THE UNIVERSITY OF IOWA

Study of ESC Assisted Driver Performance Using a Driving Simulator

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ABS	antilock brake system
ANOVA	analysis of variance
ESC	electronic stability control
GLM	general linear model
LCD	liquid crystal display
LOC	loss of control
NADS	National Advanced Driving Simulator
OEM	original equipment manufacturer
STI	Systems Technology Inc.

ABSTRACT

The goal of this study was to compare driver performance in critical loss of control situations both with and without the aid of Electronic Stability Control (ESC) systems. To accomplish this, an incursion, a tightening-radius curve, and a wind event were developed for use in the National Advanced Driving Simulator (NADS), and the implementation of two ESC systems, one on an Oldsmobile Intrigue and another on a Ford Excursion, was modeled and validated. A total of 120 participants from three age groups balanced by gender completed the study. Each participant experienced all of the events either with or without an ESC system. Results showed an 88% reduction in loss of control with the presence of an ESC system. Overall reductions in loss of control were observed for each of the events across gender and age groups. From this research, it is clear that ESC systems provide a significant safety benefit by helping drivers maintain control of their vehicles during critical steering maneuvers.

1. INTRODUCTION

The Electronic Stability Control (ESC) system is active technology that aims to improve the stability of vehicles during critical driving situations that would otherwise lead to loss of control. The ESC system utilizes sensors to detect unstable situations as created when the intended path of the vehicle does not match its actual path due to excessive skidding, sliding, or other similar conditions. The system utilizes independent wheel braking or engine torque to correct the instability. ESC-based corrections can often mitigate understeer, oversteer, and rollovers, all of which can lead to fatal accidents.

Preliminary studies indicate that the single vehicle crash rate for vehicles equipped with ESC is lower than the average by approximately 30% to 35%. Such research is encouraging; however, there has been very little work that directly studies ESC effectiveness by comparing the outcome of loss-of-control situations between vehicles with and without the system. One problem with conducting such studies is that it is very difficult to create realistic on-road scenarios because of the danger to participants. Similarly, subjective data obtained in closed-course testing can be useful, but leaves open the question of system effectiveness when ordinary drivers unexpectedly encounter critical loss-of-control situations.

The research presented here utilized the National Advanced Driving Simulator (NADS) to compare driver performance during selected loss-of-control scenarios between vehicles equipped with an ESC system and the same vehicles without the system. The NADS is the most advanced simulator in existence and provides a unique high-fidelity virtual environment that can be used to study any aspect of the interaction between the driver, the roadway, and the vehicle. Using the NADS, the effect of the ESC system could be studied by comparing the outcome of loss-of-control scenarios under controlled and repeatable conditions.

For this study, two vehicle models that are OEM-equipped with ESC systems were used. The first model was an Oldsmobile Intrigue equipped with an ESC system manufactured by Bosch. The second was a Ford Expedition equipped with an ESC system manufactured by Continental Teves. High-fidelity virtual models of these vehicles were developed specifically for this study. The ESC systems were provided by the respective manufacturers in the form of software, a large part of which was identical to the firmware running inside the ESC systems fielded in actual vehicles. Tire models were calibrated based on performance data obtained by measuring the response of OEM tires. The dynamic behavior of the vehicle models was calibrated to closely match the behavior of actual vehicles under the same maneuvers. Special emphasis was placed on maneuvers that take place during loss-of-control scenarios.

The scenarios used in the study were designed to recreate a large cross-section of typical accident situations that could be averted by an ESC system. The "44 crashes" document [7] was used as a reference for selecting these situations. A few additional events were designed that, although not explicitly included in the "44 crashes" document [7], provide situations that would test the effectiveness of ESC in avoiding loss of control. Six scenarios were initially designed and tested during a pilot study: a left curve with decreasing radius of curvature, a right curve with decreasing radius of curvature, a strong turbulent wind gust from the left, a strong turbulent wind gust from the right, a road incursion from the right, and a road incursion without a lead vehicle. From these, three scenarios were selected for the main study based on sensitivity and redundancy: the left curve with decreasing radius of curvature, the wind gust from the right, and the road incursion without a lead vehicle.

It was hypothesized that, across the two vehicles used and the three events tested, drivers with the ESC system would experience significantly less loss of control than drivers without the ESC system.

2. MODELING AND VALIDATION

2.1. Modeling

For this study a 2003 Ford Expedition and a 2002 Oldsmobile Intrigue were used. Each of these vehicles has the option of installing an ESC system. The ESC system on the Expedition is called AdvanceTrac by Ford and is manufactured by Continental Teves. The ESC system on the Intrigue is called Precision Control System by Oldsmobile and is manufactured by Bosch.

For each vehicle, a multi-body dynamics model was created using NADSDyna [1]. NADSDyna contains special elements necessary for full-vehicle, operator-in-the-loop simulations. The model starts with the chassis and suspension components modeled as individual bodies connected by joints. The data for the mass, inertia, and joint locations where measured by SEA, Inc. at their Vehicle Inertia Measurement Facility. Nonlinear spring-damper elements were used to model the shocks and springs, which where also measured by SEA, Inc.

The powertrain model in NADSDyna uses a quasi-static model of the engine, torque converter, automatic transmission, differential, and final drive. All gear ratios and shifting logic are included in this model. The engine model uses a torque map that was not completely known. However, a map was created from the maximum engine torques published by the manufacturers and maps previously obtained from similar engines.

The tire was modeled using a semi-empirical STI model that relies heavily on test data for accurate simulations. To obtain the data required for the STI model, several tires were sent to Smithers Scientific Services, Inc. to be measured on their MTS Flat-Track II measurement machine. Several tests were performed on this machine, including discrete sinusoidal steering, quasi-static discrete cambering, and quasi-static steering.

The aerodynamics element in NADSDyna uses curves to define the coefficients for the lift, drag, and side forces, and the roll, pitch, and yaw moments. Since no aerodynamics data was available for either vehicle, data from a Chevy Malibu model [3] was used for the Intrigue and data from a Jeep Cherokee model [4] was used for the Expedition, with appropriate modifications to the cross-sectional area and wheelbase.

Software was provided by Bosch and Continental Teves to model the ESC, traction control, and ABS brakes. This software was integrated into the NADSDyna software and allows for braking on individual wheels and a reduction in the power output from the engine. It is possible to disable the ESC system to test the performance of the vehicles without ESC.

2.2. Validation

To validate the NADSDyna models, each vehicle was fully instrumented and run through a series of maneuvers such as straight-line acceleration, straight-line braking, fish hook, J-turn, slowly increasing steer, and pulse steer. For each maneuver, several values were measured, including steering wheel angle, brake pedal force, accelerator pedal position, speed, lateral acceleration, roll rate, pitch rate, yaw rate, brake line pressures, and engine speed.

For each maneuver the measured driver inputs—steering wheel angle, accelerator pedal position, and brake pedal force—were used to drive the simulated vehicle, and the measured data were compared to the simulated data. An example of this comparison is shown in Figures 1 through 4 for a double lane-change maneuver with and without ESC. As indicated, the Intrigue model correlates very well with and without ESC until the return to the original lane at about 4 seconds. At this point the tires on the test vehicle slip more than the simulated vehicle, causing differences in results for the remainder of the maneuver. The Expedition model displays a lag in response to steering inputs for both the yaw rate and lateral acceleration, possibly due to excessive tire slip.

Some of the less aggressive maneuvers show a much closer correlation between the test data and simulation data [5, 6].

