

## NATURALISTIC STUDY OF LEVEL 2 DRIVING AUTOMATION FUNCTIONS

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### **ABSTRACT**

Currently, there are commercially available vehicles that include features capable of providing Level 2, Partial Driving Automation as defined by SAE International. Research on the use and performance of the systems that these vehicles employ in natural settings is needed to help clarify the systems' potential benefits. The *Naturalistic Study of Level 2 Driving Automation Functions* (L2 NDS) project described herein has generated practical data to support the understanding of the use of automated lateral and longitudinal control functionality by evaluating a subset of currently available advanced technologies as drivers experience them during daily use.

The objective of the L2 NDS project was to investigate, through a naturalistic driving study, real-world driver interaction with commercially available driving automation systems. Ten vehicles equipped with both lateral and longitudinal automated features were instrumented and loaned to participants for a 4-week period. A total of 120 drivers were recruited over a 14-month data collection period. Each study vehicle was equipped with Virginia Tech Transportation Institute's NextGen Data Acquisition System, which continuously records video of the both the driver and the roadway, as well as vehicle data and automated lateral and longitudinal control activations. These data were used to analyze driving automation system use and driver performance during the study.

Focus area 1 investigated *System Performance*, including overall use of the features. Participants drove 216,585 miles, with 70,384 miles driven with both lateral and longitudinal control features active. Focus area 2 investigated *Driver-System Interaction* and involved a review of driver behaviors during driving automation system use, specifically the prevalence of non-driving tasks. Drivers were observed engaging in non-driving tasks, but these were not related to feature use. Focus area 3 investigated *Driver Performance*, which was measured by drivers' responses to Request to Intervene (RTI) alerts generated by the driving automation systems. Driver behavior was consistent with active driving/supervision of the automated features; drivers were receptive to RTI alerts. No RTIs were associated with any safety-critical events (i.e., crashes and near-crashes). In total, 5 minor crashes (no injury or visible damage) and 66 near-crashes were observed across the entire data set. No statistical relationship was observed between safety-critical event rates and feature activation level. Focus area 4 investigated *Driver Engagement*, which includes subjective feedback obtained from participants. Participants reported that they were generally comfortable and felt safe using the features, with self-reported trust increasing over the course of the study.

## INTRODUCTION

The objective of the *Naturalistic Study of Level 2 Driving Automation Functions* (L2 NDS) project was to investigate, through a naturalistic driving study (NDS), real-world driver interaction with commercially available vehicles that could sustain lateral and longitudinal motion control. The study objectives were to observe and evaluate how drivers operated vehicles equipped with lateral and longitudinal driving automation features intended for operation in mixed traffic under a variety of roadway types, driving conditions, and speeds. This study was also intended to support the identification and/or refinement of human factors-related needs to help encourage the safe operation of vehicles with driving automation features.

Currently, there are several commercially available vehicle models offering optional features that automate at least some portion of lateral and longitudinal vehicle control. Depending on the make of the vehicle, different terms are used to name and describe these automated lateral and longitudinal control features. For example, the lateral control feature may be referred to as steering assist, lane keep assist, or lane centering, while the longitudinal control feature is often termed adaptive cruise control, intelligent cruise control, or advanced cruise control. In some cases, these systems activate together, while other implementations require two separate feature activations. When automated lateral and longitudinal control features are combined, the overall driving automation systems can be considered Level 2 (L2), Partial Driving Automation [1]. SAE describes the roles of the driving automation system and the driver during L2 driving automation in standard J3016, originally published in 2016:

The Driving Automation System (while engaged): 1) Performs part of the dynamic driving task (DDT) by executing both the lateral and longitudinal vehicle motion control subtasks, and 2) Disengages immediately upon driver request.

The Driver (at all times): 1) Performs the remainder of the DDT not performed by the driving automation system, 2) Supervises the driving automation system and intervenes as necessary to maintain safe operation of the vehicle, and 3) Determines whether/when engagement and disengagement of the driving automation system is appropriate, and immediately performs the entire DDT whenever required or desired. (p. 19)

The research team notes that there is ongoing discussion regarding classification and definitions of driving automation systems and features. Although the report title includes the term “Level 2,” the goal of this research project was not to classify features as Level 2, but rather to determine how drivers interact with a range of driving automation features. Given the myriad of terms used to name or brand these types of automation, the general terms “automated lateral control features” and “automated longitudinal control features” are used in this paper.

