite.

On interstate highways, where ACC may be most effective due to the high speeds and straight road segments, the overtrust cluster used the system always (median = 5). The cautious cluster used the system slightly less (median = 4), the neutral cluster even less (median = 3), and the distrust cluster less than sometimes (median = 2.5); interstate highway use was significantly different among clusters ($H(3) = 19.9$, $p = 0.0002$). This correlates with previous research suggesting that, despite the potential of automation in certain situations (Sarter & Woods, 1994), distrust may lead to disuse of automation (Dzindolet et al., 2002; Parasuraman & Riley, 1997; Zuboff, 1988).

The neutral cluster was impartial (median = 3) to the assertion that the cues provided by the ACC system (e.g., lights and sounds) were easy to understand. All other clusters agreed (median = 4) that the cues provided were easy to understand and this difference in response was significant ($H(3) = 8.7$, $p = 0.03$). The neutral cluster was also unsure where all the other clusters disagreed that the headway time and cruise settings were confusing ($H(3) = 12.1$, $p = 0.0071$). This apparent ambiguity may provide suggestive evidence for their neutral trust in ACC.

A multinomial logistic regression model predicted cluster membership, as summarized in Table 6.

Table 6: Cluster membership prediction in reference to overtrust cluster

Parameter	Cluster contrast *	Parameter estimate	Standard error	Chi-square	Odds ratio (95% CI)	p value
Intercept	Cautious	0.86	1.19	0.53		(NS)
	Neutral	2.24	0.79	8.07		0.005
	Distrust	1.51	0.75	4.07		0.040
Male	Cautious	-1.03	1.07	0.93	0.36 (0.04, 2.9)	(NS)
	Neutral	-1.87	0.64	8.52	0.16 (0.04, 0.54)	0.004
	Distrust	-1.09	0.54	4.06	0.34 (0.11, 0.97)	0.040
Limitation aware	Cautious	1.99	1.03	3.71	7.31 (0.97, 55.2)	0.050
	Neutral	1.27	0.72	3.10	3.57 (0.87, 14.7)	(NS)
	Distrust	1.01	0.63	2.57	2.75 (0.80, 9.49)	(NS)
Use in heavy traffic	Cautious	-1.64	1.05	2.45	0.19 (0.03, 1.51)	(NS)
	Neutral	-1.44	0.61	5.54	0.24 (0.07, 0.79)	0.020
	Distrust	-0.50	0.55	0.83	0.60 (0.20, 1.79)	(NS)
Opt for ACC again	Cautious	-3.94	1.23	10.32	0.02 (0.002, 0.2)	0.001
	Neutral	-2.41	0.69	12.26	0.09 (0.02, 0.35)	<0.001
	Distrust	-2.06	0.62	11.25	0.13 (0.04, 0.42)	<0.001
Number of observations						117
-2 Log likelihood at zero						261
-2 Log likelihood at convergence						211

Note: *Base = Overtrust; (NS) = not significant.

The results from the model illustrate that participants, compared to overtrust, were less likely to be neutral in their trust (OR = 0.16) or distrust (OR = 0.34) ACC if they were male. If participants were aware of the stopped vehicle limitation they tended to be more likely to be cautious (OR = 3.71) rather than have overtrust in ACC. The use of ACC in heavy but flowing traffic indicated that participants were less likely to be neutral (OR = 0.24) rather they would overtrust ACC. Participants that would opt for ACC again were less likely to be in the cautious (OR = 0.02), neutral (OR = 0.09), or distrust clusters (OR = 0.13) rather they overtrusted ACC.

As illustrated in Table 7, a binary logistic regression model predicted the likelihood of overtrust in reference to a combination of the other levels of trust.