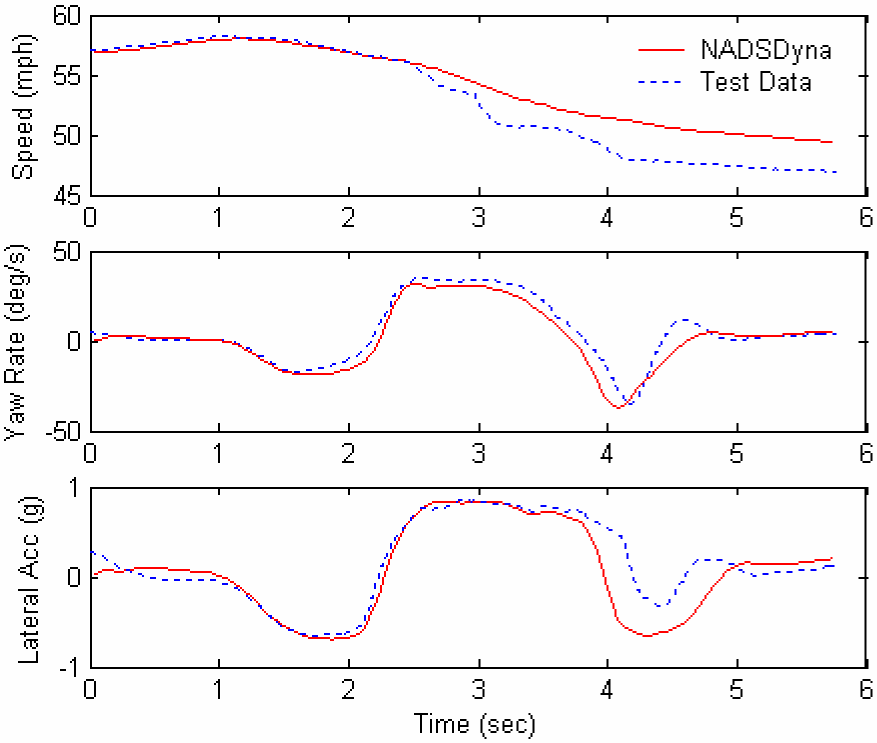

Figure 1 – Intrigue double lane change with ESC off

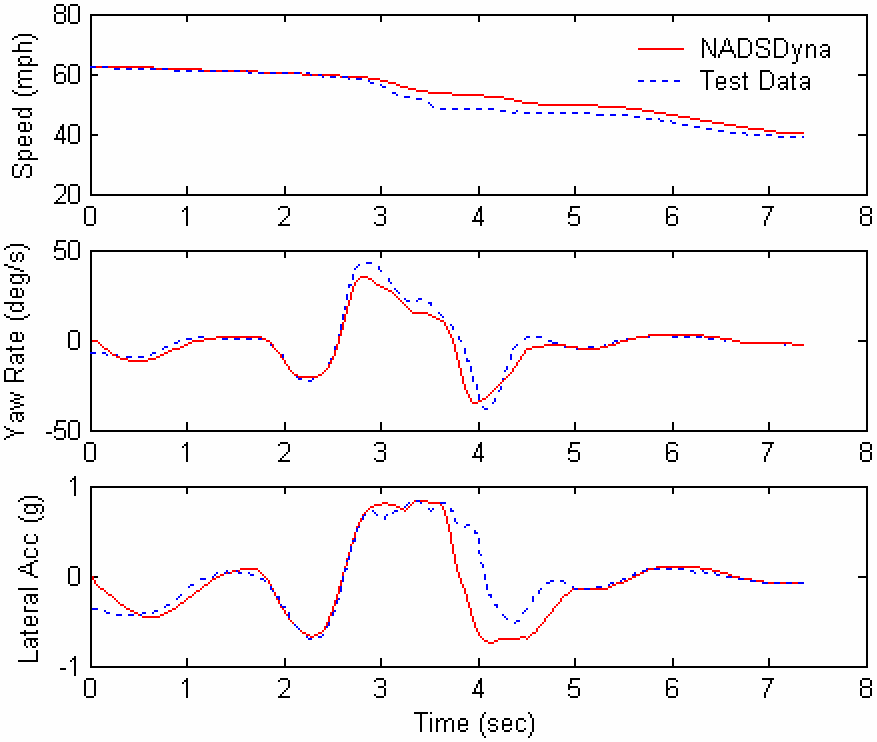

Figure 2 – Intrigue double lane change with ESC on

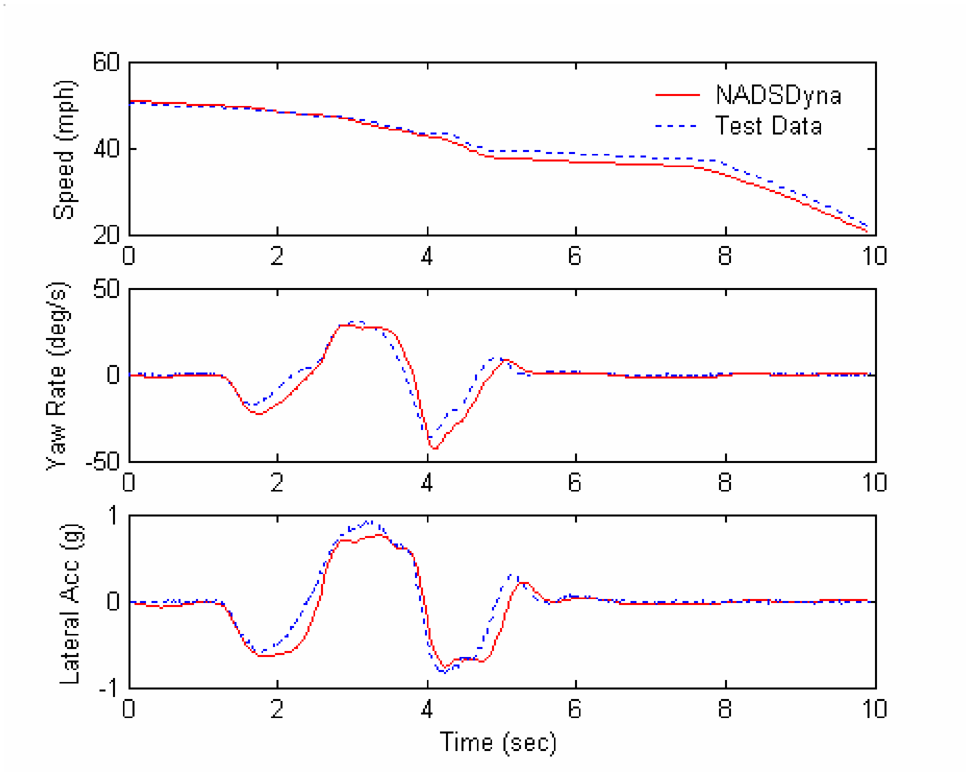

Figure 3 – Expedition double lane change with ESC off

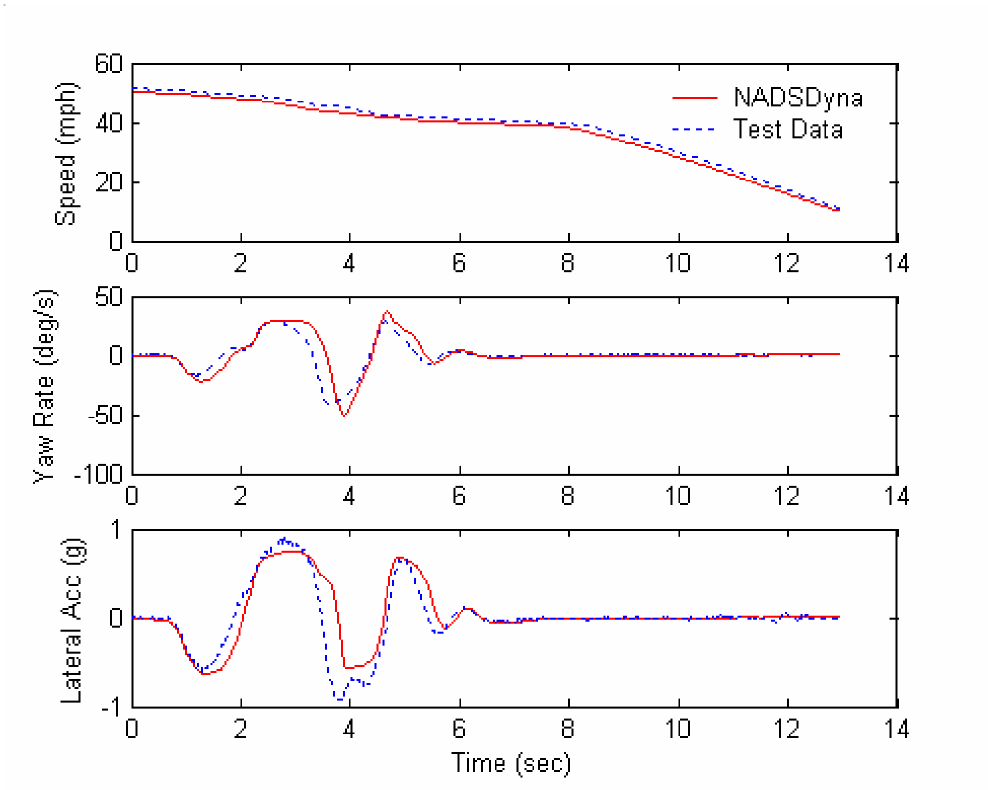

Figure 4 – Expedition double lane change with ESC on

3. SCENARIO DESCRIPTION

3.1. Incursion

In principle, this event involves the driver performing a double lane change to avoid an obstacle while driving at a high rate of speed. Specifically, the event is designed around a hidden driveway out of which another vehicle backs out into the path of the driver. The event timing was designed to ensure that steering is necessary to avoid colliding with the incurring vehicle. At the same time, oncoming traffic was used as a motivator for the second part of the double lane change maneuver.

To ensure that drivers do not slow down in anticipation of a critical event, they encounter a similar situation before reaching the actual event. Nothing of interest takes place when passing a similar house containing various stationary vehicles arranged in a similar configuration.

The posted speed limit is 65 mph, and the road profile used for this scenario is identical to the profile used in the curve departure scenario. Figure 5 illustrates the scenario.