The project was designed to address four main focus areas, with specific research questions assigned to each. Focus area 1 investigated **System Performance**. Sampled and reduced data were used to provide insight into the systems’ performance. Focus area 2 investigated **Driver-System Interaction** and involved a review of driver behaviors during driving automation system use, specifically the prevalence of non-driving tasks. Focus area 3 investigated **Driver Performance**. Driver performance was measured by drivers’ responses to Request to Intervene (RTI) alerts generated by the driving automation systems. Focus area 4 investigated **Driver Engagement**, which includes subjective feedback obtained from participants. The project also included a Longer Drive Sub-Study focused specifically on drives longer than 2 hours.

## METHODS

Two each of the following vehicles were leased for the duration of the study. Each of the selected models allowed drivers to simultaneously activate longitudinal and lateral automation features (relevant packages required are listed). As part of the lateral automation feature, all vehicles generated RTIs informing the driver to return hands to the steering wheel or otherwise administer lateral control input.

- 2017 Audi Q7 Premium Plus 3.0 TFSI Quattro with Driver Assistance Package
- 2015 Infiniti Q50 3.7 AWD Premium with Technology, Navigation, and Deluxe Touring Package
- 2016 Mercedes-Benz E350 Sedan with Premium Package, Driver Assistance Package

- 2015 Tesla Model S P90D AWD with Autopilot Convenience (software version 8.0)
- 2016 Volvo XC90 T6 AWD R with Design and Convenience Packages

Each vehicle was equipped with Virginia Tech Transportation Institute’s (VTTI’s) NextGen Data Acquisition System (DAS). As shown in Figure 1, the DAS continuously recorded video of the forward roadway, the driver’s face, an over-the-shoulder view of the driver’s hands and lap area, a view of the footwell, and a rear view. The DAS also recorded vehicle data, including speed, accelerator pedal position, brake application, acceleration, lane position, turn signal activation, and GPS coordinates.



*Figure 1. Example of video views collected by the DAS*

For each driving automation system, the general operational envelope was ascertained in various driving environments. The longitudinal control features utilized a forward-looking set of sensors (typically radar-based; for some vehicles, forward camera data was also included). None of the longitudinal control features directly responded to traffic ahead in adjacent lanes. Following distance could be adjusted by the driver, with following distance settings having an approximately 2–3-second headway.

Lateral control features varied in their overall capability. In some cases, the lateral control feature would initiate steering as the study vehicle approached a lane marking, while in others the system operated more akin to a “lane centering” feature, with active steering from the feature. Lateral control features utilized a forward-looking camera with a vehicle-specific machine vision algorithm to track lane markings.

Regardless of overall capability, all features required active monitoring from the driver and frequent intervention. For all vehicles, the intended use of the lateral control features required the driver’s hands on the wheel to engage it, and drivers were warned not to use the driving automation systems in poor visibility conditions, weather related or otherwise. As noted, the vehicles varied somewhat in feature availability and activation; in some cases, the lateral control feature was only available if the longitudinal control feature was already engaged, or the two features engaged simultaneously. For most of the vehicles, the following feature generalizations are most relevant for the current paper:

- Driving automation systems were intended for use in highway driving environments with clear weather
- Lateral control features were generally available at speeds above 40 mph with visible lane markings
- Lateral control features were based on a vehicle-specific machine vision system to track lane markings
- Additional sensors (e.g., ultrasonic) may have been used for lateral safety systems such as blind spot warning
- Longitudinal control features were available above 20 mph
- Longitudinal control features were forward-radar based

- No vehicles included corner or side-facing radar units
- RTIs were all generated as part of the lateral driving automation feature
- Timing was based on the lack of detected steering inputs from the driver and/or crossing a detected lane marking
- RTIs were multi-modal, including both a visual and auditory component (no RTIs included a haptic component)

Although some vehicles tested included a “low speed” version of driving automation (i.e., traffic jam assist, pilot assist, autopilot), baseline epochs for this effort were sampled from the speeds outlined above for lateral and longitudinal control features. However, RTIs and safety-critical events (SCEs; i.e., crashes and near-crashes) were included from all speeds.

