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Classification of Level 2 Driving Automation Events Observed on Public Roads – Part 2

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16. Abstract

This report summarizes data collected while operating two different passenger vehicles equipped with SAE level 2 driving automation systems on public roadways. SAE level 2 driving automation systems are referred to as partial driving automation systems and require the full and undivided attention of drivers at all times.

A 2020 Hyundai Palisade SEL and a 2017 Tesla Model S 90D were driven on three previously established test routes with their level 2 driving automation systems enabled. Professional drivers held their hands just above, or lightly touched, the steering wheels while the vehicles were driven in level 2 driving automation. Noteworthy events were identified by the drivers and recorded by two synchronized cameras using remote triggers attached to the steering wheels.

The three routes featured different roadway types. The first route was comprised exclusively of divided, limited access highways with exit and on ramps. The second was a rural route that consisted primarily of roads with a single lane per travel direction passing through signalized and non-signalized intersections. The third was a mixed route comprised of highway, rural, and city roadways.

Driver-annotated videos documented system operation during a variety of traffic scenarios. Three classification types describe events observed during the drives: (1) events where the vehicle, during otherwise normal and unremarkable driving, suddenly terminated its level 2 driving automation system operation and transferred at least lateral control back to the driver (Type I); (2) driving situations where the system remained in operation but satisfied certain classification criteria (Type II); and (3) driving situations where either the driver performed a manual override to disengage the system, or an unintended lane or road departure had occurred (Type III). Details regarding the various events recorded and the prevailing road and weather conditions are provided.

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Executive Summary

This report summarizes data collected while operating two different passenger vehicles equipped with SAE level 2 driving automation systems capable of providing simultaneous lateral and longitudinal control on public roadways. SAE level 2 driving automation systems are referred to as partial driving automation systems and require the full attention of drivers at all times (SAE, 2018).

A 2020 Hyundai Palisade SEL and a 2017 Tesla Model S 90D were driven on three previously established test routes with their level 2 driving automation systems enabled (Rao & Forkenbrock, 2020). Professional drivers held their hands just above, or lightly touched, the steering wheels while the vehicles were operated in level 2 driving automation, and used slight steering inputs to maintain it when needed (i.e., a few degrees of steering wheel angle using low torque and steering velocity, but not enough to affect the vehicle heading angle). Noteworthy events were identified by the drivers and recorded by two synchronized cameras using remote triggers attached to the steering wheels.

The three routes each featured a different roadway type. The first route was comprised exclusively of divided, limited-access highways with exit and on ramps. The second was a rural route that consisted primarily of roads with a single lane per travel direction passing through signalized and non-signalized intersections. The third was a mixed route comprised of highway, rural, and city roadways.

Driver-annotated videos were used to document system operation during various real-life traffic scenarios. Three classification types were used to describe events that were observed during the drives.

- A Type I event occurred when the level 2 driving automation system, during otherwise normal and unremarkable driving operation, suddenly terminated its level 2 driving automation operation, issued a takeover notification to the driver; and transferred at least lateral control back to the driver. This required the driver to immediately respond by resuming manual control of the vehicle.
- A Type II event occurred when the level 2 driving automation system exhibited some form of subjectively noteworthy operation, but not to the point where the driver believed it was necessary to manually override the system to regain full control of the vehicle. At the time of the Type II event, the level 2 driving automation system was required to be actively providing lateral and longitudinal control of the vehicle without issuing an alert or warning to the driver.
- A Type III event had two sub-categories: (1) a “driver intervention event” where the driver performed an override input to immediately disengage the system and resumed full manual control, and (2) a “lane departure with automatic centering event” where the vehicle, while operating in level 2 driving automation without traffic in an adjacent lane, breached a lane boundary but then automatically returned back towards the center of the original travel lane (i.e., without any intervention from the driver).

From the driver’s perspective, the important distinction between Type II and III events was how they responded to the events. A driving situation where the vehicle maintained a lane position bias near the roadway center line separating the driver’s vehicle from oncoming traffic, but the driver did not manually override the level 2 driving automation system, is an example of a

Type II event. Conversely, when a Type III event concluded with the driver applying a manual override, it was because the driver believed the vehicle was unable to continue automatically performing the driving task. A common Type III event example occurred when the vehicle entered, and initially responded to, a curved section of road, but was unable to maintain lane position within the entire curve. In this case, the driver had to resume manual steering of the vehicle to prevent a lane and/or road departure.

In summary, for the Hyundai Palisade:

- Type I events per 100 miles averaged 9.1, 43.7, and 27.7, for the highway, rural, and mixed routes.
- Type II events per 100 miles averaged 4.6, 3.1, and 29.7, for the highway, rural, and mixed routes.
- Type III events per 100 miles averaged 13.3, 149.2, and 61.2, for the highway, rural, and mixed routes. Overall, 946 of the 1,085 Type III events observed during drives performed with the Hyundai Palisade were lane departure events.

For the Tesla Model S:

- Type I events per 100 miles averaged 0.1, 0.6, and 21.3, for the highway, rural, and mixed routes.
- Type II events per 100 miles averaged 21.6, 25.1, and 4.8, for the highway, rural, and mixed routes.
- Type III events per 100 miles averaged 5.7, 11.5, and 27.5, for the highway, rural, and mixed routes. Overall, 161 of the 198 Type III events observed during drives performed with the Tesla Model S were lane departure events.

1 Introduction

There are many factors that can affect the performance of SAE driving level 2 driving automation systems[1] (SAE, 2018), and not all systems have the same operational characteristics. As such, better understanding of how vehicles equipped with these systems operate in the real world is of great interest to the National Highway Traffic Safety Administration.

The objective of the work described in this report was to document the operation of the level 2 driving automation systems installed in two different passenger vehicles on public roadways. To facilitate this, three professional drivers drove both vehicles on three previously established test routes (Rao & Forkenbrock, 2020). This work is not intended to function as a vehicle performance assessment, nor is it intended to compare vehicle operation.

When level 2 driving automation was enabled, drivers held their hands just above, or lightly touching, the steering wheels, and used slight steering inputs to maintain level 2 driving automation when needed (i.e., a few degrees of steering wheel angle using low torque and steering velocity, but not enough to affect the vehicle heading angle). Noteworthy events were subjectively identified by the drivers (i.e., flagged for further review) and recorded by two synchronized cameras using remote triggers attached to the steering wheels. Data were processed after the drives, at which time the vehicle's response was classified during the event. The lane, traffic, environmental, and roadway conditions present at the time of an event were also documented, along with the driver's comments.

[1] SAE J3016 defines level 2 driving automation as "the sustained and ODD-specific execution by a driving automation system of both the lateral and longitudinal vehicle motion control subtasks of the DDT with the expectation that the driver completes the OEDR subtask and supervises the driving automation system," where the ODD is the operational design domain, DDT is the dynamic driving task, and OEDR is the object and event detection and response.

2 Test Protocol

2.1 Test Vehicles

A 2020 Hyundai Palisade SEL and a 2017 Tesla Model S 90D were used for the research described in this report. Both vehicles were equipped with level 2 driving automation systems. Since this work was a continuation of similar research performed during 2018 (Rao & Forkenbrock, 2020), the number of vehicles was limited to two. The Hyundai Palisade was selected to further expand NHTSA's familiarization with commercially available level 2 driving automation systems (NHTSA had not previously documented the operation of a vehicle so-equipped from Hyundai). Although NHTSA had used the Tesla Model S for previous level 2 driving automation system research, an October 10, 2019, update to the vehicle's firmware that enabled automated lane changes and automated transitions from highways to exit ramps was used for the work described in this report. These features were not available during NHTSA's previous research, and only Tesla models offered this capability at the time of this report.

2.1.1 2020 Hyundai Palisade SEL

The level 2 driving automation system installed on the Hyundai Palisade (Figure 1) consists of "lane keeping assist," which can automatically steer to maintain lane position on roads that have two lane lines, and "Smart Cruise Control," which maintains speed and a set distance to the vehicle ahead. The vehicle was also equipped with a "Highway Driving Assist (HDA)" system that when enabled and operational, automatically adjusts the Smart Cruise Control set speed to the posted speed limit of roadways within the vehicle's operational design domain (ODD). According to the Hyundai Palisade owner's manual (Hyundai Motor America, 2020), HDA requires that (1) the vehicle is being driven on a highway, (2) Smart Cruise Control is operating, and (3) vehicle speed is under 95 mph (153 km/h).

Image courtesy of Hyundai Motor Company

Figure 1. 2020 Hyundai Palisade

The owner's manual also provides a set of conditions related to driver inputs and/or the driving environment which may cause HDA to be unavailable and/or temporarily suspended, as follows.

- The turn signal is turned on before changing a lane.
- The vehicle is not in the middle of the lane when the system is turned on.
- Electronic stability control (ESC) or "Vehicle Stability Management" is activated.
- The vehicle is driven on a sharp curve.

- The vehicle makes sharp lane changes.
- The vehicle brakes suddenly.
- Only one lane marker is detected.
- The lane is very wide or narrow.
- There are more than two lane markers on the road (e.g. construction area).
- Radius of a curve is too small.
- The vehicle is driven on a steep incline.
- The steering wheel is turned suddenly.

When the vehicle is not being operated within the HDA ODD, enabling both lane keeping assist[2] and Smart Cruise Control can still provide level 2 driving automation; however, the Smart Cruise Control set speed will no longer be automatically adjusted to the posted speed limit. According to the owner's manual, Smart Cruise Control will automatically be canceled when:

- The driver's door is opened.
- The vehicle is shifted to N (Neutral), R (Reverse) or P (Park).
- The electronic parking brake is applied.
- The vehicle speed is over 110 mph (170 km/h).
- The vehicle stops on a steep incline.
- The ESC, traction control system, or antilock brake system is operating.
- The ESC is turned off.
- The sensor or the cover is dirty or blocked with foreign matter.
- The vehicle is stopped for a certain period of time.
- The vehicle stops and goes repeatedly for a long period of time.
- The accelerator pedal is continuously depressed for a long period of time.
- The engine stops or the engine performance is abnormal.
- Engine rpm is in the red zone.
- The driver starts driving by pushing the toggle switch up (RES+) or down (SET-), as shown in Figure 2; or depressing the accelerator pedal, after the vehicle is stopped by the Smart Cruise Control system with no other vehicle ahead.
- The "Forward Collision-Avoidance Assist" is activated.
- The driver starts driving by pushing the toggle switch up (RES+) or down (SET-); or depressing the accelerator pedal, after stopping the vehicle with a vehicle stopped far away in front.
- The engine is stopped by "Idle Stop & Go" (if equipped).

Messages observed on the Hyundai Palisade's driver's display are detailed in Appendix 7.1. For the drives discussed in this report, Smart Cruise Control was set to the nearest (i.e., closest) headway.

[2] The vehicle speed must be at least approximately 40 mph (64 km/h) to enable the Hyundai Palisade lane keeping assist system.