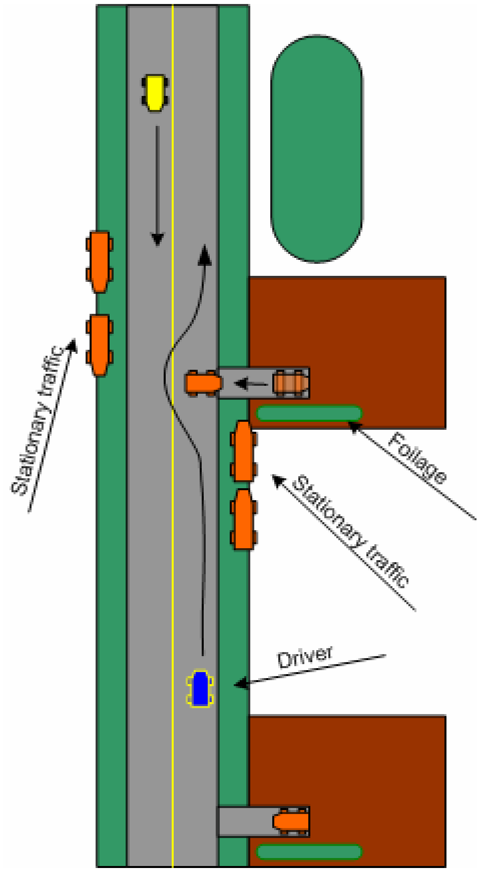

Figure 5 – Incursion event

3.2. Curve departure

This scenario involves the driver going too fast around a left curve and losing control due to over-correction or under-correction and running off the road with the potential for simultaneous loss of control. In real life, such a situation typically occurs due to aggressive driving, when drivers assume they can handle the curve, or due to inattention, when drivers do not properly anticipate the need to slow down in order to negotiate the turn. To create the same situation in the simulator, this scenario utilized a left curve with a radius of curvature that decreased abruptly when compared to the initial onset. The roadway speed limit was 65 mph and even though advisory signs warning of the upcoming curve were present along with an advisory speed limit of 50 mph, there were no visual or other indications of the upcoming curve-tightening. In addition, a much smoother right curve was placed immediately before the critical curve, in order to comfort the driver into assuming a similar uneventful event was coming up.

In addition to the curve geometry, the scenario involved surrounding traffic. One vehicle was set to travel about 500 feet ahead of the driver at the posted 55 mph speed limit. That vehicle did not slow down when negotiating the critical curve, further assuring the driver that there was no need to slow down. Augmenting the lead vehicle were several vehicles in the opposite lane. These vehicles were timed to meet the driver during the most critical part of the curve, thus providing motivation for the driver to stay in the lane.

The lateral road profile was designed according to what is typically used in rural two-lane roadways. A 12-foot lane was used, with a solid white line separating the pavement from the shoulder. The shoulder itself consisted of a one-foot asphalt section augmented by a 12-foot gravel section. The coefficient of friction (mu) for the asphalt was set to 0.85 and the coefficient of friction for the gravel section was set to 0.5. Figure 6 illustrates the top-down road layout used in this scenario, including the lateral road profile.

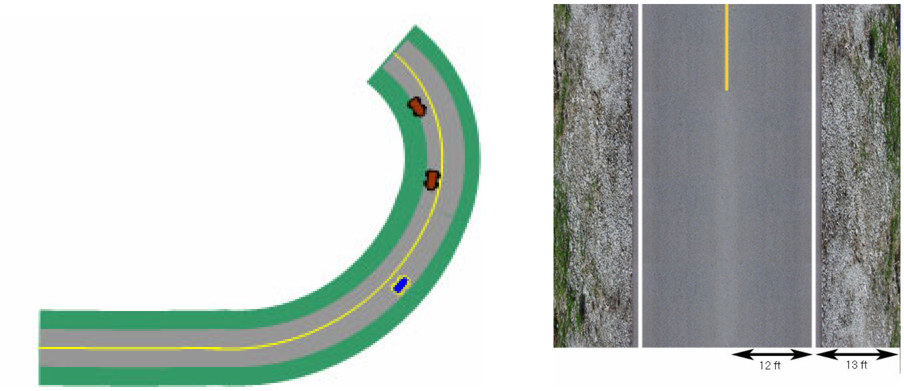

Figure 6 – Curve departure left layout

3.3. Wind gust

This scenario is not explicitly listed in the "44 crashes" document [7]. It involves a turbulent wind gust from the right that pushes the vehicle into oncoming traffic. The wind intensity increases, then suddenly disappears. The cycle is repeated once more. The net effect of this interaction is that the driver is forced to steer to the right to counteract the initial gust and then forced to correct for the disappearance of the gust by steering to the left. The repeated nature of this cycle introduces the potential for periodic steering that causes high yaw rates that can lead to instability. Whereas the cause of this situation does not specifically appear in the "44 crashes" document [7] there are several scenarios involving drivers performing corrections similar to the ones caused in this scenario. These include crash #10 (aggressive departure), crash #11 (slick road departure), crash #12 (rough road departure), and crash #91 (inexperience departure). Figure 7 illustrates the wind gust scenario. The posted speed limit for this event was 65 mph.

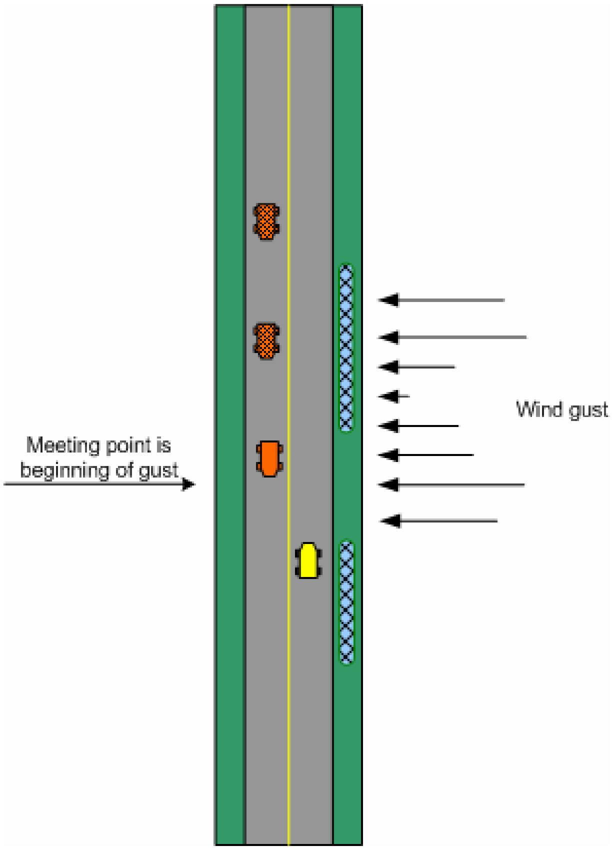

Figure 7 – Wind gust right

4. METHOD

4.1. Apparatus

The simulation was conducted at the National Advanced Driving Simulator (NADS) facility located at The University of Iowa. The NADS consists of a 24-foot-diameter dome mounted on a base (see Figure 8). The dome is able to hold an entire car, tractor, or truck cab. In this study a Chevy Malibu and a Jeep Cherokee were used as the cabs in the dome.

The motion consists of a 64-foot by 64-foot X-Y, a six degree-of-freedom motion hexapod, 330 degrees of yaw, and four high-frequency vibration actuators. This system combines to provide the driver with a feeling of realistic motion with actual acceleration, braking, and steering cues.

The visual system consists of a 15-projector liquid crystal display (LCD) to produce the latest high-resolution imagery. The field of view is 360° horizontal and 39° vertical. The visual system provides a realistic field of view, including rear-view mirror and side mirror images. The NADS is capable of producing realistic animation of busy traffic situations, three-dimensional objects that vehicles may encounter (animals, potholes, concrete joints, pillars, etc.), high-density multiple-lane traffic, common intersection types (including railroad crossings, tunnels, etc.), and time-of-day and atmospheric effects.

The auditory system is motion-correlated, with three-dimensional, realistic sounds emanating from other vehicles (including sirens), highway surfaces, contact with objects (potholes, pillars, etc.), and environmental sources (including wind).

Figure 8 – National Advanced Driving Simulator illustration

4.2. Participants

A total of 123 participants were enrolled in this study and 120 participants completed participation. The study sample included 40 participants in each of the following age groups: 18-25, 30-40, and 55-65. Each age group was equally divided between males and females. All participants were required to have a valid, unrestricted U.S. driver's license (except for corrective eyeglasses and contact lenses), to have a minimum of three years of driving experience, and to be in good general health. Each participant completed one test session lasting approximately 60 minutes. Participants were paid $25.