## **PARTICIPANTS**

A total of 120 participants were recruited—12 participants for each of the 10 selected study vehicles. All participants were recruited from the Washington, DC region, which included both northern Virginia and Maryland suburbs. Participants were balanced across age and gender and were recruited from two age groups: 25 to 39 years old, and 40 to 54 years old, which were the age groups used in previous test track research [2]. For each set of 12 participants, six were from the younger age group (three male and three female) and six were from the older age group (three male and three female).

Drivers were compensated up to \$500 as follows: 1) up to \$360 if their total mileage was under or equal to 1,200 miles; or 2) \$500 if they exceeded 1,200 miles. They were also lent a transponder that gave them free access to the high-occupancy toll lanes managed by Transurban.

## **APPROACH**

Each driver was assigned to one vehicle for the duration of their 4-week participation time in the study. Drivers received training on the vehicles designed to mimic what they would receive at a dealership if purchasing a new car. Training consisted of a static orientation and a two-part test drive. The static orientation included instruction on all of the driving automation system features. During the first part of the test drive, the onsite researcher drove the study vehicle and demonstrated the driving automation features. Once the researcher completed the demonstration of the features, the participant took over driving the vehicle. The participant was then able to experience features and ask the researcher any remaining questions. After completing training, participants drove the study vehicle instead of their own vehicle during the 4-week participation period.

Participant data was saved to a secure server and analyzed once driving periods were complete. Continuously recorded data were then sampled for further annotation and analysis. Trained data reductionists reviewed the sampled recorded video, audio, and parametric data to annotate the driver, vehicle, and environmental factors that were present during each of the sample types (driving automation system use, RTI alerts, and SCEs).

## **DATA SAMPLING AND REDUCTION**

NDSs provide continuous data recording while participants are driving. The focus of this section is to describe the approach to sampling, reducing, and analyzing continuously recorded data. Established kinematic algorithms (e.g., hard decelerations, lane departures, high yaw rates) were used to identify potential SCEs. Trained data reductionists (see below) then inspected the videos associated with these events to verify the occurrence of an SCE. For baseline driving samples, 15-second epochs were sampled from the continuously recorded data. The 15 seconds were divided into 10 seconds prior to and 5 seconds after the time of interest. Samples were taken during instances in which both the lateral and longitudinal driving automation features were engaged, during instances in which the driving automation system was available but not engaged, and during instances in which both features of the driving automation system were available but only one was engaged. Instances in which an RTI was issued were also sampled. Driving automation was available when the vehicle was traveling above the speed required for activation on a road with visible lane markings. The sampling approach was as follows:

- All periods in which the driving automation system was available for use and also active were identified using a VTTI-developed machine-vision algorithm combined with available vehicle network information.
- Up to twelve 15-second epochs per driver were randomly sampled from the periods in which the driving automation system was active (samples were stratified by each week of participation). It was determined that 12 samples per driver were needed to provide a reliable statistical estimate of driver performance, and 15-second samples allowed for the assessment of drivers' visual behavior and engagement in non-driving-related tasks; this sampling method was adapted from a previous NDS [3].
- Up to 12 epochs per driver of instances in which the driving automation system was available, but only one feature (either lateral or longitudinal) was active, were sampled. These were instances where only lateral or only longitudinal control was automated, but vehicle speed was above 40 mph and data reductionist-verified lane markings were present.
- Up to 12 epochs per driver of instances in which both functions of the driving automation system were available, but neither lateral nor longitudinal control automation was active, were sampled. These were instances where the vehicle speed was above 40 mph and data reductionist-verified lane markings were present.
- Up to 12 RTI epochs per driver per week were sampled. These were instances where an RTI was issued by the vehicle's human-machine interface.
- All SCEs that were observed in the dataset were analyzed. See the Results section below for details regarding the total number and type of SCEs (crashes and near-crashes) observed during data collection.

This sampling strategy was implemented to allow comparisons of driver behavior and roadway scenarios between levels of driving automation system engagement (when such activation was available). As noted, for each epoch type, 12 epochs per driver week were planned. In practice, 12 epochs were not observed in all cases for all vehicles; Table 2 shows the number of samples collected. In cases where there were fewer than 12 samples for a week, all instances of that activation were reduced.