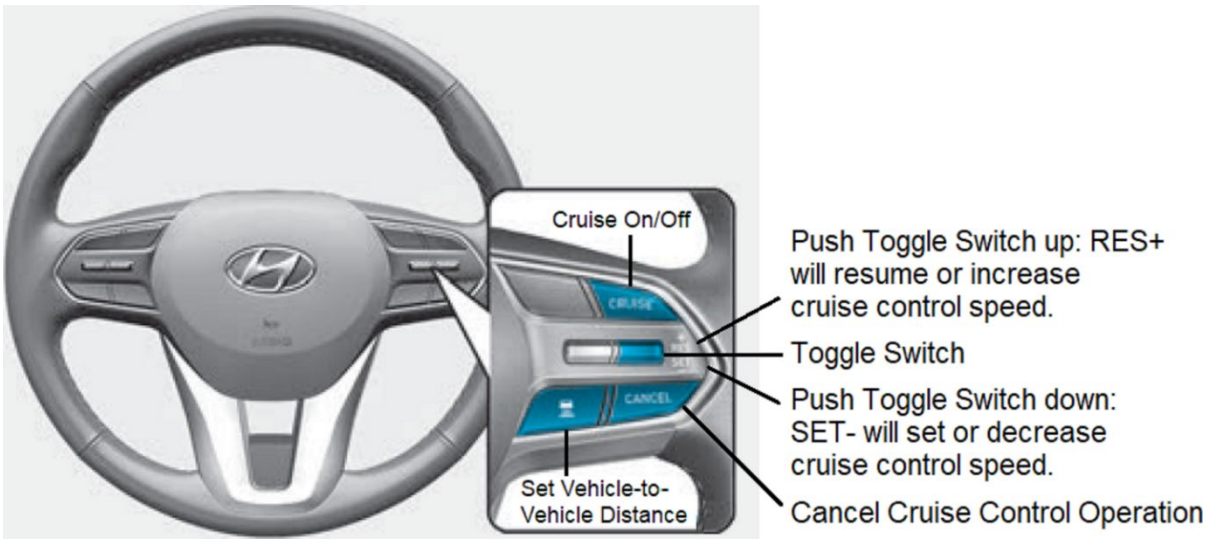

Figure 2. Smart Cruise Control switch, from Hyundai Palisade owner's manual page 5-129

2.1.2 2017 Tesla Model S 90D

The Tesla Model S (Figure 3) was equipped with an optional suite of advanced driver assistance system (ADAS) technologies collectively named "Autopilot," some of which enable level 2 driving automation. Before the drives described in this report were performed, an over-the-air update was used to update the Tesla Model S firmware to Version 10.0 Build 2019.32.12.1 on October 10, 2019. This was the latest available firmware available as the Tesla Model S drives were initiated, and it remained on the vehicle for the duration of testing described in this report. Although not directly related to the research, the vehicle's automatic emergency braking was also set to "on," and the forward collision warning system was set to "early."

Image courtesy of Tesla, Inc.

Figure 3. 2017 Tesla Model S

The active features that were enabled for the drives described in this report, and their respective driver-selectable settings, were the following.

- Auto Lane Change: On
- Autosteer: On
- Lane Assist: On
- Lane Departure Warning: On

- Navigate on Autopilot: On
- Traffic-Aware Cruise Control:[3] to the nearest (i.e., closest) headway

Regarding the Navigate on Autopilot feature, the settings were the following.

- Speed Based Lane Changes: Mad Max[4]
- Require Lane Change Confirmation: Yes
- Lane Change Notification: Chime

According to Tesla's website, the Navigate on Autopilot feature is designed to help guide the vehicle "from a highway's on-ramp to off-ramp, including suggesting and making lane changes, navigating highway interchanges, and taking exits." (The Tesla Team, 2019) The two types of lane changes that Navigate on Autopilot suggests are route-based lane changes designed to keep the vehicle on the navigation route, and speed-based lane changes designed to keep the vehicle moving as close to the set speed as possible. With the Navigate on Autopilot firmware version used for the work described in this report, the driver-configurable settings allowed the driver to confirm all automated on-highway lane changes by using the turn-signal stalk before the car would move into an adjacent lane. However, this was not always the case for the automated transition from highway-to-exit ramp, where Navigate on Autopilot automatically performed the maneuver without confirmation from the driver. In either case, the driver could always terminate an automated lane change by using a manual override.

To use the Navigate on Autopilot feature, the destination address is input to the vehicle's navigation system via the center console's display screen. That screen then displays a topographic map with a single blue line that indicates the suggested route, an example of which can be seen in Figure 4.

The driver's dash display has a smaller topographic map with the suggested route highlighted with a blue line, an example which can be seen in Figure 5. Navigate on Autopilot was used when driving the Tesla on the test routes described in Section 2.2. Due to the length and round-trip nature of the three routes, multiple destinations were used (i.e., input) during the drives so that Navigate on Autopilot would consistently direct the vehicle along the pre-determined route, including use of the same exit ramps, where applicable.

[3] Tesla's name for its traffic jam assist system.

[4] The firmware present on the Tesla Model S, at the time of the drives described in this report, allowed the driver to select one of four speed-based lane change settings: "Disabled, Mild, Average, or 'Mad Max.'" According to Tesla, "The Mild setting suggests lane changes when you're traveling significantly slower than your set speed (in response to a slower moving vehicle ahead in your vehicle's travel lane), whereas Mad Max will suggest lane changes when traveling just below your (Navigate on Autopilot) set speed." (The Tesla Team, 2019)

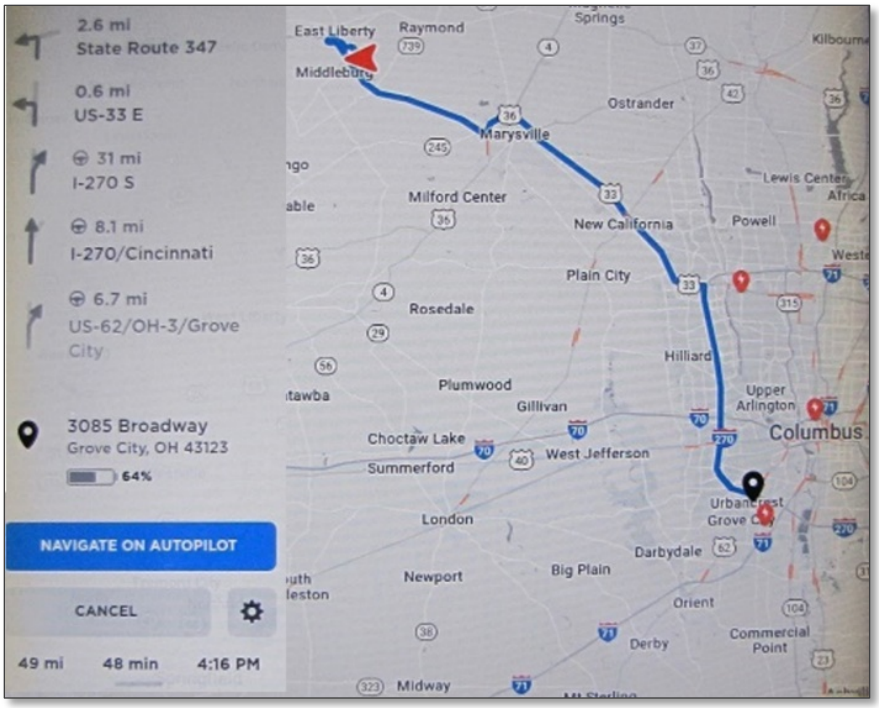

Figure 4. Center console display of Navigate on Autopilot (highway route).

Figure 5. Driver's dash display of Navigate on Autopilot (rural route).

As a reference, the following operating parameters (specifically, the speeds where a given feature can be initialized from) were noted from the Tesla Model S owner's manual (Tesla Inc., 2019).

- Lane assist operates from 28 to 90 mph (45 to 145 km/h).
- Traffic-Aware Cruise Control operates from 18.6 to 93.2 mph (30 to 150 km/h).
- Lane departure warning operates from 36.7 to 93.2 mph (59 to 150 km/h).

Similarly, the Tesla Model S owner's manual also indicates there are many factors that can adversely affect Navigate on Autopilot performance due to system limitations. According to Tesla, these include (but are not limited to) the following.

- Poor visibility (due to heavy rain, snow, fog, etc.)
- Bright light (due to oncoming headlights, direct sunlight, etc.)
- Damage or obstructions caused by mud, ice, snow, etc.
- Interference or obstruction by objects mounted onto the vehicle (such as a bike rack)
- Obstruction caused by applying excessive paint or adhesive products (such as wraps, stickers, rubber coating, etc.) onto the vehicle
- Narrow or winding roads
- A damaged or misaligned bumper
- Interference from other equipment that generates ultrasonic waves
- Extremely hot or cold temperatures

Messages observed on the Tesla Model S driver's display are detailed in Appendix 7.2.

2.1.3 Level 2 Driving Automation System Implementation and Functionality

The implementation and functionality of the level 2 driving automation systems of the vehicles used in this study are presented in Table 1.

Table 1. Level 2 Driving Automation System Implementation and Functionality Summary

Description	Hyundai Palisade	Tesla Model S
Sensors	Forward-facing radar and mono camera. Mapping and GPS from the navigation system.	8 cameras located around the vehicle (3 forward-facing, 4 side-facing, 1 rear-facing), 12 ultrasonic sensors, and a forward-facing long-range radar. Mapping and GPS from the navigation system.
Geographical operational design domain (ODD)	Highway driving	Highway driving
Availability	Level 2 driving automation capability available on public roads with two lane lines at the discretion of driver. The Highway Driving Assist feature is available only on certain highways.	Level 2 driving automation capability available on all public roads with lane lines at the discretion of driver, however the operator's manual states that "Traffic-Aware Cruise Control is primarily intended for driving on dry, straight roads, such as highways and freeways."
Auto lane change capability	None	Yes
Driver attention monitoring	Driver engagement monitored via a steering wheel torque sensor.	Driver engagement monitored via a steering wheel torque sensor.
Hands-free driving	Limited duration (~30s) of hands-off driving before system issues "hands on steering wheel" warning. System turns off 40s after the first warning but can be restarted while still underway.	Limited duration (varies from ~12-25s) of hands-off driving before system issues steering wheel warning. System completely turns off 25s after the first warning, after which restarting the vehicle from rest is required to re-enable Navigate on Autopilot.
Hands-off alert modality	Visual icons and messages on the instrument cluster; repeated auditory beeps	Visual icons and messages on the instrument cluster; repeated auditory tones

2.2 Test Routes

The three test routes used for the work drives described in this report each included a mix of road types and diverse operating conditions. Although some of these routes were outside the stated ODD of the test vehicles' respective level 2 driving automation systems, each system was able to be enabled and activated for at least part of each route. For this reason, all routes were retained and utilized for both vehicles. The routes are described in the following subsections.

2.2.1 Highway Route

The highway route (Figure 6) consisted exclusively of divided, controlled-access highways with exit and on ramps. This route was 108 miles long, and under normal traffic conditions took approximately 2 hours to complete.