4.3. Experimental design

This study utilized a 2 (between) x 2 (between) x 3 (within) x 3 (between) x 2 (between) fixed-effects model. Independent variables were presence of ESC system (system present or system absent), vehicle/system used (Vehicle 1 or Vehicle 2), scenario event (incursion, curve, or wind), age (young, middle, or older, specified as 18 to 25, 30 to 40, or 55 to 65 years of age, respectively), and gender (male or female). The dependent measure was loss of vehicle control.

4.4. Independent variables

Five independent variables were analyzed in this study. Details of each variable follow.

For *ESC presence*, half of the participants were assigned to a condition where the ESC system was present and half were assigned to a condition where the ESC system was absent.

For *vehicle/system used*, participants were assigned to one of the two systems/vehicle platforms. Vehicle 1 was the Ford Expedition with Continental Teves ESC system. Vehicle 2 was the Oldsmobile Intrigue with the Bosch ESC system. Vehicle 1 was implemented using the NADS Jeep cab, and Vehicle 2 was implemented using the NADS Malibu cab.

For the *events*, each participant experienced the three scenario events in the following order: incursion, curve departure, and wind gust right[1]. The avoidance departure event involved a vehicle backing out onto the roadway in front of the participant from an obscured driveway (see Figure 5). The curve departure event involved the participant trying to negotiate a turn that tightens appreciably once the vehicle is already in the curve (see Figure 6). The wind gust right event involved a straight-line gust of wind from the right as the participant was approaching some oncoming traffic (see Figure 7). This order of events was chosen to minimize the opportunity for the participant to predict the event and take action that might negate it (i.e., the avoidance departure event was the easiest for participants to negate by slowing prior to the event so it was run first, whereas little could be done to avoid the wind gust right event, so it was run last)[2].

For *age*, there were three age groups: young drivers aged 18 to 25, middle-aged drivers aged 30 to 40, and older drivers aged 55 to 65.

For *gender*, both male and female drivers were included.

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[1] Based on the results of the pilot study, it was determined that when participants encountered the incursion event as anything other than the first event, they would perform actions such as slowing down to mitigate the event prior to its occurrence, creating a "null" event. To address this, it was determined that the incursion event would be run first for all participants. When examining the remaining two events, it was decided that the wind event offered participants the least opportunity to negate the event, so it would be run last, allowing the curve event to be run second. The researchers expected that the varying nature of the incursion and curve event would not cause drivers to slow too much because the first event, if anything, would cause the participants to be watching for vehicles entering the roadway rather than for changes in roadway geometry.

[2] Please note that because the events were run in the same order for every participant, event is completely confounded with trial, and therefore trial is not analyzed. The expectation of the research team is that the order chosen for the events would result in the least impact on an order effect.

4.5. Dependent measures

The primary performance measure of interest was *loss of control* (LOC), which is defined as follows:

> Participant departed road beyond shoulder while oriented away from road with high rotational velocity. If vehicle came to rest, does not count as LOC, even when beyond the shoulder.

To determine loss of control, videos of the events were reviewed and a determination as to loss of control was made for each event based on this definition. The coding of loss of control for each event for each participant was performed by two researchers. Discrepancies between the reviews were resolved by the Principal Investigator. Where necessary, experimenter logs, operator logs, and in-cab logs were reviewed to aid in determining loss of control.

4.6. Procedure

Prior to being enrolled in the study, all participants underwent a telephone screening to ensure that they met all requirements to be a participant. After passing the telephone screening, the participant was scheduled and assigned a participant number.

Upon arrival at NADS, the participant was checked in and escorted to a prep room. Once in the prep room, the experimenter summarized the informed consent (see Appendix 1) for the participant and then asked the participant to read the consent document. After participant questions were answered, the participant and experimenter signed the informed consent document.

The experimenter then explained that assistive technology would be present in the participant's car. The participant was given a summary of the technology along with a list of frequently asked questions (see Appendix 2) and their answers to review. Any questions the participant might have were then answered. The participant was then asked to fill out a form for compensation.

Next, the participant was escorted to the simulator by the in-vehicle experimenter. Upon arrival in the simulator, key controls and displays were pointed out to the participant, and the participant was allowed to adjust the seat and the mirrors. Prior to driving, the participant was briefed on what would be occurring and asked to maintain posted speed limits. The first drive was a practice drive in which the participant was asked to change lanes, accelerate, and brake in order to become familiar with the handling of the vehicle. When necessary, the practice was repeated. All participants completed three main drives in the following order: the first trial including the incurring vehicle, the second trial including the tightening curve to the left, and the third trial including the wind gust from the right. Following all drives, the participant was asked to fill out a simulator sickness questionnaire and a reaction survey. After completing these questionnaires, the participant was free to leave.

4.7. Statistical approach

A general linear model (GLM) was utilized to examine the effects of presence of the system. For all analyses, independent variables were entered into the model in the following order: system active, system, event type, age, and gender. Tukey follow-up tests were conducted where appropriate.

5. RESULTS

Results of these analyses are summarized in Table 1 below. Full ANOVA tables can be found in Appendix 3. The model effect and the level of significance are listed for the analyses of loss of control. As can be seen from Table 1, effects attributed to system presence, vehicle/system used, event, and the interaction between vehicle and event were all highly significant. The independent variables of ESC presence, vehicle/system used, and event will be discussed first, followed by the age and gender effects.

Table 1 – Summary of results

	Loss of Control
System Present (Sys)	****
Vehicle/System (Veh)	****
Event (EV)	****
Sys x Veh	**
Sys x EV	*
Veh x EV	****
Sys x Veh x EV	*
Sys x Gender	*
EV x Gender	*
Sys x Veh x Gender	*

* = Significant at the 0.05 level

** = Significant at the 0.01 level

**** = Significant at the 0.0001 level

5.1. Loss of control

5.1.1. ESC presence, vehicle/system configuration, and event effects

The primary interest is the ESC effect under each of the two vehicle/system configurations. These effects are examined under three driving events to gauge the effectiveness of the system for preventing loss of control. Table 2 summarizes the loss of control experienced for the various combinations of system activation, vehicle/system combination, and events. This significant ($p<0.0001$) three-way interaction is illustrated in Figure 9. The significant two-way interactions between event, system activation, and vehicle/system will be discussed as part of the three-way interaction. Figures illustrating these effects can be found in Appendix 4.

Table 2 – Summary of loss of control by system, system activation, and event

	Vehicle 1			Vehicle 2			Total
	Incursion	Curve	Wind	Incursion	Curve	Wind	
ESC Absent	2/30 6.7%	9/30 30.0%	3/30 10.0%	5/30 16.7%	10/30 33.3%	21/29 [3] 72.4%	50/179 27.9%
ESC Present	0/30 0%	0/30 0%	0/30 0%	0/29 [4] 0%	0/30 0%	6/30 20.0%	6/179 3.4%
Total (Event by Vehicle/ System)	2/60 3.3%	9/60 15.0%	3/60 5.0%	5/59 8.5%	10/60 16.7%	27/59 45.8%	56/358 15.6%
Total (Vehicle/ System)	14/180 7.8%			42/178 23.6%			

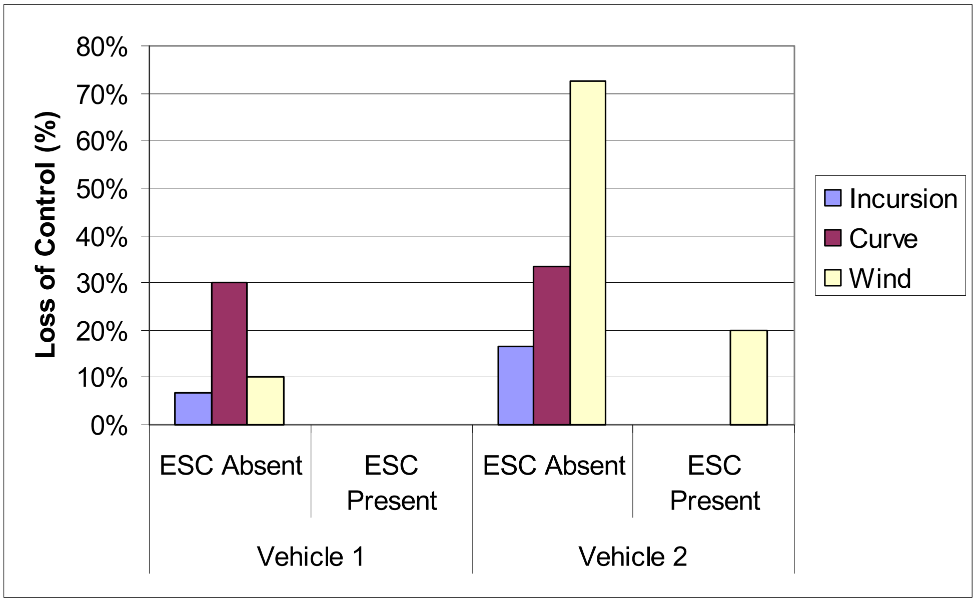

Figure 9 – Illustration of loss of control by vehicle, ESC presence, and event

The three-way interaction between event, ESC presence, and vehicle/system configuration shows that when ESC is present, there was no loss of control with Vehicle 1 and loss of control only in the wind event with Vehicle 2. Additionally, for Vehicle 1 without the ESC present, the curve event was the most severe; however, for Vehicle 2, the wind event was the most severe. In all cases, there was a benefit to having the system.