Table 7: Binary logistic regression: likelihood of overtrust

Parameter	Parameter estimate	Standard error	Chi-square	Odds ratio (95% CI)	p value
Intercept	-2.87	0.70	16.74		< 0.0001
Male	1.61	0.52	9.59	5.01 (1.81, 13.87)	0.002
Feel safe using ACC	1.37	0.59	5.33	3.92 (1.23, 12.50)	0.021
Limitation aware	-1.26	0.61	4.23	0.28 (0.09, 0.94)	0.038
Use in heavy traffic	0.93	0.49	3.59	2.53 (0.97, 6.62)	(NS)
Opt for ACC again	1.90	0.59	10.47	6.70 (2.11, 21.20)	0.0012
Number of observations					117
-2 Log likelihood at zero					161
-2 Log likelihood at convergence					114

The outcome in Table 7 shows that males were more likely (OR = 5.01) to overtrust rather than exhibit other levels of trust in ACC. If participants felt safe when using ACC they were more likely (OR = 3.92) to overtrust ACC. Awareness of the stopped vehicle limitation showed that participants were less likely (OR = 0.28) to overtrust ACC. If given the choice, opting for ACC again alluded to an increased likelihood (OR = 6.70) of overtrust in the system. While this finding is not surprising, it may be important as there are obvious safety concerns if those with the greatest willingness to use ACC in the future are also most likely to overtrust the system.

Chapter 4 Summary

The results from the pilot and main analyses were presented in Chapter 4. The pilot analysis (and literature from Chapter 1) suggested that trust in ACC may be an explanatory variable for behavior while using the system and other perceptions. The main analysis provided credence to this suggestion by showing that overtrust generally corresponds to potentially hazardous use of ACC and a lack of awareness regarding the systems' limitations. Chapter 5 will summarize this thesis and propose some implications in light of the findings.

CHAPTER 5 SUMMARY AND IMPLICATIONS

It was shown in Chapter 1 that there may be a relationship between trust in automation, awareness of limitations, and use of automation. Relevant to automated longitudinal vehicle control (through an ACC system), this thesis aimed to (1) determine if there exists overtrust, distrust, and intermediate levels of trust in ACC; (2) assess the influence of these levels of trust, specifically overtrust, on the use of ACC; (3) determine those most likely to exhibit particular levels of trust in automated control. A pilot analysis was undertaken and this demonstrated that many ACC users were not aware of the systems' limitations and engaged in potentially hazardous behavior. From the literature it was suggested that limitation awareness and system use were consequences of trust. Therefore, the main analysis used a cluster analysis to determine varying levels of trust (overtrust, cautious, neutral, and distrust) in ACC, realizing aim (1). Kruskal-Wallis ANOVA and other comparative analyses then determined the influence of these levels of trust on awareness and system use. In realization of aim (2), it was shown that overtrust corresponded with lower levels of awareness and increased misuse. The cautious cluster seemed to have an 'appropriate' level of trust in the ACC. That is, their use and awareness of the systems' limitations seemed to be matched to the capabilities of the system (J. D. Lee & See, 2004). The literature, and the results here, showed that overtrust and distrust often led to inappropriate usage (misuse and disuse, respectively) of automation.

To meet aim (3), logistic regression models were used to determine those most likely to exhibit particular levels of trust. Notably males rather than females were prone to overtrust ACC. This may have been due to the more positive feelings males generally hold towards assistive computerized technology (Venkatesh et al., 2000; Whitley, 1997). Although the apparent ambiguity shown by the neutral cluster relevant to the system interface, and the overtrust clusters' idealistic view may also explain levels of trust, more research is required to understand the specific reasons for trust or a lack thereof. Indeed, future research will further probe trust in ACC (e.g., after obtaining levels of trust, this line of questioning will continue by asking participants why they have that level of trust).

The data used in this thesis were obtained through self-administered questionnaires. The author recognizes the many biases associated with such data and the need for more research to account for these biases. Notably, the *a priori* levels of trust were not obtained before users had experience with the system and therefore may have been biased towards their present level of trust. An interviewer administered questionnaire of users before and after they are exposed to ACC may more effectively capture *a priori* and current trust levels. Moreover, the participants may not have shared or understood the logic of trust applied in this study. The format of questioning used reflected the logic however an explicit lay description may be required to orient participants in future research. Observation and assessment of users during their use of ACC will provide credence to questionnaire responses. It is proposed that a field study involving the collection of in-vehicle data (e.g., braking behavior, activation of ACC, and speed) may provide the means for a more representative analysis. This will reduce or eliminate the lead time, incurred in the data collection phase of this thesis, between actions and data collection.