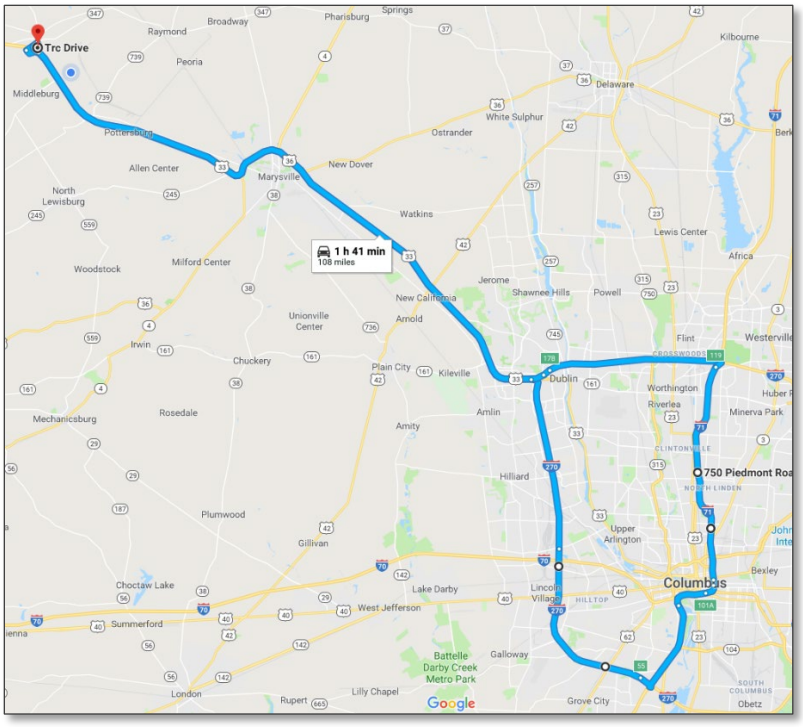

Figure 6. Highway route

Specifically, the highway route:

- Began on Ohio State Route 347 heading west at the entrance of the Transportation Research Center (TRC),
- Turned southwest on U.S. 33,
- Went onto I-270 south counter-clockwise around Columbus,
- Took I-71 north through Columbus,
- Merged onto I-270 west,
- Went onto US 33 traveling northeast, and
- Ended on OH SR 347 at the TRC entrance.

2.2.2 Rural Route

The rural route (Figure 7) was comprised of single-lane-per-direction-of-travel roads that had signed or signalized intersections. This was 32.4 miles long, and under normal traffic conditions took approximately 57 minutes to complete. Unlike the highway route, some sections of the rural route included undulations (hills) and sharp corners. The rural route did not have any exit ramps and few lane merging locations.

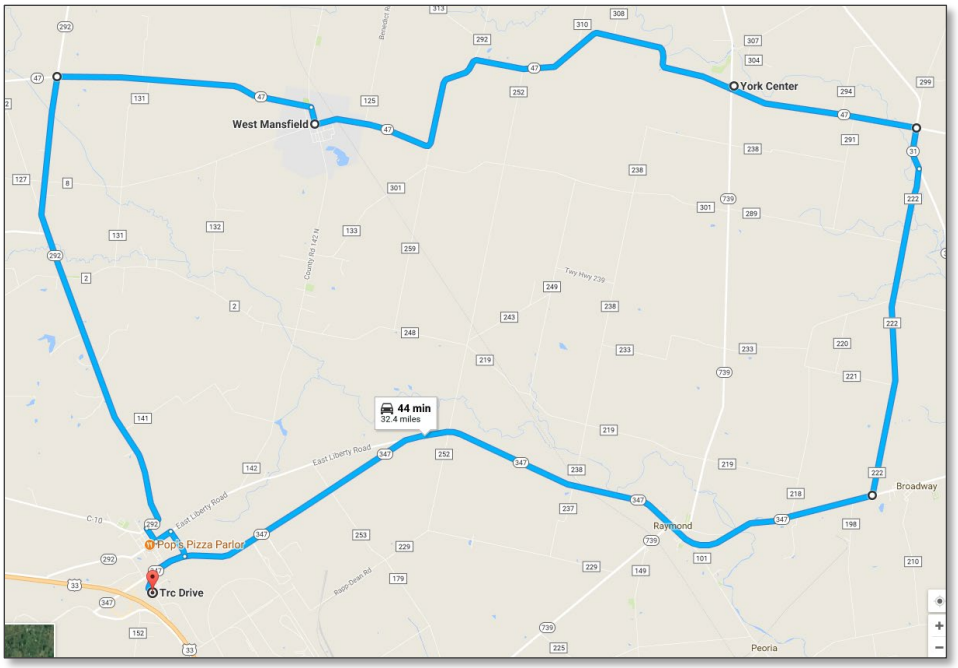

Figure 7. Rural route

Specifically, the rural route:

- Started on OH SR 347 at the TRC entrance (heading east),
- Headed north on Yearsley Road,
- Continued to OH SR 31,
- Headed west on OH SR 47,
- Went south on OH SR 292, and
- Ended on OH SR 347 at the TRC entrance.

2.2.3 Mixed Route

The mixed route (Figure 8) consisted of highway, rural, and residential roads. The different roadway types on the mixed route, and their corresponding distances, are listed in Table 2. The mixed route was 63.1 miles long, and under normal traffic conditions took approximately 1 hour and 28 minutes to complete.

Table 2. Mixed Route Roadway Types and Distances

Environment	Distance (miles)
Freeway	16.1
Rural	41.1
Residential	5.9
Total	63.1

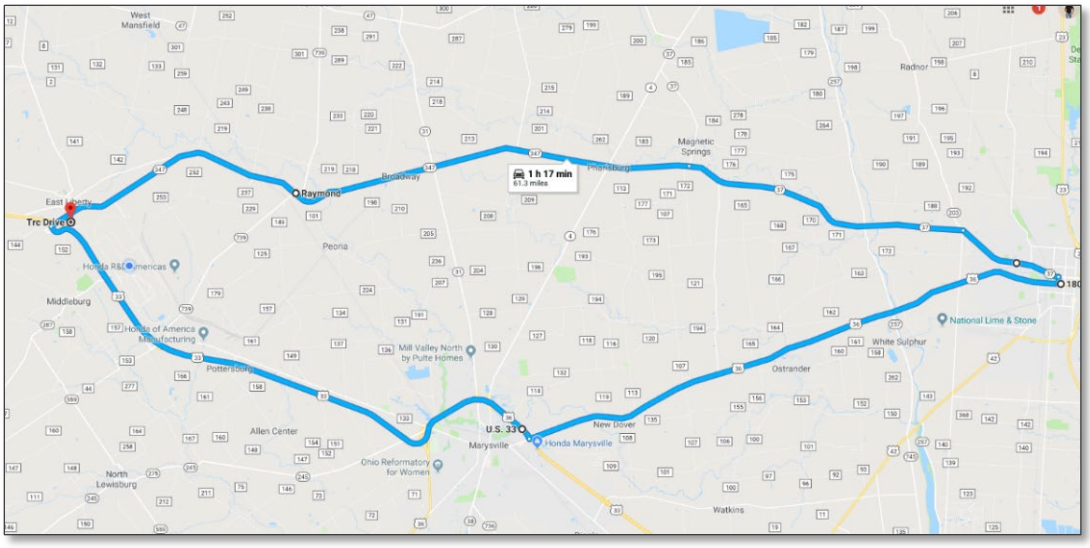

Figure 8. Mixed route

Specifically, the mixed route:

- Began heading west on OH SR 347 from the TRC entrance,
- Turned south on US 33,
- Exited left onto US 36 toward Delaware, OH,
- Went west on OH SR 37,
- Continued onto OH SR 347, and
- Ended on OH SR 347 at the TRC entrance.

2.3 Vehicle Drives Matrix

The test plan nominally specified that both vehicles were to be driven 15 times on each of the three routes. However, the actual number of times the vehicles were driven on a given route are shown in Table 3. No attempt was made to normalize for wet or dry pavement conditions.

Table 3. Vehicle Drives Matrix

Vehicle	Highway Route		Rural Route		Mixed Route	
	No.	Miles	No.	Miles	No.	Miles
Hyundai Palisade	15	1,620	6	194.4	15	946.5
Tesla Model S	15	1,620	15	486	15	946.5

Hyundai Palisade testing on the rural route was reduced to six exploratory drives for two reasons. First, the system was not available (i.e., not able to be enabled or put into operation) on one 3.9-mile-long section of the route that was missing the right lane line. Second, when the Hyundai Palisade level 2 driving automation system was in operation, a relatively high number of events were observed (described in Section 3.3.2). Completing 15 rural route drives would therefore have imposed an unnecessarily high data processing, analysis, and reporting burden without the value-added benefit of introducing new or unique opportunities to observe system behavior.

2.4 Instrumentation and Data Reduction

Two Waylens Horizon cameras were used to capture video and GPS data during testing. This equipment recorded GPS data at 10 Hz and video with a resolution of 1,080p at 60 frames per second. One camera was mounted on the windshield to record the forward view outside of the vehicle, and the second camera was mounted over the driver's shoulder to record driving actions (Figure 9).

Figure 9. In-vehicle camera placement.

Video highlights from the two camera views were stitched together into a single split-screen video clip during data post processing (Figure 10). Drivers reviewed their own video highlights and classified the flagged events and roadway conditions in a spreadsheet using the guidelines described in Section 3 of this report.

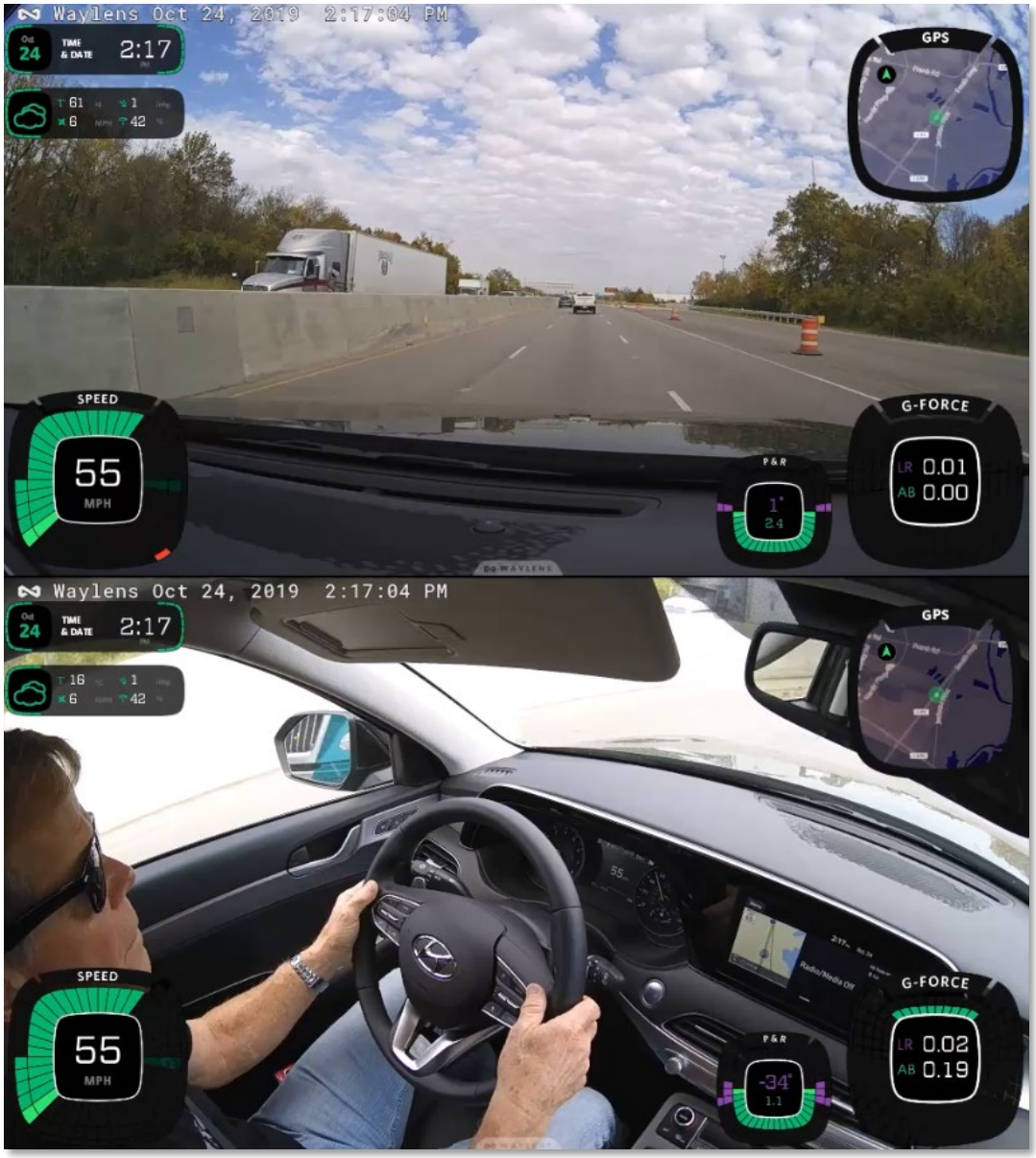

Figure 10. Split-screen video clip example

3 Event Occurrence and Prevailing Driving Conditions

This chapter defines the three types of driving events observed while attentive professional drivers were operating each vehicle in level 2 driving automation. The environmental and roadway conditions at the time of the events were also recorded, reviewed, and classified.