When considering only the significant interaction (p=0.0076) associated with ESC presence and vehicle/system used, loss of control issues were much more pronounced with Vehicle 2 than with Vehicle 1. This interactive effect is affected by the floor effect for Vehicle 1 in that it is not

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[3] For Participant 80, a system problem occurred prior to driving the wind event drive. The participant was to come back at a later date to finish the drive; however, due to scheduling constraints that was not possible. As a result there were only 29 observations in this cell.

[4] For Participant 114, the system aborted just as the incurring vehicle appeared, resulting in no data for this participant for this event. This leaves only 29 observations in this cell.

possible to have loss of control in less than 0% of the trials. What remains clear, regardless of which vehicle was used, is that the presence of an ESC system significantly reduced the loss of control experienced by the drivers.

When considering the significant interaction (p=0.0135) between ESC presence and the events, a reduction was observed for each event type. For the incursion and the curve events, loss of control was reduced to zero. For the wind event, loss of control was reduced to zero for Vehicle 1 and was reduced from 72.4% to 20% for Vehicle 2.

When considering only vehicle/system used across the events, loss of control with Vehicle 2 was more prevalent than with Vehicle 1, regardless of the event type; however, the difference was least for the curve event.

Now that it is understood how these independent variables interact, they will be considered separately. Figure 10 and Figure 11 show the relative effect of the independent variables on loss of control. There was a significant 24.6 percentage point decrease (p<0.0001) in loss of control in conditions in which the system was absent compared to conditions in which the system was present (27.93% vs. 3.35%). For Vehicle 1, there was significantly (p<0.0001) less loss of control than for Vehicle 2 (7.78% vs. 23.60%). The main effect of the events did not clearly emerge for the higher-order interactions.

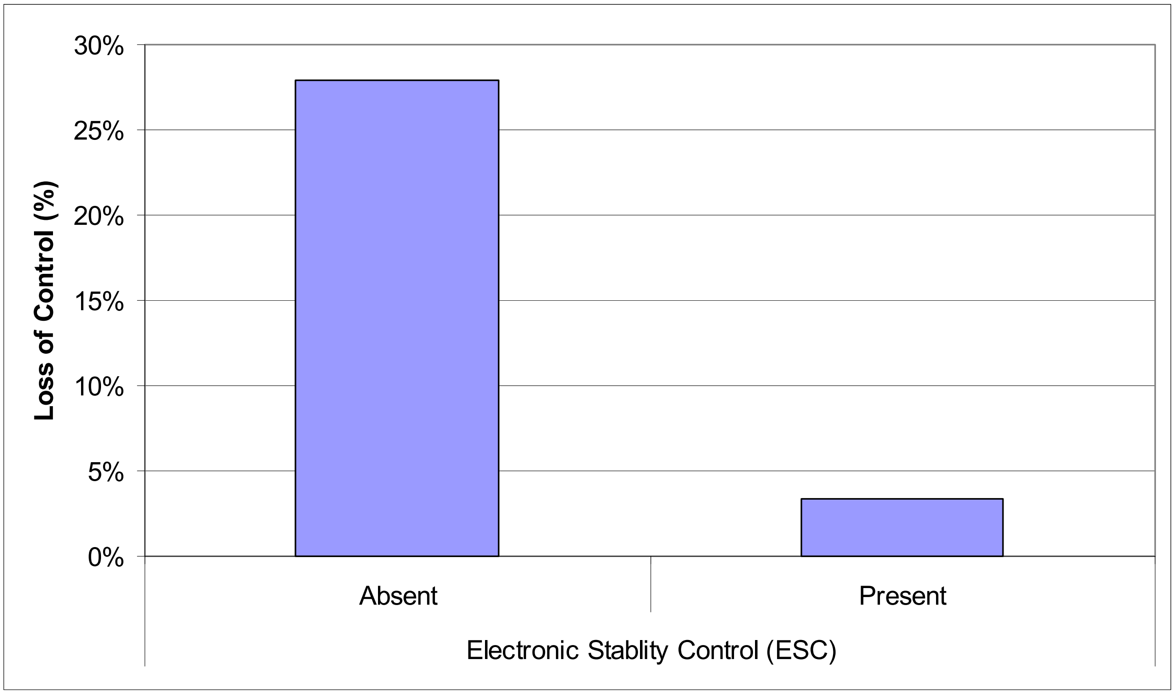

Figure 10 – The effect of ESC presence on loss of control

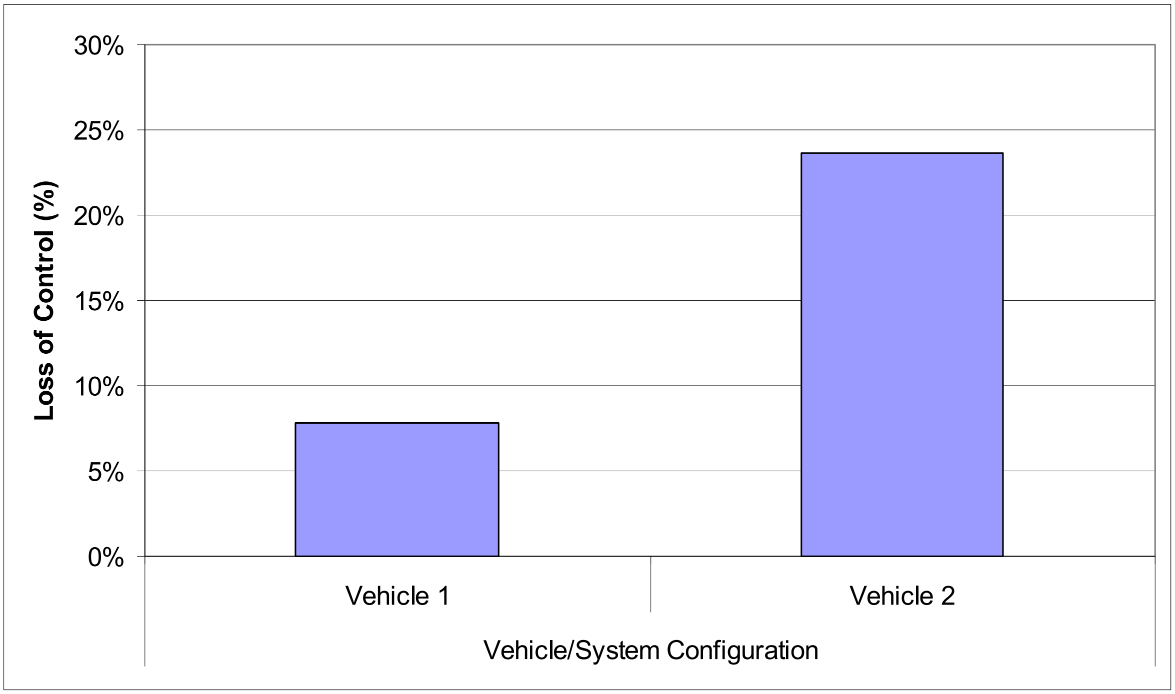

Figure 11 – The effect of vehicle/system configuration on loss of control

5.1.2. Age and gender effects

Having examined the effects of system activation, vehicle/system configuration, and events, the effects of age and gender must now be considered to determine if systematic differences exist that affect the effectiveness of the system in preventing loss of control. With regard to age, as can be seen in Table 1, there were no significant effects. That is to say that across the three age groups there was no significant difference in ability to maintain control of the vehicle and that there was no difference in the utility of the ESC system across these age groups.

With regard to gender, there was no main effect found; however, there were several significant interactions involving gender. These interactions will be examined, starting with the higher-order interactions.

There was a significant (p=0.0430) interactive effect of gender with ESC presence and vehicle/system configuration. This interaction is illustrated in Figure 12. As shown in the figure, for Vehicle 1 there was no difference in performance between male and female participants; however, for Vehicle 2, females performed better than males with ESC absent and males performed better than females with ESC present. However, both males and females performed better with the ESC present regardless of vehicle or gender. Although there was a significant effect for the interaction of ESC presence with gender, this interaction does not hold in light of the three-way interaction that also includes vehicle/system configuration, and therefore will not be discussed independently.

The remaining significant interaction (p=0.0282) involving gender included the events experienced by the participants. Figure 13 illustrates this interaction. As can be seen for the first two events (the incursion and the tightening-radius curve), female participants performed better than male participants. However, for the final event (the wind), the results were reversed, with male participants performing better than female participants.