The distrust cluster was rather small in number and this may also have had an effect on the results obtained. For example, some of the parameter estimates in the logistic regression models were suggestive of the expected differences between the distrust and overtrust cluster however the distrust cluster sample size may have hindered realization of these differences. Related to parameter estimates, the data reduction required in the logistic regression models (e.g., reduction of multinomial explanatory variables to binary) may have also restricted the representativeness of the results obtained. The size of the clusters may have been influenced by a potential bias in the sample. ACC may have only been an economically expensive option on the vehicle makes considered here. The uptake of this option may therefore suggest strong positive feelings for ACC and may explain the high number of participants in the overtrust cluster. In future studies participants may be asked why they have a vehicle with ACC. If participants indicate that they have the vehicle by specifically paying extra for ACC it would seem to suggest that they have a positive bias towards ACC. The effect of this bias may be mitigated in the future by disqualifying such participants or recruiting only participants with ACC as standard in their vehicle.

The cluster analysis and subsequent comparative analyses undertaken here may have taken the first step to defining an intermediary level of trust termed “cautious” that corresponds with an appropriate appreciation and use of automation. Being only a first step, further research into this suggestion is clearly required. For example, a field study may measure trust prior to ACC use and assess whether participants previously characterized as “cautious” exhibited an appropriate balance between automatic and manual control in their observed use. A strong correlation between initial trust and present trust existed therefore *a priori* trust levels of potential ACC users should be sought so to predict their future behavior. In an attempt to preserve the potential benefits of ACC, appropriate guidance - relevant to the levels of trust displayed - may also be given or demonstrated through test use. Moreover, as they were shown most likely to overtrust and misuse, concentrated training should be provided to males and those who are most keen to obtain ACC.

APPENDIX QUESTIONNAIRE

The National Advanced Driving Simulator

Using Adaptive Cruise Control

Thank you for taking the time to take part in our research study that will make our nation's roads safer. This survey will take 10-15 minutes to complete.

Whether you have driven a vehicle with Adaptive Cruise Control (ACC) or not, we appreciate your participation in this study, and as such, when you finish this survey you are entitled to a $10 gift card redeemable at your choice of Starbucks, Walmart, or Barnes & Noble.
Please proceed through the survey, answering questions relevant to you. Please direct any questions you have to the contacts at the end of the survey.

A Little About You

This section aims to learn a little about you, this information is required only to assist in our analysis and will remain confidential.

Q1 Please enter the 5-digit invitation number that is found at the top left corner of your invitation letter

☐

Q2 Please state your age

☐

Q3 Please state your gender

Male ☐
Female ☐

Q4 On average, how many people are in your vehicle, including yourself?

☐

Q5 How many miles do you typically drive in a seven-day week?

☐

Q6 Do any of these conditions affect your driving ability? (*Please check all that apply)*

Vision difficulties ☐
Hearing difficulties ☐
Dexterity difficulties (e.g. arthritis) ☐
Difficulty turning your head/ neck ☐
None of the above ☐
Other, please specify ☐

Please turn over the page for Question 7

What you think about Adaptive Cruise Control (ACC)

The following section is to be answered whether or not you have used ACC.

The car you own may have Adaptive Cruise Control (ACC). **This is a new technology different from regular cruise control.** Regular cruise control is found in most cars and maintains a constant speed without you keeping your foot on the accelerator pedal. Adaptive Cruise Control (ACC) does this as well however it also **automatically slows your vehicle down without you pressing your foot on the brake pedal.** The ACC laser sensors can detect moving vehicles in front of your own vehicle and, if required, slow your vehicle.