Note: The events and prevailing driving conditions are reported as they were encountered. Testing was not designed nor intended to normalize for exposure to the various environmental, road, or time-of-day conditions. As an example, no attempt was made to have a similar number of drives in wet and dry conditions; it was only noted if the roadway was wet or dry when an event occurred.

3.1 Event Classification

While operating the vehicles in level 2 driving automation, the drivers, who were professional experimenters and/or test drivers, held their hands just above or lightly touched the steering wheels until noteworthy events occurred, at which time they would typically place their hands back on the steering wheels, push steering wheel-mounted buttons to flag the events in the drive video, then briefly and verbally annotate the driving situation. Later, during post-processing, the drivers reviewed their respective video/audio recordings and subjectively[5] classified their flagged events into one of three categories, Type I, Type II, or Type III.

A **Type I** event occurred when the system, during otherwise normal and unremarkable driving, suddenly terminated its level 2 driving automation operation, issued a takeover notification to the driver, and transferred at least lateral control back to the driver. This required that the driver immediately resume manual control of the vehicle's accelerator pedal and/or steering wheel. The takeover prompts can be any combination of auditory, visual, and/or haptic modality. To be classified as a Type I takeover event, it was required that the vehicle was being driven in level 2 driving automation, and that the system was performing the driving task in a manner free from anomalous behavior until the transfer of control occurred.

A **Type II** event occurred when the level 2 driving automation system exhibited some form of subjectively noteworthy operation, but not to the point where the driver believed it was necessary to manually override the system to regain full control of the vehicle. At the time of a Type II event, the level 2 driving automation system was required to be actively providing lateral and longitudinal control of the vehicle without issuing an alert or warning to the driver.

A driving situation where the level 2 driving automation system biased the vehicle's lane position very near the roadway center line separating the driver's vehicle from oncoming traffic is an example of a Type II event referred to as "lane line hugging." Another example occurred when the level 2 driving automation system repeatedly steered the vehicle to the left and right of the lane center while being driven in a curve, which can cause the vehicle to wander back and forth about the lane center. In this report, this phenomenon is referred to as "dithering in lane."

A **Type III** event was comprised of into two sub-categories: "driver intervention events" and "lane departure with automatic centering events."

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[5] To remove as much ambiguity from this process as possible, each driver received a common set of Type I, II, and III event definitions and examples of how sample driving events should be classified before post-processing began.

A **Type III driver intervention event** occurred during driving situations where the driver, believing the vehicle was unable to automatically perform the driving task any further, performed a manual override input to immediately disengage the system and resume full manual control. Transfer of complete control from the vehicle back to the driver always occurred after the override input during a Type III driver intervention event. The driver override inputs used during a Type III driver intervention event could be any combination of steering or braking, which are described as lateral and longitudinal interventions, respectively.

A **Type III lane departure with system recovery event**[6] occurred when the vehicle, while operating in level 2 driving automation without traffic in an adjacent lane, breached a lane boundary but then automatically (i.e., without any intervention from the driver) returned back towards the center of the original travel lane.

The key difference between the initial conditions of the two Type III event sub-categories had to do with whether other vehicles were present near or approaching the test vehicle. If so, the driver was instructed to prevent the vehicle from entering the adjacent lane, and the event was classified as a Type III driver intervention event. If not, and if the driver believed if the unintended lane departure into an adjacent lane would not affect other traffic present on the roadway, the driver used the opportunity to let the event play out to assess if or how their vehicle was able to recover from the unintentional (i.e., vehicle-induced) lane departure. If the recovery was successful, the event was classified as a Type III lane departure with automatic system recovery event. If the recovery was not successful, the driver performed a manual override to steer the vehicle back into the original travel lane and the event was classified as a Type III driver intervention event.

3.2 Driving Condition Classification

The driving conditions present during each event were recorded and classified into three broad categories: roadway type, roadway condition, and lane line condition.

Roadway type
Roadways where events occurred were considered "normal" by default unless they were classified as either an entry/exit ramp or as a merge lane.

> Entry/Exit Ramp: Highway entry and exit ramps can have sharp curves, high banking, and steep grades. These conditions pose challenges to vehicles operating in level 2 driving automation. If the event occurred on an entry/exit ramp, it was classified as such.

[6] Type III lane departure with system recovery events were previously referred to as "Type III lane departure with automatic lane centering events" (Rao & Forkenbrock, 2020). The updated classification name is believed to more accurately represent the events it is used to describe since it is possible the level 2 driving automation system could successfully resolve an unintended lane departure, but not successfully reestablish lane position in the center of the original travel lane.

Merge Lane: When two lanes merge or split, the lane lines between them (e.g., the right line of the left lane, and the left line of the right lane) often disappear for a short distance. The results in a driving situation where the effective lane width increases beyond that of a typical travel lane. Situations like this can pose problems for vehicles operating in level 2 driving automation (e.g., in defining where the new lane center is, whether/where lane position bias is appropriate, etc.), and hence the category is of interest. On the rural and mixed routes, turn lanes that opened up beside the travel lane were classified as a merge lane.

Roadway condition
Roadway conditions had three binary-choice classifications that were subjectively applied during video review.

Wet/Dry: The road surface was marked as being either wet or dry.

Straight/Curved: The segment of road was either straight or curved.

Flat/Not Flat: The segment of road was either flat or obviously not flat.

Lane line condition
Lane line condition can affect a level 2 driving automation system's ability to initialize, remain active, and keep the vehicle centered within the travel lane. Therefore, the condition of the lane lines where the event occurred was subjectively classified into one of the following categories: good, degraded, or missing. A missing lane line meant one or both lines were absent during the event.

3.3 Hyundai Palisade Results

3.3.1 Hyundai Palisade – Highway Route Event Responses

The Hyundai Palisade was driven 15 times on the highway route for a nominal total of 1,620 miles. A total of 438 events were recorded. These events included 148 Type I events, 74 Type II events, and 216 Type III events, as shown in Table 4.

Table 4. Hyundai Palisade Highway Route Event Types Breakdown

Event Category	Number
Type I	148
Type II	74
Type III	216
Total	**438**

3.3.1.1 Type I Event Summary – Hyundai Palisade, Highway Route

The Hyundai Palisade highway route Type I event distribution over the various driving conditions is presented in Table 5. As noted previously, the drives were not designed to normalize for exposure to the various environmental, roadway, and/or traffic conditions.

Table 5. Hyundai Palisade Highway Route Type I Event Results

Total Type I Events		148	
Roadway Type	Exit Ramp	69	46.6%
	Merge Lane	27	18.2%
	Normal	52	35.1%
Road Condition	Dry	135	91.2%
	Wet	13	8.8%
	Straight	38	25.7%
	Curved	110	74.3%
	Flat	133	89.9%
	Not Flat	15	10.1%
Lane Line Condition	Good	109	73.6%
	Degraded	12	8.1%
	Missing	27	18.2%

Of the 148 Type I events, 46.6 percent occurred on exit ramps, 18.2 percent occurred beside merge lanes, and 35.1 percent occurred on normal highway roads. Dry conditions were observed during 91.2 percent of the Type I events and were primarily flat (89.9%). A majority of the Type I events occurred on curved road segments (74.3%).[7] Lane lines were generally in good condition (73.6%), with only 8.1 percent of the events occurring with degraded lane lines, and 18.2 percent occurring when one or both lines were missing.

3.3.1.2 Type II Event Summary – Hyundai Palisade, Highway Route

The Hyundai Palisade highway route Type II event distribution for the various event types and driving conditions is presented in Table 6. Of the 74 total Type II events, dithering in lane accounted for 66.2 percent of the total number of events. Lane line hugging accounted for 18.9 percent of the events, while 14.9 percent were miscellaneous "Other" Type II events. Most of these were due to false positive lane departure warnings believed to have been issued in response to pavement seam sealer inside of the lane running parallel to the lane lines, or for a reason unclear to the driver.

[7] Appendix 7.3 provides detailed statistics for some of the tabular results. Data were selected for detailed examination when the percentage of straight and curve roadways exceeded a 60/40 ratio and a minimum of 30 events were noted.

Table 6. Hyundai Palisade Highway Route Type II Event Results

Total Type II Events		74	
Event Sub-Type	Dithering in Lane	49	66.2%
	Lane Line Hugging	14	18.9%
	Other	11	14.9%
Roadway Type	Exit Ramp	9	12.2%
	Merge Lane	32	43.2%
	Normal	33	44.6%
Road Condition	Dry	70	94.6%
	Wet	4	5.4%
	Straight	44	59.5%
	Curved	30	40.5%
	Flat	74	100.0%
	Not Flat	0	0.0%
Lane Line Condition	Good	46	62.2%
	Degraded	10	13.5%
	Missing	18	24.3%

The distribution of Type II events across roadway type showed that 12.2 percent occurred on exit ramps, 43.2 percent occurred beside merge lanes, while the remaining 44.6 percent occurred on normal highway roads. A majority of the events occurred on dry (94.6%) and flat (100%) surfaces, 59.5 percent of which were straight, while the rest were curved.[8] The lane lines were generally in good condition (62.2%), although 13.5 percent were degraded, and 24.3 percent were missing one or both lane lines.

3.3.1.3 Type III Event Summary – Hyundai Palisade, Highway Route

The Hyundai Palisade highway route Type III event distribution for the various event types and driving conditions is presented in Table 7. Of the 216 Type III events recorded, 20.8 percent were lane departures where the system eventually returned the vehicle into the original travel lane, 53.2 percent of the incidents were lateral driver interventions, and the remaining 25.9 percent of the incidents were longitudinal driver interventions.