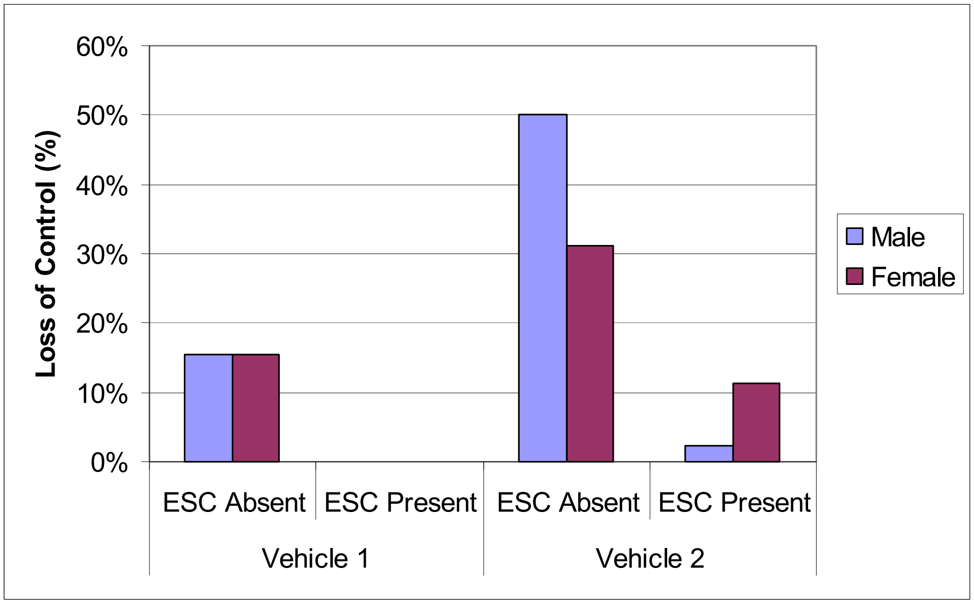

Figure 12 – The effect of gender on vehicle/system configuration and ESC presence

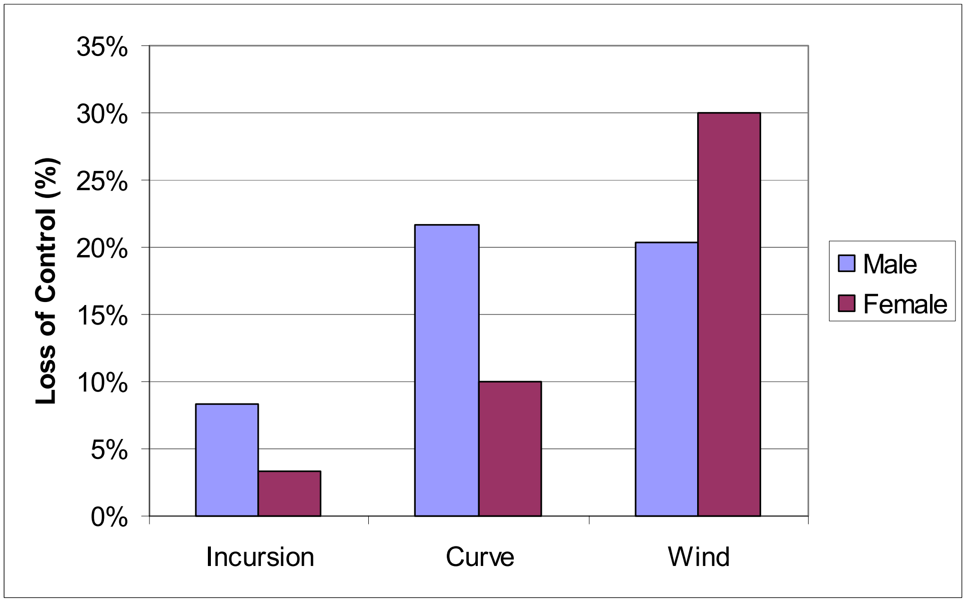

Figure 13 – The effect of gender on loss of control for various events

In order to further investigate the effects of gender, it was determined that the starting conditions for each of the events should be examined to determine if male and female drivers were encountering the same situations. To do this, the speed at the onset of the event was examined. For the incursion event, the speed was measured just before the incurring vehicle became visible to the participant. For the curve event, the speed was measured just before the vehicle entered the tightening portion of the curve. For the wind event, the speed was measured just before the vehicle encountered the wind. For each of these events, a t-test was conducted to compare the initial speed between males and females. Table 3 details the results of the t-tests, including the speeds for males and females for each of the events. There were no significant differences in speed for either the incursion event or the wind event; however, female drivers entered the curve event approximately 2 mph slower than their male counterparts. This may help to explain why females had approximately 12% less loss of control for the curve event.

To further examine the issue, a follow-up t-test was conducted on loss of control for the interaction between gender and events. This follow-up test found no significant difference based on gender for any of the events (see Table 4). For only the curve event did a gender difference even approach significance (p=0.0815). Therefore, when the results of this follow-up test are combined with an examination of the initial speed at the start of the events, it could be argued that the main effect of gender is that female drivers entered the curve event at a slower speed resulting in less loss of control for female drivers than for male drivers. No other clear gender effect emerges from these analyses.

Table 3 – Summary of speed at onset of event

Event	Mean Speed (mph)		p
	Female	Male	
Incursion	61.5	61.4	0.9099
Curve	48.6	51.0	0.0033
Wind	62.9	62.8	0.9168

Table 4 – Summary of follow-up test for loss of control examining gender effects for the three events

Event	Loss of Control (%)		p
	Female	Male	
Incursion	3.4	8.3	0.2543
Curve	10.0	21.7	0.0815
Wind	30.0	20.3	0.2284

Based on the results of these analyses concerning age and gender, it is clear that, although there were some interactions involving gender, the presence of the system provides a benefit in maintaining control of the vehicle regardless of age or gender.

6. DISCUSSION

The primary question being asked in this research was “Does the presence of an ESC system aid the driver in maintaining control of the vehicle in critical citations?” To help answer this question, two commercially available ESC systems were tested in two different vehicles by male and female drivers from a cross-section of age groups. Based on all analyses completed, it is clear that the presence of a system in the vehicle enables drivers to better maintain control of the vehicle. There was 24.5 percentage point reduction between situations in which the drivers lost control with the system present and situations in which the system was absent. This constitutes an 88% reduction in loss of control. Looking at the data from an improvement standpoint, 34% more drivers retained control with ESC than without ESC. This clearly illustrates that there is a significant and meaningful safety benefit associated with driving a vehicle equipped with an ESC system.

It is important to understand how this benefit is realized with the two vehicle/system configurations across the three different events tested. In Figure 9, the overall interaction between system activation, vehicle/system configuration, and events is illustrated. As discussed in that section, for each of the three events for both systems, there was a benefit associated with having a system active in the vehicle, although that benefit varied by event and by system. Figure 15 in Appendix 4 illustrates the relationship between the event and the system used. The two vehicle/system configurations performed similarly for the incursion and the curve event with a slight advantage toward the Vehicle 1 configuration; however, for the wind event, there was a large divergence between the performances of the two vehicle/system configurations. This divergence can be explained by carefully looking at the characteristics of the two vehicles when encountering the side wind. Even though the SUV has a larger side surface area, it is also heavier, which reduces the effect of the wind gust. The passenger vehicle has smaller side surface area but is also significantly lighter, which amplifies the wind effect. Most importantly, however, the geometry of the SUV is such that side winds do not produce as much yawing moment as produced for the passenger vehicle. Combined with driver over-correction, the yawing moment generated by the wind makes the passenger vehicle much more susceptible than the SUV to loss of control while under the effect of the gust. Unfortunately, lack of aerodynamic performance data prevented a thorough validation of the models’ behavior. It is important to note, however, that even under the increased sensitivity, presence of ESC significantly reduced loss of control.

It is also important to consider the effects of gender and age. Based on all analyses, it is clear that the presence of an ESC system helped reduce loss of control regardless of age or gender, and that the benefit of the system was substantially the same. The only major effect of either age or gender involved female participants on the curve event. In this event, as discussed in Section 5.1.2, female drivers slowed more than their male counterparts upon approaching the curve. As a result, they traveled slower through the curve. At this lower speed, it was less likely that the vehicle would begin to skid, resulting in loss of control. It appears that a more cautious approach to the curve, as evidenced by the lower entrance speed, helped the female participants maintain better control of the vehicle.

In conclusion, the ESC systems provided a significant safety benefit to drivers by helping them avoid losing control of the vehicle during critical steering maneuvers as evidenced by the 88% reduction in loss of control situations.

7. ACKNOWLEDGMENTS

We would like to thank all the NADS staff who contributed to the successful completion of this research project: Bin Chen for helping reduce the data; Shannon Guest, Samantha Hench, Cheryl Benn, and Leah Teuwen for helping edit video clips of all drives and subsequently helping code the data; Ethan Fox for producing the video clips demonstrating system operation; Melanie Laverman for editing project documentation.