Q7 Based just on the description of ACC above, please state how much you agree or disagree with the following statements

	Strongly Disagree	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
A. I trust an ACC system would work	☐	☐	☐	☐	☐
B. I would feel safe using an ACC system	☐	☐	☐	☐	☐
C. If I had ACC, I would use it often	☐	☐	☐	☐	☐
D. I feel that an ACC system would allow me to do other things while driving e.g. use cell phone, map, radio, GPS etc.	☐	☐	☐	☐	☐
E. I would do other things (e.g. use cell phone, map, radio, GPS etc.) more often if I had ACC	☐	☐	☐	☐	☐
F. I think ACC would reduce my stress while driving	☐	☐	☐	☐	☐
G. ACC can be set to improve traffic flow (e.g. it can be set to follow vehicles at a high speed and close distance). I would set ACC to this setting	☐	☐	☐	☐	☐
H. ACC can also be set to improve driver comfort (e.g. it can be set to follow vehicles at a low speed and far distance). I would set ACC to this setting	☐	☐	☐	☐	☐

Q8 What is your vehicle's make, model and product year?

Make (e.g. Honda)............. ☐

Model (e.g. Civic)............... ☐

Year (e.g. 2006)................. ☐

Q9 If you purchased this same vehicle again, would you want it to have ACC?

Yes .... ☐

No.. ☐

I Don't know .... ☐

Q10 Have you ever owned or driven a vehicle with ACC?

Yes .... ☐ **Go to Q11 (over the page)**

No............................ ☐

If "No", why not? ***(Please check all that apply)***

It was not an option on my vehicle........................ ☐

It never occurred to me to look for it when I purchased the vehicle .... ☐

I thought it would be a nuisance or distraction....... ☐

I don't trust that it will work .... ☐

It was only available with other options that I didn't want .... ☐

It was not worth the extra cost .... ☐

I was not the person who decided to get this vehicle and its associated options......................... ☐

I have never heard of it .... ☐

If you answered "No" to Q10, please now skip to Q24 (on the back page)

How you feel about using ACC

Please skip to Q24 if you have never used ACC. **The following questions are only to be answered if you have used ACC.** These questions are based on your actual use of ACC.

Q11 How long have you owned/ driven a vehicle with Adaptive Cruise Control (ACC)?

Years............................... ☐

Months............................ ☐

Q12 How did you you learn to use ACC? *(Please check all that apply?)*

Dealer demonstration .... ☐

Owners Manual.. ☐

Demonstrations or reviews on the internet/ in magazines.. ☐

Self-taught... ☐

Did not learn.. ☐

Other, please specify ☐

Q13 Was there anything difficult about learning to use ACC?

Yes.. ☐

No .... ☐

***If Yes,** please explain* ☐

Q14 Does ACC create any new driving problems or safety concerns for you?

Yes.. ☐

No .... ☐

***If Yes,** please explain* ☐

Q15 <u>Based on your actual use of ACC</u>, please state how much you agree or disagree with the following statements

	Strongly Disagree	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
A. I trust the ACC system	☐	☐	☐	☐	☐
B. I feel safe using the ACC system	☐	☐	☐	☐	☐
C. Using ACC reduces my stress while driving	☐	☐	☐	☐	☐
D. I tend to perform other tasks (e.g. use cell phone, map, radio, GPS, etc.) **<u>more often</u>** with ACC on	☐	☐	☐	☐	☐
E. In general, I use ACC often	☐	☐	☐	☐	☐

Q16 How quickly do you notice and react to unexpected road hazards when ACC is turned on, compared to when it is turned off? *(Please check only one)*

Much slower .... ☐

Slower .... ☐

Neither slower nor quicker................................. ☐

Quicker.. ☐

Much Quicker .... ☐

Don't know... ☐

Q17 Have you ever hit something in front of your vehicle with ACC turned on?

Yes.. ☐

No .... ☐

***If Yes**, please describe the situation:* ☐

Q18 Please rate how much you think that ACC would help you in avoiding a crash with the vehicle in front of you if...

	Not at all 1	2	*Neutral* 3	4	*Very Much* 5	*Don't know*
A. You are following the vehicle in stop-and-go traffic	☐	☐	☐	☐	☐	☐
B. The vehicle stopped in your lane	☐	☐	☐	☐	☐	☐
C. You are following the vehicle on a curvy road	☐	☐	☐	☐	☐	☐

How you adjust and use ACC

This section is related to how you adjust and use ACC and how this differs from your previous driving habits.