[8] Of the 49 dithering events noted in Table 6, 36 (73.5%) occurred while the travel lane was nominally straight.

Table 7. Hyundai Palisade Highway Route Type III Event Results

Total Type III Events		216	
Event Sub-Type	Lane Departure with System Recovery	45	20.8%
	Driver Lateral Intervention	115	53.2%
	Driver Longitudinal Intervention	56	25.9%
Roadway Type	Exit Ramp	52	24.1%
	Merge Lane	67	31.0%
	Normal	97	44.9%
Road Condition	Dry	197	91.2%
	Wet	19	8.8%
	Straight	100	46.3%
	Curved	116	53.7%
	Flat	204	94.4%
	Not Flat	12	5.6%
Lane Line Condition	Good	185	85.6%
	Degraded	13	6.0%
	Missing	18	8.3%

The distribution of Type III events across roadway type showed that 24.1 percent occurred on exit ramps, 31 percent occurred beside merge lanes, and the remaining 44.9 percent occurred on normal highway roads. A majority of the events occurred on dry (91.2%) and flat (94.4%) surfaces but were closely split between straight (46.3%) and curved (53.7%) roadways. A majority of the lane lines were in good condition (85.6%), with only 6% degraded, and 8.3% missing one or both lane lines.

3.3.2 Hyundai Palisade – Rural Route Event Responses

The lane keeping feature of the Hyundai Palisade requires both left- and right-side lane lines for the vehicle's level 2 automation system to be active and engaged. However, a 3.9-mile section of the rural route did not have a right lane line (Yearsley Rd.), so level 2 driving automation was not available on that portion of the route. Additionally, when the level 2 driving automation system was in operation, a relatively high number of events were observed. Completing 15 rural route drives would therefore have imposed an unnecessarily high data processing, analysis, and reporting burden without the value-added benefit of introducing new or unique opportunities to observe system behavior. Therefore, the total number of rural-route drives was reduced from 15 to 6, for a nominal total of 194.4 miles. A total of 381 events (presented in Table 8) were recorded which included 85 Type I events, 6 Type II events, and 290 Type III events.

Table 8. Hyundai Palisade Rural Route Event Categories Breakdown

Event Category	Number
Type I	85
Type II	6
Type III	290
Total	**381**

3.3.2.1 Type I Event Summary – Hyundai Palisade, Rural Route

The Hyundai Palisade rural route Type I event distribution for the various driving conditions is presented in Table 9.

Table 9. Hyundai Palisade Rural Route Type I Event Results

Total Type I Events		85	
Roadway Type	Exit Ramp	n/a	n/a
	Merge Lane	3	3.5%
	Normal	82	96.5%
Road Condition	Dry	85	100.0%
	Wet	0	0.0%
	Straight	42	49.4%
	Curved	43	50.6%
	Flat	50	58.8%
	Not Flat	35	41.2%
Lane Line Condition	Good	70	82.4%
	Degraded	1	1.2%
	Missing	14	16.5%

A total of 85 Type I events were recorded, all of which were recorded on dry roads. A majority of the events occurred on normal roads (96.5%), while the rest occurred beside a merge lane. The events were distributed evenly between straight (49.4%) and curved (50.6%) roadways, and split closely between flat (58.8%) and not flat (41.2%). The lane lines associated with Type I events were generally in good condition (82.4%), although one (1.2%) occurred beside a degraded line and 12 occurred (16.5%) near missing lines.

3.3.2.2 Type II Event Summary – Hyundai Palisade, Rural Route

The Hyundai Palisade rural route Type II event distribution for the various event types and driving conditions is presented in Table 10. During the 6 rural route drives, the Hyundai Palisade had 6 total Type II events; it dithered in lane once and hugged the lane line during the other 5 times (the center lane line 4 times and the right lane line once). All Type II events occurred on normal roads with good lane lines when conditions were dry, straight, and flat.

Table 10. Hyundai Palisade Rural Route Type II Event Results

Total Type II Events		6	
Event Sub-Type	Dithering in Lane	1	16.7%
	Lane Line Hugging	5	83.3%
	Other	0	0.0%
Roadway Type	Exit Ramp	n/a	n/a
	Merge Lane	0	0.0%
	Normal	6	100.0%
Road Condition	Dry	6	100.0%
	Wet	0	0.0%
	Straight	6	100.0%
	Curved	0	0.0%
	Flat	6	100.0%
	Not Flat	0	0.0%
Lane Line Condition	Good	6	100.0%
	Degraded	0	0.0%
	Missing	0	0.0%

3.3.2.3 Type III Event Summary – Hyundai Palisade, Rural Route

The Hyundai Palisade rural route Type III event distribution for the various event types and driving conditions is presented in Table 11. Of the 290 Type III events recorded, 63.4 percent were lane departures where the system eventually returned the vehicle into the original travel lane, 25.2 percent of the incidents were lateral driver interventions, and the remaining 11.4 percent of the incidents were longitudinal driver interventions.

The distribution of Type III events across roadway type indicates nearly all (99.7%) occurred on normal roadways, while one event (0.3%) occurred beside a merge lane. For these events, the roadways were always dry, usually flat (90.3%), and split evenly between straight (49.7%) and curved (50.3%) roadways. A majority of the lane lines were in good condition (86.9%), with only 0.3 percent degraded and 12.8 percent missing one or both lane lines.

Table 11. Hyundai Palisade Rural Route Type III Event Results

Total Type III Events		290	
Event Sub-Type	Lane Departure with System Recovery	184	63.4%
	Driver Lateral Intervention	73	25.2%
	Driver Longitudinal Intervention	33	11.4%
Roadway Type	Exit Ramp	n/a	n/a
	Merge Lane	1	0.3%
	Normal	289	99.7%
Road Condition	Dry	290	100.0%
	Wet	0	0.0%
	Straight	144	49.7%
	Curved	146	50.3%
	Flat	262	90.3%
	Not Flat	28	9.7%
Lane Line Condition	Good	252	86.9%
	Degraded	1	0.3%
	Missing	37	12.8%

3.3.3 Hyundai Palisade – Mixed Route Event Responses

The Hyundai Palisade was driven 15 times on the mixed route for a nominal total of 947 miles. A total of 1,119 events (presented in Table 12) were recorded, which included 262 Type I events, 277 Type II events and 580 Type III events.

Table 12. Hyundai Palisade Mixed Route Event Categories Breakdown

Event Category	Number
Type I	262
Type II	277
Type III	580
Total	**1,119**

3.3.3.1 Type I Event Summary – Hyundai Palisade, Mixed Route

The Hyundai Palisade mixed route Type I event distribution over the various driving conditions is presented in Table 13. Of the 262 Type I events, 5.0 percent occurred on exit ramps, 10.7 percent occurred beside merge lanes, and 84.4 percent occurred on normal highway roads. Road conditions observed during the Type I events were mostly dry (74.4%) and flat (72.1%). The events occurred more frequently on straight roads (59.9%) than curved ones. Slightly more than half the events occurred when lane lines were in good condition (56.1%), while 6.1 percent had degraded lines, and 37.8 percent occurred when one or both lane lines were missing.

Table 13. Hyundai Palisade Mixed Route Type I Event Results

Total Type I Events		262	
Roadway Type	Exit Ramp	13	5.0%
	Merge Lane	28	10.7%
	Normal	221	84.4%
Road Condition	Dry	195	74.4%
	Wet	67	25.6%
	Straight	157	59.9%
	Curved	105	40.1%
	Flat	189	72.1%
	Not Flat	73	27.9%
Lane Line Condition	Good	147	56.1%
	Degraded	16	6.1%
	Missing	99	37.8%

3.3.3.2 Type II Event Summary – Hyundai Palisade, Mixed Route

The Hyundai Palisade mixed route Type II event distribution for the various event types and driving conditions is presented in Table 14. Of the 277 total Type II events, dithering in lane accounted for 74.0 percent of them, 6.9 percent were lane line hugging events (the center lane line 9 times and the right lane line 10 times), and 19.1 percent were miscellaneous "Other" Type II events predominately related to lane departure warning system operation, which included alerting for a reason unknown to the driver (including, but not limited to, appearing to alert in response to pavement seam sealer applied to the roadway within and parallel to the travel lane, or alerting when the vehicle drove through a curve without being particularly close to a lane line).

The distribution of Type II events across Roadway type showed that 1.4 percent occurred on exit ramps, and 2.9 percent occurred beside a merge lane, but most occurred on normal roadways (95.7%). Road conditions were usually flat (89.2%), generally straight (72.6%), and slightly drier (53.8%) than not (46.2%). Lane lines were in good condition 87.7 percent of the time, with degraded (2.2%) and missing (10.1%) lane lines making up the rest.

Table 14. Hyundai Palisade Mixed Route Type II Event Results

Total Type II Events		277	
Event Sub-Type	Dithering in Lane	205	74.0%
	Lane Line Hugging	19	6.9%
	Other	53	19.1%
Roadway Type	Exit Ramp	4	1.4%
	Merge Lane	8	2.9%
	Normal	265	95.7%
Road Condition	Dry	149	53.8%
	Wet	128	46.2%
	Straight	201	72.6%
	Curved	76	27.4%
	Flat	247	89.2%
	Not Flat	30	10.8%
Lane Line Condition	Good	243	87.7%
	Degraded	6	2.2%
	Missing	28	10.1%

3.3.3.3 Type III Event Summary – Hyundai Palisade, Mixed Route

The Hyundai Palisade mixed route Type III event distribution for the various event types and driving conditions is presented in Table 15. Of the 580 total Type III events, 64.5 percent were lane departures where the system eventually returned the vehicle into the original travel lane, 26.9 percent of the incidents involved driver lateral interventions, and the remaining 8.6 percent of the incidents were driver longitudinal interventions.

The distribution of Type III events across roadway type showed that almost all of them (98.1%) occurred on normal roadways, with three occurring on exit ramps (0.5%), and the remaining eight occurring beside a merge lane (1.4%).

A majority of the mixed route Type III events occurred on dry (79.0%) and flat (81.2%) surfaces but were closely split between straight (51.7%) and curved (48.3%) roadways. A majority of the lane lines were in good condition (91.6%), with only 1.2 percent degraded, and 7.2 percent missing one or both lane lines.

Table 15. Hyundai Palisade Mixed Route Type III Event Results

Total Type III Events		580	
Event Sub-Type	Lane Departure with System Recovery	374	64.5%
	Driver Lateral Intervention	156	26.9%
	Driver Longitudinal Intervention	50	8.6%
Roadway Type	Exit Ramp	3	0.5%
	Merge Lane	8	1.4%
	Normal	569	98.1%
Road Condition	Dry	458	79.0%
	Wet	122	21.0%
	Straight	300	51.7%
	Curved	280	48.3%
	Flat	471	81.2%
	Not Flat	109	18.8%
Lane Line Condition	Good	531	91.6%
	Degraded	7	1.2%
	Missing	42	7.2%

3.4 Tesla Model S Results

3.4.1 Tesla Model S – Highway Route Event Responses

The Tesla Model S was driven 15 times on the highway route for a nominal total of 1,620 miles. A total of 444 events were recorded. These events included 1 Type I event, 350 Type II events, and 93 Type III events, which are presented in Table 16.