Finally, we would like to acknowledge the ESC Coalition for their support.

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APPENDIX 1: INFORMED CONSENT

INFORMED CONSENT DOCUMENT

Project Title: **Investigating Driver Reactions to In-Vehicle Driver Augmentation Systems Under Realistic Driving Conditions on a Driving Simulator**

Research Team: **Yiannis Papelis, Ph. D., Timothy Brown, Ph.D., Ginger Watson, Ph.D., Shannon Guest, Ph.D., Samantha Hench, M.S., Judith Wightman, M.S., Julie Qidwai, M.S., Cheryl Benn, B.S., Scott Egerton, B.S., Twila Finkelstein, RN, Sue Ellen Salisbury, B.S.**

WHAT IS THE PURPOSE OF THIS STUDY?

This study involves driving research. The purpose of this research study is to investigate drivers' performance when using assistive technology designed to aid the driver in maintaining control of the vehicle on the roadway. We are inviting you to participate in this research study because you, have a valid, unrestricted U.S. driver's license (except for corrective eyeglasses and contact lenses), have a minimum of 3 years driving experience, are in good general health, and are either between the ages of 18 and 25, 30 and 40, or 55 and 65.

HOW MANY PEOPLE WILL PARTICIPATE?

Approximately 120 people will take part in this study at the University of Iowa.

HOW LONG WILL I BE IN THIS STUDY?

If you agree to take part in this study, your involvement will last for 1 hour.

WHAT WILL HAPPEN DURING THIS STUDY?

Upon arrival at the simulator facility, you will be briefed on the experimental procedure and participant rights, and will be asked to read and sign this Informed Consent Document. You will be given a brief description of the assistive technology that may be present in your vehicle during your drives. The experimenter will then escort you to the simulator, brief you on the simulator cab, and explain the procedures for your drives.

After completing your drives, you will be asked to complete an additional questionnaire about your experience in the simulator. After leaving the simulator, you will be asked to complete your payment voucher.

All driving trials will be recorded on video.

The simulator contains sensors that measure certain aspects of vehicle operation, vehicle motion, and driver actions. The system also contains video cameras that capture images of driver actions (e.g., driver's hand position on the steering wheel, forward road scene). These sensors and video cameras are located in such a manner that they will not affect your driving, the vehicle's performance, or obstruct your view while driving. The information collected using these sensors and video cameras is recorded onto data storage media for subsequent analysis by research staff.

WHAT ARE THE RISKS OF THIS STUDY?

There may be some risks from being in this study. The risk to you, if you actually drive the simulator, is discomfort associated with simulator disorientation. Previous studies with similar driving intensities and simulator setups have produced mild to moderate disorientation effects such as slight uneasiness, warmth, or eyestrain for a small number of participants. These effects are believed to last for only a short time, usually 10-15 minutes, after leaving the simulator. If you ask to quit driving as a result of discomfort, you will be allowed to quit at once. You will be asked to sit and rest before leaving, while consuming a beverage and a snack. This time may coincide with completion of the questionnaires. There is no evidence that driving ability is hampered in any way; therefore, if you show few or no signs of discomfort, you should be able to drive home. If you experience anything other than slight effects, transportation will be arranged through other means. If you are driven home, a follow-up call will be made 24 hours later to ensure that you are not feeling ill effects. Most people enjoy driving in the simulator and do not experience any discomfort.

An experimenter will be present in the back seat of the simulator cab with you to ensure your safety while driving the simulator.

WHAT ARE THE BENEFITS OF THIS STUDY?

You may not benefit personally from being in this study. However, we hope that, in the future, other people might benefit from this study by gaining useful information regarding driving with assistive technologies and how these types of systems affect driving performance. Additionally, many participants do find driving in a simulator of this type to be an exciting and unique experience.

WILL IT COST ME ANYTHING TO BE IN THIS STUDY?

You will not have any costs for being in this research study.

WILL I BE PAID FOR PARTICIPATING?

You will be paid for being in this research study. Should you agree to participate in this study, your compensation will be $25 for your participation which is expected to take approximately 1 hour. Payment will be made by check and will require that you provide your Social Security Number.

WHO IS FUNDING THIS STUDY?

Continental-Teves and Bosch are funding this research study. This means that the University of Iowa is receiving payments from them to support the activities that are required to conduct the study. No one on the research team will receive a direct payment or an increase in salary from Continental-Teves or Bosch for conducting this study.

WHAT ABOUT CONFIDENTIALITY?

We will keep your participation in this research study confidential to the extent permitted by law. However, it is possible that other people may become aware of your participation in this study. For example, federal government regulatory agencies and the University of Iowa Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you, especially where video data are concerned. Participants in the study will be assigned a number to which they will be referred, thereby reducing personal identification of participants. If we write a report or article about this study, we will describe the study results in a summarized manner so that you cannot be identified.

The **engineering data** collected and recorded in this study (including any performance scores based on these data) will be analyzed along with data gathered from other participants. These data may be publicly released in final reports or other publications or media for scientific (e.g., professional society meetings), educational (e.g., educational campaigns for members of the general public), outreach (e.g., nationally televised programs highlighting traffic safety issues), legislative (e.g., data provided to the U.S. Congress to assist with law-making activities), or research purposes (e.g., comparison analyses with data from other studies). Engineering data may also be released individually or in summary with that of other participants, but will not be presented in a way that permits personal identification, except when presented in conjunction with video data.

The **video data** (video image data recorded during your drive) recorded in this study includes your video-recorded likeness and all in-vehicle audio including your voice (and may include, in some views, superimposed performance information). Video and in-vehicle sounds will be used to examine your driving performance and other task performance while driving. Video image data (in continuous video or still formats) and associated audio data may be publicly released, either separately or in association with the appropriate engineering data for scientific, educational, outreach, legislative, or research purposes (as noted above). By initialing in the space provided, you verify that you have been told that audio/visual recordings will be generated during the course of this study.

_______________ Participant’s initials

IS BEING IN THIS STUDY VOLUNTARY?

Taking part in this research study is completely voluntary. You may choose not to take part at all. If you decide to be in this study, you may stop participating at any time. If you decide not to be in this study, or if you stop participating at any time, you won’t be penalized or lose any benefits for which you otherwise qualify.

Under certain circumstances, your participation in this research study may be ended without your consent. This might happen if you fail to operate the research vehicle in accordance with the instructions provided, or if there are technical difficulties with the driving simulator.

WHAT IF I HAVE QUESTIONS?

We encourage you to ask questions. If you have any questions about the research study itself, please contact: **Dr. Timothy Brown, (319) 335-4785.**

If you have questions about the rights of research subjects or research related injury, please contact the Human Subjects Office, 300 College of Medicine Administration Building, The University of Iowa, Iowa City, Iowa, 52242, (319) 335-6564, or e-mail irb@uiowa.edu. General information about being a research subject can be found by clicking "Info for Public" on the Human Subjects Office web site, http://research.uiowa.edu/hso.

Your signature indicates that this research study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Subject's Name (printed): ____

______________________________ ______________________

(Signature of Subject) (Date)

VIDEO DATA RELEASE STATEMENT

I, ________________________, grant permission to use, publish or otherwise disseminate video image data (including continuous video and still photo formats derived from the video recording) and associated in-vehicle audio data collected about me in this study, either separately or in association with the appropriate engineering data for scientific, educational, outreach, legislative, and research purposes or to demonstrate the fidelity of the National Advanced Driving Simulator. I understand that such use may involve widespread distribution to the public and may involve dissemination of my likeness in video or still photo formats, but will not result in release of my name or other identifying personal information.

I may withdraw the permissions granted in this video data release by contacting Timothy Brown at (319) 335-4785 or timothy-l-brown@uiowa.edu. Withdrawal of this video data release may only be accomplished **within seven days (1 calendar week)** of the date recorded on this consent. The ability to withdraw video data does not extend to the ability to withdraw engineering data.

Signature of Participant	Date

Statement of Person Who Obtained Consent

I have discussed the above points with the subject or, where appropriate, with the subject's legally authorized representative. It is my opinion that the subject understands the risks, benefits, and procedures involved with participation in this research study.

______________________________ ______________________

(Signature of Person who Obtained Consent) (Date)

APPENDIX 2: ESC SUMMARY AND FAQ

Electronic Stability Control (ESC)

ECS is a stability enhancement system designed to electronically detect and assist the driver in critical driving situations. To accomplish this, the system can apply the brakes to individual wheels and adjust the power applied to the wheels. The system helps you maintain control in all weather conditions by helping to prevent skids, spins and rollovers. ECS also include Antilock Braking capability and Traction Control.

> **Antilock Braking System (ABS)** controls brake pressure to help prevent wheel lock-up during braking, so you can steer and maneuver around obstacles during braking.
>
> **Traction Control System (TCS)** applies brakes at drive wheels and reduces power to the wheels to help reduce wheel spin during acceleration. It works across a full range of speeds, whether you're accelerating after a stop or passing on the highway.