Q19 Please rate how often you use ACC in the following conditions

	Not at all 1	2	*Sometimes* 3	4	*Always* 5
Rain	☐	☐	☐	☐	☐
Snow	☐	☐	☐	☐	☐
Low/ no sunlight	☐	☐	☐	☐	☐
In heavy - "stop-and-go" - traffic	☐	☐	☐	☐	☐
In heavy traffic that is flowing	☐	☐	☐	☐	☐
On interstate highways	☐	☐	☐	☐	☐
Freeway off ramps, or when exiting highways	☐	☐	☐	☐	☐
On city streets with traffic lights	☐	☐	☐	☐	☐
On curvy roads	☐	☐	☐	☐	☐
On roads with lower speed limits	☐	☐	☐	☐	☐
When tired or otherwise impaired	☐	☐	☐	☐	☐
When performing other tasks (e.g. using cell phone, map, radio, GPS, etc.)	☐	☐	☐	☐	☐

Q20 Do you normally use the same following distance or do you set the distance based on driving conditions?

- ☐ *I don't know how to set the following distance*
- ☐ *I always set the same following distance*
- ☐ *I set the amount of following distance as conditions change*
- ☐ *My ACC does not allow me to set the following distance*

Q21 At what following distance do you usually set your ACC

- ☐ *At the shortest setting, which is as close to the lead vehicle as my ACC allows*
- ☐ *At a medium setting*
- ☐ *At the longest setting, which is as far from the lead vehicle as my ACC allows*
- ☐ *I don't know*

Q22 Please identify the length of your following distance when using ACC, compared to when not using ACC

- ☐ *Smaller distance*
- ☐ *Slightly smaller distance*
- ☐ *About the same*
- ☐ *Slightly larger distance*
- ☐ *Larger distance*

Your opinion on ACC

These questions relate to how you feel about ACC and how it affects you as a driver.

Q23 For each of the following statements, please state how much you agree or disagree

	Strongly Disagree	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*	*Not Applicable*
A. I tend to change lanes less frequently when using ACC	☐	☐	☐	☐	☐	☐
B. I set ACC to follow vehicles at a high speed and close distance.	☐	☐	☐	☐	☐	☐
C. I set ACC to follow vehicles at a low speed and far distance.	☐	☐	☐	☐	☐	☐
D. The sounds made by the ACC system are easy to understand	☐	☐	☐	☐	☐	☐
E. The lights/symbols on the ACC system are confusing	☐	☐	☐	☐	☐	☐
F. The ACC following distance setting is easy to understand	☐	☐	☐	☐	☐	☐
G. The ACC cruise speed setting is confusing	☐	☐	☐	☐	☐	☐
H. More cars cut me off or pull in front of me when I am using my ACC	☐	☐	☐	☐	☐	☐
I. ACC sometimes locks onto a vehicle other than the vehicle immediately in front of me	☐	☐	☐	☐	☐	☐
J. I rely more on ACC than when I first started using it	☐	☐	☐	☐	☐	☐
K. I am a safer driver now that I use ACC	☐	☐	☐	☐	☐	☐

Please turn over the page to declare your interest in future studies and select your gift card

Future Research

If you would be willing to participate in future University of Iowa engineering research studies, please fill in the personal (optional) information below. We will only be contacting a limited number of respondents for future studies. They will be selected randomly from those who volunteer. The information you provide will be kept on file however not all volunteers will be contacted for future studies.

Q24 Would you like to take part in a telephone interview?

- *Yes* .... ☐
- *No* .... ☐

Q25 Would you be willing to participate in future studies at the U. Iowa if we compensate you for your time and travel? *(Please check all that apply)*

- *On-road study* .... ☐
- *Simulator study* .... ☐

Q26 If you would be interested in taking part in any future studies, please provide us with the following details

- Name (optional) .... ☐
- Telephone number .... ☐
- Best time of the day to call..... ☐

Thank you for completing our survey.

Please select the $10 gift card of your choice. The gift card compensation processing will be kept completely separate from your survey to ensure your anonymity.

Gift card choice *(Please check only one)*

- Walmart .... ☐
- BARNES&NOBLE BOOKSELLERS .... ☐
- STARBUCKS COFFEE .... ☐

Preferred mailing address

☐

Please direct any questions or concerns regarding this survey to:

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