Table 16. Tesla Model S Highway Route Event Types Breakdown

Event Category	Number
Type I	1
Type II	350
Type III	93
Total	**444**

3.4.1.1 Type I Event Summary – Tesla Model S, Highway Route

The Tesla Model S highway route Type I event distribution for the various driving conditions is presented in Table 17. The one Type I event occurred on a dry, flat, straight highway beside a merge lane with no right lane line.

Table 17. Tesla Model S Highway Route Type I Event Results

Total Type I Events		1	
Roadway Type	Exit Ramp	0	0.0%
	Merge Lane	1	100.0%
	Normal	0	0.0%
Road Condition	Dry	1	100.0%
	Wet	0	0.0%
	Straight	1	100.0%
	Curved	0	0.0%
	Flat	1	100.0%
	Not Flat	0	0.0%
Lane Line Condition	Good	0	0.0%
	Degraded	0	0.0%
	Missing	1	100.0%

3.4.1.2 Type II Event Summary – Tesla Model S, Highway Route

The Tesla Model S highway route Type II event distribution for the various event types and driving conditions is presented in Table 18. Of the 350 total Type II events, dithering in lane accounted for 36.3 percent of the total number of events, and there were 3 lane line hugging events (0.9%) with respect to a left white dashed line once and the right lane line twice. That said, most Type II events with the Tesla Model S were categorized as "Other" (62.9%), with many being related to the operation of Navigate on Autopilot, including:

- Signaling to change lanes when another vehicle was beside the Tesla Model S, within its blind zone, or approaching in a left adjacent lane at a higher speed (45 times). During 6 of these events, there was another vehicle beside the Tesla Model S but not ahead of it.
- Signaling a lane change that the driver had to cancel (33 times; 28 where the turn signal stalk was used, and 5 where the driver provided a small steering wheel input to disable Navigate on Autopilot operation via manual override).
- Signaling to change lanes for a reason unclear to the driver (22 times).[9]

[9] As stated in Section 2.1.2 of this report, the two types of lane changes that Navigate on Autopilot suggests are (1) route-based lane changes designed to keep the vehicle on the navigation route, and (2) speed-based lane changes

- Signaling to change lanes but stopped signaling on its own (12 times).
- Signaling to change lanes, began to move towards the adjacent lane after the driver accepted the lane change recommendation, then terminated the maneuver, at which time the vehicle moved back towards the center of the initial travel lane, and turned the signal off (4 times).
- Repeatedly signaling a lane change even after the driver had canceled the suggested move (8 times), which are not included in the second bullet above.
- Changing lanes without the driver first confirming (i.e., approving) the suggested move (5 times).
- Attempting to take the wrong exit (4 times) or to move into a merge lane that was ending (2 times).

Table 18. Tesla Model S Highway Route Type II Event Results

Total Type II Events		350	
Event Sub-Type	Dithering in Lane	127	36.3%
	Lane Line Hugging	3	0.9%
	Other	220	62.9%
Roadway Type	Exit Ramp	25	7.1%
	Merge Lane	130	37.1%
	Normal	195	55.7%
Road Condition	Dry	341	97.4%
	Wet	9	2.6%
	Straight	310	88.6%
	Curved	40	11.4%
	Flat	350	100.0%
	Not Flat	0	0.0%
Lane Line Condition	Good	265	75.7%
	Degraded	23	6.6%
	Missing	62	17.7%

With regards to roadway type, the distribution of Type II events observed with the Tesla Model S includes normal highway roads (55.7%), exit ramps (7.1%), and beside merge lanes (37.1%). All of the events occurred on flat surfaces, while the majority of them occurred on dry (97.4%)

designed to keep the vehicle moving as close to the set speed as possible. The "Other" events where the vehicle signaled to change lanes for a reason unclear to the driver occurred in driving situations believed to be different than these two conditions.

and straight (88.6%) roadways. Most of lane lines were in good condition (75.7%), with only 6.6 percent degraded and 17.7 percent missing one or both lane lines.

A total of 220 "Other" events involved the manner in which the vehicle reacted to the driver's response to a vehicle-issued instructional prompt. Examples of such events include driving situations that began with the driver being asked to confirm a suggested lane change, or to satisfy an "Apply slight turning force to the steering wheel" message. In both cases, despite the driver responding with handwheel inputs believed to be consistent with previous responses to identical vehicle-issued requests (i.e., use of comparable steering torque, angle, and velocity), the system became disabled for reasons unknown to the driver. In addition, there were 3 times when Navigate on Autopilot did not complete an automated lane change requested by the driver. In each of these 3 instances, Navigate on Autopilot was on, there was no nearby traffic, and the road conditions were not remarkable.

3.4.1.3 Type III Event Summary – Tesla Model S, Highway Route

The Tesla Model S highway route Type III event distribution for the various event types and driving conditions is presented in Table 19. Of the 93 Type III events recorded, 73.1 percent of the incidents were lateral driver interventions, and the remaining 26.9 percent of the incidents were longitudinal driver interventions. No lane departure with system recovery events were observed.

Table 19. Tesla Model S Highway Route Type III Event Results

Total Type III Events		93	
Event Sub-Type	Lane Departure with System Recovery	0	0.0%
	Driver Lateral Intervention	68	73.1%
	Driver Longitudinal Intervention	25	26.9%
Roadway Type	Exit Ramp	25	26.9%
	Merge Lane	22	23.7%
	Normal	46	49.5%
Road Condition	Dry	88	94.6%
	Wet	5	5.4%
	Straight	61	65.6%
	Curved	32	34.4%
	Flat	89	95.7%
	Not Flat	4	4.3%
Lane Line Condition	Good	60	64.5%
	Degraded	6	6.5%
	Missing	27	29.0%

With regards to roadway type, the distribution of Type III events observed with the Tesla Model S includes normal highway roads (49.5%), exit ramps (26.9%), and beside merge lanes (23.7%). A majority of the events occurred on dry (94.6%) and flat (95.7%) surfaces but were split between straight (65.6%) and curved (34.4%) roadways. Most of lane lines were in good condition (64.5%), with only 6.5 percent degraded and 29 percent missing one or both lane lines.

3.4.2 Tesla Model S – Rural Route Event Responses

The Tesla Model S was driven 15 times on the rural route for a nominal total of 486 miles. A total of 181 events (presented in Table 20) were recorded, which included 3 Type I events, 122 Type II events, and 56 Type III events.

Table 20. Tesla Model S Rural Route Event Categories Breakdown

Event Category	Number
Type I	3
Type II	122
Type III	56
Total	**181**

3.4.2.1 Type I Event Summary – Tesla Model S, Rural Route

The Tesla Model S rural route Type I event distribution for the various driving conditions is presented in Table 21. All 3 Type I events occurred on normal, dry, straight roads with good lane lines, and occurred as the vehicle crested a high point in the road.

Table 21. Tesla Model S Rural Route Type I Event Results

Total Type I Events		3	
Roadway Type	Exit Ramp	n/a	n/a
	Merge Lane	0	0.0%
	Normal	3	100.0%
Road Conditions	Dry	3	100.0%
	Wet	0	0.0%
	Straight	3	100.0%
	Curved	0	0.0%
	Flat	0	0.0%
	Not Flat	3	100.0%
Lane Line Condition	Good	3	100.0%
	Degraded	0	0.0%
	Missing	0	0.0%

3.4.2.2 Type II Event Summary – Tesla Model S, Rural Route

The Tesla Model S rural route Type II event distribution for the various event types and driving conditions is presented in Table 22.

Table 22. Tesla Model S Rural Route Type II Event Results

Total Type II Events		122	
Event Sub-Type	Dithering in Lane	39	32.0%
	Lane Line Hugging	2	1.6%
	Other	81	66.4%
Roadway Type	Exit Ramp	n/a	n/a
	Merge Lane	7	5.7%
	Normal	115	94.3%
Road Condition	Dry	122	100.0%
	Wet	0	0.0%
	Straight	96	78.7%
	Curved	26	21.3%
	Flat	69	56.6%
	Not Flat	53	43.4%
Lane Line Condition	Good	88	72.1%
	Degraded	0	0.0%
	Missing	34	27.9%

Of the 122 total Type II events, dithering in lane accounted for 32 percent of the total number of events. Lane line hugging accounted for 1.6 percent of the events, while 66.4 percent were miscellaneous "Other" Type II events that included:

- The vehicle applied the brakes as it crested a hill 31 times, reducing speed from 1 to 21 mph (1.6 to 33.8 km/h), with an average reduction in speed of 10.8 mph (17.4 km/h).
- There were 20 times when the Tesla Model S did not establish vehicle speed at the speed limit on certain sections of road (with and without signage).
- There were 4 times when the driver noted that the Tesla Model S lateral acceleration was markedly (albeit subjectively) high while being driven on a curved section of road, and 4 times where the vehicle was not centered within the lane after exiting a curve.

- The vehicle automatically applied the brakes as it approached one particular non-signalized intersection during 12 of 15 drives, reducing speed from 12 to 24 mph (19.3 to 38.6 km/h), with an average speed reduction of 18.9 mph (30.4 km/h).[10]
- The distribution of Type II events across roadway type showed that a majority of the events occurred on normal roads (94.3%), while the rest occurred beside a merge lane. Note that there were no exit ramps, and few merge lanes on rural route; a consideration when interpreting the number of events that occurred near a merge lane. All events were recorded on dry roads. The events were split closely between flat (56.6%) and not flat (43.4%) roadways, 78.7 percent of which were straight, while the rest were curved. The lane lines were generally in good condition (72.1%), while the remaining 27.9 percent were missing one or both lane lines.

3.4.2.3 Type III Event Summary – Tesla Model S, Rural Route

The Tesla Model S rural route Type III event distribution for the various event types and driving conditions is presented in Table 23. Of the 56 Type III events recorded, 17.9 percent were lane departures where the system eventually returned the vehicle into the original travel lane, 69.6 percent of the incidents were lateral driver interventions, and the remaining 12.5 percent of the incidents were longitudinal driver interventions.

[10] During the remaining 3 of the 15 rural route drives, (1) the vehicle slowed at the intersection due to a tractor trailer combination turning left across its forward path, (2) the vehicle slowed due to a dump truck turning right at the intersection, and (3) the driver pressed the accelerator to manually maintain speed because of other traffic immediately behind.

Table 23. Tesla Model S Rural Route Type III Event Results

Total Type III Events		56	
Event Sub-Type	Lane Departure with System Recovery	10	17.9%
	Driver Lateral Intervention	39	69.6%
	Driver Longitudinal Intervention	7	12.5%
Roadway Type	Exit Ramp	n/a	n/a
	Merge Lane	4	7.1%
	Normal	52	92.9%
Road Conditions	Dry	56	100.0%
	Wet	0	0.0%
	Straight	13	23.2%
	Curved	43	76.8%
	Flat	51	91.1%
	Not Flat	5	8.9%
Lane Line Condition	Good	43	76.8%
	Degraded	1	1.8%
	Missing	12	21.4%

The distribution of Type III events across roadway type showed that a majority of the events occurred on normal roads (92.9%), while the rest occurred beside a merge lane. As stated previously, there were not exit ramps on the rural route, and the number of events observed near a merge lane may have been confounded by the low number merge of lanes on the route. All events were recorded on dry roads. A majority of the events occurred on flat surfaces (91.1%), and mostly on curved (76.8%) versus straight (23.2%) roadways. Most of the lane lines were in good condition (76.8%), with only 1.8 percent degraded and 21.4 percent missing one or both lane lines.