Use of ESC

ESC works automatically as needed, so you can concentrate on driving. ESC compares a driver's intended course with the vehicle's actual movement. When instability is detected, ESC automatically applies brakes to individual wheels and can also reduce power to the wheels to help keep you on track.

Frequently Asked Questions

How does Electronic Stability Control (ESC) work?
Using information from vehicle sensors, ESC constantly compares the driver's intention with the vehicle's actual behavior. A central microcomputer analyzes the incoming data. When instability is detected, ESC immediately triggers a response to provide stability, automatically braking any of the four wheels and/or adjusting power to the wheels.

What distinguishes ESC from ABS and TCS?
ABS prevents wheel lock during braking and TCS enhances traction by controlling driven wheel spin during acceleration, but ESC goes a step further: it reduces the risk of skidding in all driving situations. ESC recognizes hazardous situations and intervenes without any action on the part of the driver. It applies the brakes selectively to individual wheels to stabilize the vehicle and keep it on course.

If I have ESC, do I still need ABS?
The function of ABS is incorporated into ESC.

When I'm driving, how do I activate ESC?
ESC is an active safety system and does not need to be activated by the driver. When sensors detect that loss of control is imminent, the system automatically engages to help you maintain control of your vehicle.

Can I drive more aggressively with ESC?
No. Aggressive driving is neither appropriate nor safe with any vehicle. ESC can only act within the physical limits of the vehicle.

Do I have to change my style of driving if I have a vehicle with ESC?
No. ESC supports the driver, but it does not require any changes in your usual style of driving - in other words take due care and pay attention to other road users, and always look ahead. If, for example, you have taken part in a safety training course, you should apply everything you learned there. ESC will provide you with further assistance and help you to master critical situations within the physical limits of the vehicle.

APPENDIX 3: ANALYSIS OF VARIANCE TABLES

Significance is coded as follows:

* = Significant at the 0.05 level

** = Significant at the 0.01 level

*** = Significant at the 0.001 level

**** = Significant at the 0.0001 level

Loss of Control

Variable	Df	SS	MS	F	p	Significance
Sys	1	5.5369067	5.5369067	52.72	<.0001	****
veh	1	2.26365588	2.26365588	21.55	<.0001	****
veh*Sys	1	0.78037878	0.78037878	7.43	0.0076	**
EV	2	2.36376585	1.18188292	13.60	<.0001	****
EV*Sys	2	0.76568554	0.38284277	4.40	0.0135	*
veh*EV	2	2.90206659	1.4510333	16.69	<.0001	****
veh*EV*Sys	2	0.66071577	0.33035789	3.80	0.0241	*
age	2	0.63216236	0.31608118	3.01	0.0540	
Sys*age	2	0.62141293	0.31070646	2.96	0.0567	
veh*age	2	0.03570132	0.01785066	0.17	0.8440	
veh*Sys*age	2	0.03963578	0.01981789	0.19	0.8284	
EV*age	4	0.16335021	0.04083755	0.47	0.7579	
EV*Sys*age	4	0.17514533	0.04378633	0.50	0.7331	
veh*EV*age	4	0.08739654	0.02184914	0.25	0.9086	
veh*EV*Sys*age	4	0.09400047	0.02350012	0.27	0.8968	
gender	1	0.06468949	0.06468949	0.62	0.4345	
Sys*gender	1	0.44206557	0.44206557	4.21	0.0429	*
veh*gender	1	0.06453337	0.06453337	0.61	0.4351	
veh*Sys*gender	1	0.44196593	0.44196593	4.21	0.0430	*
EV*gender	2	0.63234232	0.31617116	3.64	0.0282	*
EV*Sys*gender	2	0.09401044	0.04700522	0.54	0.5832	
veh*EV*gender	2	0.29836552	0.14918276	1.72	0.1825	
veh*EV*Sys*gender	2	0.02341059	0.0117053	0.13	0.8741	
age*gender	2	0.52995294	0.26497647	2.52	0.0855	
Sys*age*gender	2	0.2503466	0.1251733	1.19	0.3081	
veh*age*gender	2	0.39086008	0.19543004	1.86	0.1611	
veh*Sys*age*gender	2	0.11043222	0.05521611	0.53	0.5928	
EV*age*gender	4	0.22871681	0.0571792	0.66	0.6221	
EV*Sys*age*gender	4	0.03055077	0.00763769	0.09	0.9861	
veh*EV*age*gender	4	0.09332679	0.0233317	0.27	0.8980	
veh*EV*Sys*age*gende	4	0.02681895	0.00670474	0.08	0.9892	
SN(veh*Sys*age*gend)	96	10.08333333	0.10503472	.	.	
EV*SN(ve*Sy*age*gen)	190	16.51666667	0.08692982	.	.	

APPENDIX 4: ADDITIONAL FIGURES

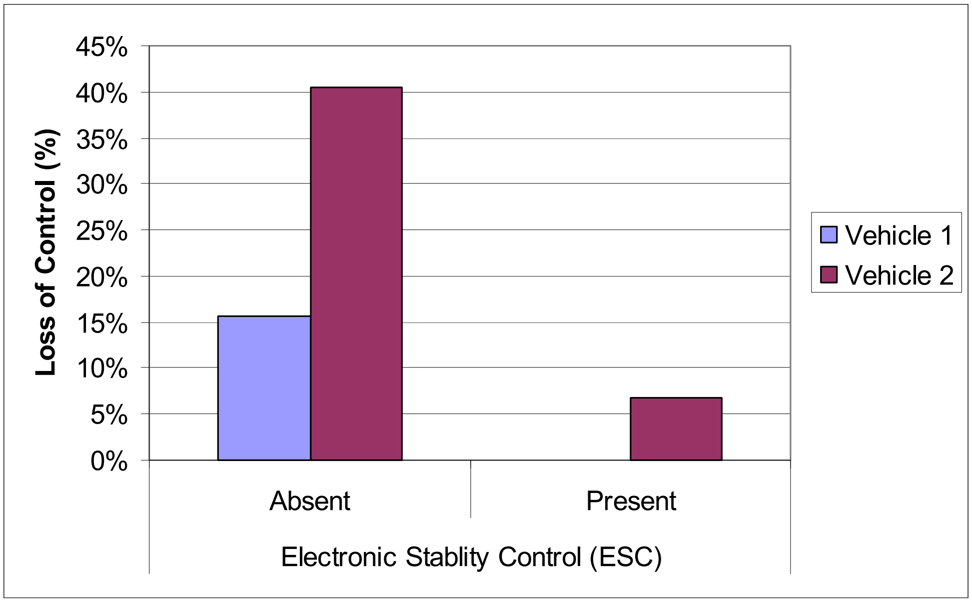

Figure 14 – Effects of system activation and vehicle/system configuration on loss of control

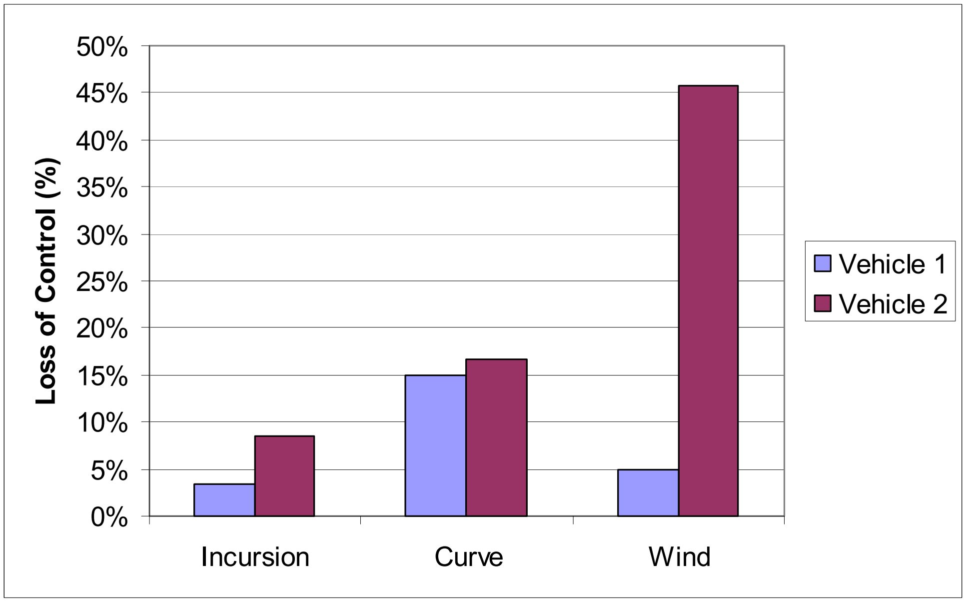

Figure 15 – Effects of vehicle/system configuration and events on loss of control