**Table 1.**  
**Total epochs samples and average samples per driver**

Epoch	Total	Average Samples per Driver	Average Samples per Week
Both Features Engaged	1,295	11	3
No Features Engaged, Both Features Available	1,052	9	2
One Feature Engaged, Both Features Available	1,083	9	2
RTIs	449	4	1
SCEs	71		

## RESULTS AND KEY FINDINGS

The L2 NDS was intended to produce an initial understanding of commercially available driving automation systems. This project is the first study sponsored by the National Highway Traffic Safety Administration to review driver interaction with vehicles that include lateral and longitudinal automated features in real world settings. This research effort was intended to provide insight into four focus areas: System Performance (during unscripted, on-

road driving), Driver System Interaction, Driver Performance, and Driver Engagement. Key findings for each focus area are summarized below.

### **System Performance**

Across all 120 participants, a total of 216,585 miles were driven (1,805 average per participant), with 53,360 miles driven below 40 mph. The remaining 163,225 miles were driven at speeds at or above 40 mph—of these, 70,384 miles were driven with both lateral and longitudinal driving automation active, 50,454 with one feature active, and 42,431 with no features active.

The analysis of environmental factors observed indicated that, in most cases, participants were operating the driving automation system-equipped vehicles in a manner consistent with manufacturers' intended use. When operating the vehicles at speeds above 40 mph, drivers typically drove with both features active. Drivers were less likely to activate the systems in heavy traffic, on non-interstate roads, and in rainy weather conditions.

### **Driver System Interaction**

Non-driving task prevalence was observed to be similar across all activation levels; there was no increase in non-driving tasks when both lateral and longitudinal control features were active. The most common non-driving tasks observed were interacting with a passenger and monitoring the instrument panel. Furthermore, the types of tasks performed and eyes-off-road time were also similar across activation levels. The observed prevalence of non-driving tasks was high, but it should be noted that the current study used a 15-second reduction window to assess non-driving tasks. Previous estimates of secondary tasks performed as part of the Second Strategic Highway Research Project (SHRP 2) were based on a 6-second reduction window [3]. Additionally, drivers were observed to be monitoring and/or interacting with the instrument panel (center dashboard console and instrument cluster) in about 10% of sampled cases; this is consistent with supervisory behaviors as feature activation level (e.g., on or off), settings (e.g., following distance setting), or other system status (e.g., lane marking tracking) were presented in the instrument panel.

### **Driver Performance**

In total, there were 71 SCEs observed in the data set. Five SCEs were crashes, and 66 were near-crashes. All crashes were low severity, rated as Level 3 or Level 4 based on previously adapted SHRP 2 definitions [4] (Virginia Tech Transportation Institute, 2015). No statistical relationships were observed between SCE rates and feature activation level. No RTIs were observed in the context of any SCE. The one observed crash with both features active was a single vehicle crash in which the driver struck a toll lane access gate at low speed (the driver attempted to enter a buses-only entrance). Although both features were active at some point during the reduction window, the driver pressed the brake prior to impact, overriding the driving automation features. The driver was not distracted and had at least one hand on the wheel throughout the event. No damage to the gate or vehicle was observed in this instance.

A total of 449 RTIs were sampled; in 118 of these, drivers were observed to have hands off the wheel. Analysis of reaction times for the RTIs in which drivers had hands off the wheel showed that the average reaction time of 0.94 seconds was within an expected range based on the results of previous research (e.g., [2]). However, there were some cases that showed longer response times or no intervention from the driver. Examination of these cases revealed that drivers were exploring the boundary conditions associated with the driving automation systems (e.g., intentionally keeping hands off wheel to test RTI duration and lateral control feature capabilities). Drivers were often observed explaining system functionality to passengers in these events, which all occurred when traffic was generally free flowing, weather was clear, and drivers were looking forward and attentive.

### **Driver Engagement**

Overall, drivers appeared to trust the driving automation systems, and were comfortable using them. Driver interviews and trust ratings gathered at specific intervals during the 4-week participation period suggested that there was little change in trust in the lateral systems, although summarized comments also indicated that there were situations reported where the lateral systems did not function as expected. Again, these limitations are consistent with how the vehicles were characterized, and it is likely that even after the features were demonstrated, participants still had a higher than realistic expectation of function. Trust in the longitudinal system did increase over time; subjective feedback suggested that drivers learned the limitations of the longitudinal system and were able to use it more effectively after understanding its limitations.

## REFERENCES

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