3.4.3 Tesla Model S – Mixed Route Event Responses

The Tesla Model S was driven 15 times on the mixed route for a nominal total of 947 miles. A total of 163 events (presented in Table 24) were recorded, which included 3 Type I events, 111 Type II events, and 49 Type III events.

Table 24. Tesla Model S Mixed Route Event Categories Breakdown

Event Category	Number
Type I	3
Type II	111
Type III	49
Total	**163**

3.4.3.1 Type I Event Summary – Tesla Model S, Mixed Route

The Tesla Model S mixed route Type I event distribution over the various driving conditions is presented in Table 25. All three Type I events occurred on a straight, flat road with no lane lines due to merge lanes opening up on either side of the lane of travel. A review of the event videos showed that these 3 Type I events occurred at the same place on the route, and each time with another vehicle just ahead of the Tesla Model S (which may have potentially obstructed the forward view of the lane lines just as space between the left and right lane lines widened to create two turning lanes).

Table 25. Tesla Model S Mixed Route Type I Event Results

Total Type I Events		3	
Roadway Type	Exit Ramp	0	0.0%
	Merge Lane	3	100.0%
	Normal	0	0.0%
Road Condition	Dry	2	66.7%
	Wet	1	33.3%
	Straight	3	100.0%
	Curved	0	0.0%
	Flat	3	100.0%
	Not Flat	0	0.0%
Lane Line Condition	Good	0	0.0%
	Degraded	0	0.0%
	Missing	3	100.0%

3.4.3.2 Type II Event Summary – Tesla Model S, Mixed Route

The Tesla Model S mixed route Type II event distribution for the various event types and driving conditions is presented in Table 26. Of the 111 total Type II events, dithering in lane accounted for 46.8 percent of them, one was lane line hugging event (0.9%), and 52.3 percent were miscellaneous "Other" Type II events. Of the 58 "Other" events, 22 occurred on the highway section of the route, while the other 36 occurred on the rural section.

Table 26. Tesla Model S Mixed Route Type II Event Results

Total Type II Events		111	
Event Sub-Type	Dithering in Lane	52	46.8%
	Lane Line Hugging	1	0.9%
	Other	58	52.3%
Roadway Type	Exit Ramp	3	2.7%
	Merge Lane	23	20.7%
	Normal	85	76.6%
Road Condition	Dry	92	82.9%
	Wet	19	17.1%
	Straight	87	78.4%
	Curved	24	21.6%
	Flat	76	68.5%
	Not Flat	35	31.5%
Lane Line Condition	Good	82	73.9%
	Degraded	3	2.7%
	Missing	26	23.4%

There were a variety of events related to the operation of Navigate on Autopilot while on the highway section of the mixed route.

- Signaling a lane change that the driver had to cancel (7 times)
- Signaling to change lanes for a reason unclear to the driver (3 times)
- Signaling to change lanes but stopped signaling on its own (3 times)
- Returning to the right lane, using an automated lane change, with little space between the rear of the Tesla Model S and the front of the vehicle it had just passed (2 times)
- Signaling to change lanes when the lane was occupied (1 time)

Additional "Other" events observed on the highway section of the mixed route included 4 brake applications where the drivers subjectively believed the Tesla Model S was automatically braked harder than needed (e.g., a crash-imminent situation was not present), and 2 events where Navigate on Autopilot was disabled in response to the driver's steering input used to accept an automated lane change suggestion despite the driver responding with an input (i.e., steering torque, angle, and velocity) believed to be consistent with previous responses to identical vehicle-issued requests. "Other" events related to Navigate on Autopilot operation while on the rural section of the mixed route included:

- Automatically applying the brakes as the vehicle crested a hill 25 times, reducing speed from 1 to 21 mph (1.6 to 33.8 km/h), with an average reduction in speed of 6.4 mph (10.3 km/h).

- There were 6 times when Navigate on Autopilot did not complete an automated lane change requested by the driver. Two of those occurred while it was raining, 2 occurred while the sun was directly ahead and low on the horizon, and for the other 2 instances, Navigate on Autopilot was on, there was no nearby traffic, and the road conditions were not remarkable.
- There were 5 miscellaneous "Other" events on the rural section that involved the driver unintentionally disabling Navigate on Autopilot while attempting to satisfy an "Apply slight turning force to the steering wheel" request by using with an input (i.e., steering torque, angle, and velocity) believed to be consistent with previous responses to identical vehicle-issued requests.

The distribution of Type II events across roadway type showed that 2.7 percent occurred on exit ramps, and 20.7 percent occurred beside a merge lane, but most occurred on normal roadways (76.6%). Road conditions were typically flat (68.5%), generally straight (78.4%), and usually dry (82.9%). Lane lines were in good condition during 73.9 percent of the events, degraded for 2.7 percent of the events, and missing during 23.4 percent of the events.

3.4.3.3 Type III Event Summary – Tesla Model S, Mixed Route

The Tesla Model S mixed route Type III event distribution for the various event types and driving conditions is presented in Table 27. Of the 49 total Type III events, 30.6 percent were lane departures where the system eventually returned the vehicle into the original travel lane, 59.2 percent of the incidents were lateral driver interventions, and the remaining 10.2 percent of the incidents were driver longitudinal interventions.

The distribution of Type III events across roadway type showed that most occurred on normal roadways (79.6%), with the rest split between exit ramps (8.2%), and beside merge lanes (12.2%). Road conditions were typically dry (79.6%) and flat (71.4%) but split similarly between straight (44.9%) and curved (55.1%) roadways. A majority of the lane lines were in good condition (69.4%), while the rest were missing one or both lane lines (30.6%).

Table 27. Tesla Model S Mixed Route Type III Event Results

Total Type III Events		49	
Event Sub-Type	Lane Departure with System Recovery	15	30.6%
	Driver Lateral Intervention	29	59.2%
	Driver Longitudinal Intervention	5	10.2%
Roadway Type	Exit Ramp	4	8.2%
	Merge Lane	6	12.2%
	Normal	39	79.6%
Road Condition	Dry	39	79.6%
	Wet	10	20.4%
	Straight	22	44.9%
	Curved	27	55.1%
	Flat	35	71.4%
	Not Flat	14	28.6%
Lane Line Condition	Good	34	69.4%
	Degraded	0	0.0%
	Missing	15	30.6%

4 Summary Of Average Number Of Events Per Category

This chapter presents a normalized event summary for five vehicles: the two used for the work discussed in this report, and for the three used in previous NHTSA work (Rao & Forkenbrock, 2020). The number of events per 100 miles of driving was calculated for each event category, route, and vehicle.

4.1 Overall Highway Route Event Summary

With the exception of the Lexus LS500, each vehicle shown in Figure 11 was nominally driven the same number of miles, using 15 repeated drives, on the highway route (the Lexus LS500 was only driven 5 times on the highway route, for a nominal distance of 540 miles). A plot of the highway-route "events per 100 miles" statistic for each event category is shown in Figure 11.

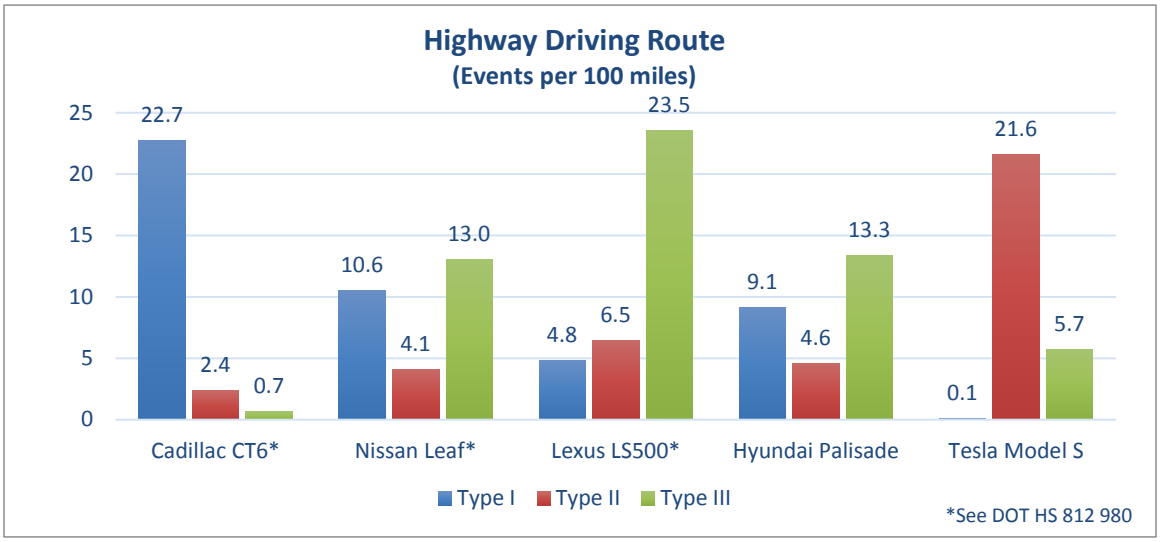

Figure 11. Highway route - events per 100 miles comparison by event category

The Hyundai Palisade and Tesla Model S had an average of 9.1 and 0.1 Type I events per 100 miles of level 2 driving automation on the highway route, respectively. For the Type II events, the Hyundai Palisade and the Tesla Model S averaged 4.6 and 21.6 events per 100 miles, respectively. The Hyundai Palisade and Tesla Model S had an average of 13.3 and 5.7 Type III events per 100 miles, respectively.

4.2 Overall Rural Route Event Summary

The Tesla Model S was used to perform 15 drives of the rural route, whereas 6 rural drives were performed with the Hyundai Palisade (as described in Section 3.3.2 of this report), and 3 rural drives were used for the Nissan Leaf and Lexus LS500. The Cadillac CT6 level 2 driving automation system (known as Super Cruise) was not able to be enabled or put into operation on the rural route, as described in (Rao & Forkenbrock, 2020). A plot of the rural route "events per 100 miles" statistic for each event category is shown in Figure 12, where applicable.

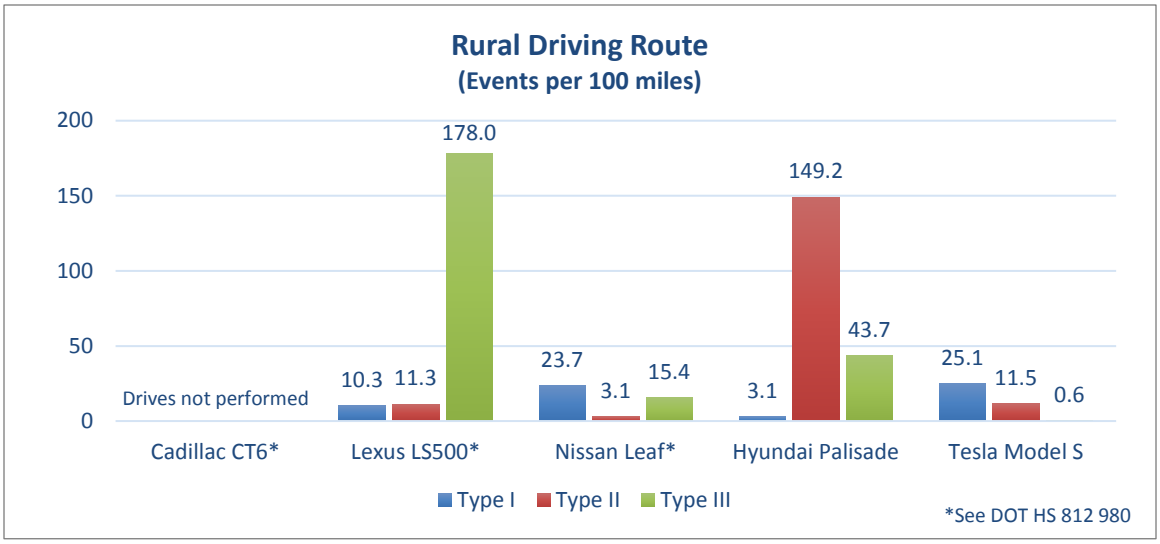

Figure 12. Rural route - events per 100 miles comparison by event category

The Hyundai Palisade and Tesla Model S had an average of 43.7 and 0.6 Type I events per 100 miles of level 2 driving automation on the rural route, respectively. For the Type II events, the Hyundai Palisade and the Tesla Model S averaged 3.1 and 25.1 events per 100 miles, respectively. The Hyundai Palisade and Tesla Model S had an average of 149.2 and 11.5 Type III events per 100 miles, respectively.

4.3 Overall Mixed Route Performance

The Hyundai Palisade, Nissan Leaf, and Tesla Model S were each driven 15 times on the mixed route. The Lexus LS500 was only driven 5 times on the mixed route, for a nominal distance of 316 miles. The Cadillac CT6 was not driven on the mixed route, as described in Rao & Forkenbrock (2020). A plot of the mixed route "events per 100 miles" statistic for each event category is shown in Figure 13, where applicable.

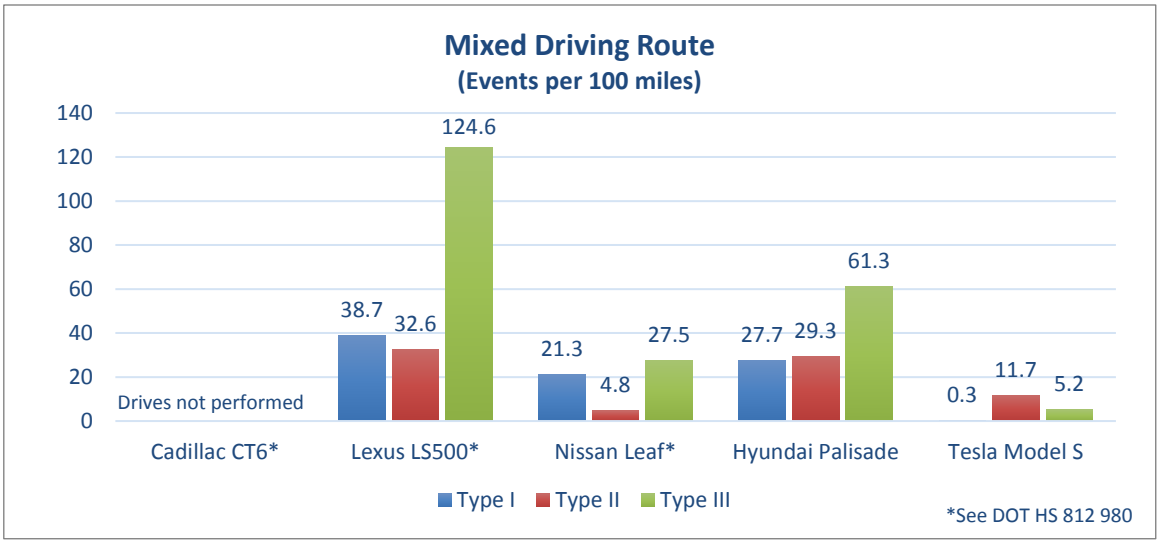

Figure 13. Mixed route - events per 100 miles comparison by event category

The Hyundai Palisade and Tesla Model S had an average of 27.7 and 0.3 Type I events per 100 miles of level 2 driving automation on the mixed route, respectively. For the Type II events, the Hyundai Palisade and the Tesla Model S averaged 29.3 and 11.7 events per 100 miles, respectively. The Hyundai Palisade and Tesla Model S had an average of 61.3 and 5.2 Type III events per 100 miles, respectively.

4.4 Miscellaneous Comments

- When operated without a driver input for an extended interval, both vehicles would step through a cascade of increasingly urgent notifications intended to encourage the driver to put their hands back on the steering wheel. The vehicle's respective icons can be seen in the Appendix.
- Both vehicles relied on handwheel torque to detect if the driver had their hands on the steering wheel while the level 2 driving automation system was engaged and in operation.
- If the driver failed to provide a sufficient input to the handwheel after being presented with the respective alert cascades, both vehicles disabled their level 2 driving automation system feature.
- The Hyundai Palisade would turn off Smart Cruise Control and the vehicle would gradually slow down. However, it would continue to maintain lane position. A slight handwheel input would restore the system's functionality, but the driver would have to reengage Smart Cruise Control to completely restore the level 2 driving automation system operation.
- The Tesla Model S would turn off Navigate on Autopilot completely, which disabled the steering and adaptive cruise control operation. The system would remain off until the vehicle was stopped, and a new ignition cycle was initiated. To reenable level 2 driving automation system operation during the drives described in this report, the driver pulled off the road, turned the car off, and then back on.

5 Conclusions

The level 2 driving automation driver assistance system operation of two light vehicles was observed using three real-world test routes. With one exception, both vehicles were driven 15 times on each test route with the least amount of driver input possible (only six rural route drives were performed with the Hyundai Palisade). Events observed during the drives were recorded, categorized, and normalized. A summary is shown in Table 28.

Table 28. Overall Events Per 100 Miles of Driving Summary

Vehicle	Highway Route			Rural Route			Mixed Route		
	Type I	Type II	Type III	Type I	Type II	Type III	Type I	Type II	Type III
Hyundai Palisade	9.1	4.6	13.3	43.7	3.1	149.2	27.7	29.3	61.3
Tesla Model S	0.1	21.6	5.7	0.6	25.1	11.5	0.3	11.7	5.2

Other noteworthy overall observations relate to Type III lane departure events, where:

- 946 of the 1085 Type III events observed during drives performed with the Hyundai Palisade were lane departure events that, depending on the driving situation and presence of other traffic, either required driver intervention, or the system was allowed to eventually return the vehicle into the original travel lane.
- 161 of the 198 Type III events observed during drives performed with the Tesla Model S were lane departure events that, depending on the driving situation and presence of other traffic, either required driver intervention, or the system was allowed to eventually return the vehicle into the original travel lane.

Finally, while this study documents observed statistics for the identified categories of events associated with the tested SAE level 2 driving automation systems, there are no documented or implied conclusions in this report over their correlation to driving safety, driver engagement, or consumer acceptance.

6 References

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Appendix A

This appendix documents driver-display images representative of those observed during testing.

Hyundai Palisade Driver Display

The Hyundai Palisade instrument cluster-based driver display is shown in Figure 14 and Figure 15. This image shows the level 2 driving automation system engaged.

Figure 14. Instrument cluster of Hyundai Palisade being driven in level 2 automation

Figure 15. Hyundai Palisade instrument cluster with icons labeled

If the Hyundai Palisade LKA enabled and detects the lane lines, but the system is not available to actively control the vehicle's lane position, the steering wheel icon will turn white, as can be seen in Figure 16. This occurs if the turn signal is on or if the system alerts the driver to resume full manual control of the vehicle.

Figure 16. Hyundai Palisade display when LKA and steering wheel control are deactivated

When the Hyundai Palisade LKA is enabled, but does not detect the lane lines, both the LKA and steering wheel icons turn white, as can be seen in Figure 17. This can happen if one lane line is degraded or disappears.

Figure 17. Hyundai Palisade display when LKA and steering wheel control are deactivated

If the LKA system does not detect steering wheel input after 30 seconds, the driver receives a first "Keep hands on steering wheel" alert, as shown in Figure 18. This is accompanied by two audible beeps in close succession.

Figure 18. Hyundai Palisade's first LKA "hands on" alert message to the drive

This first warning lasts for 15 seconds. The second "Keep hands on steering wheel" warning has a red steering wheel, as shown in Figure 19. This is accompanied by continuous audible beeps for the next 25 seconds.

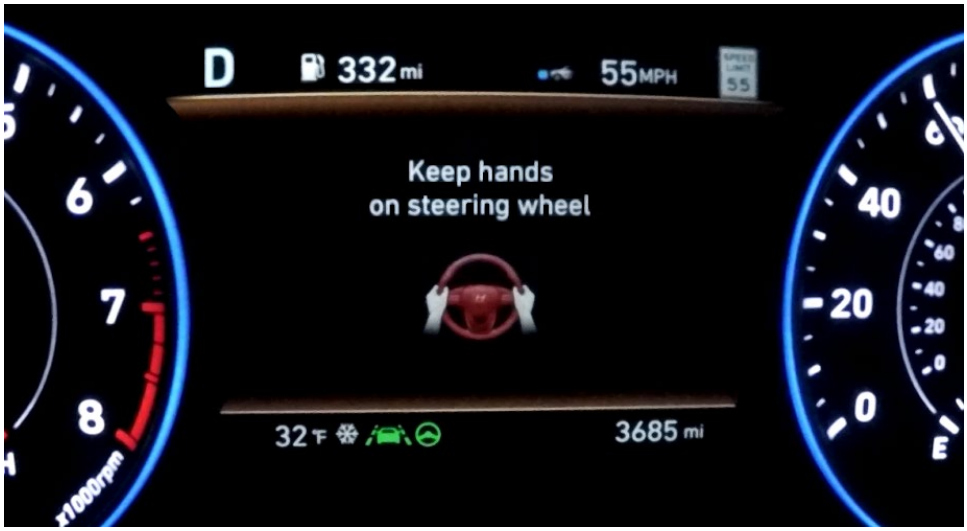

Figure 19. Hyundai Palisade's second LKA "hands on" alert message to the driver

Ignoring this final warning leads to the system turning off level 2 automated driving and notifying the driver with the message shown in Figure 20. The system releases the throttle but maintains steering control to keep the vehicle in the lane.

Figure 20. Hyundai Palisade's "Driving Convenience systems canceled" notification

When Smart Cruise Control brings the vehicle to a stop, the message in Figure 21 is displayed. Note that the vehicle-to-vehicle distance icon displays a lead vehicle and the Hyundai Palisade is stopped. Also note that the LKA icon has turned white because it does not operate below 40 mph (64.4 km/h).

Figure 21. Message when Smart Cruise Control has brought the vehicle to a stop

When the lead vehicle moves, Smart Cruise Control displays the message shown in Figure 22 and beeps.

Figure 22. Smart Cruise Control notification that a lead vehicle movement has been detected

Tesla Model S Driver Display

Figure 23 shows the Tesla Model S instrument cluster-based driver display images when Navigate on Autopilot is off (left side image) and just after it has been enabled (right side image). The Traffic-Aware Cruise Control speed setting (set to 23 mph in the upper left of both images), the Autosteer steering-wheel indicator (in the upper right of both images), and the lane lines all turn blue when Navigate on Autopilot is engaged. A message advising the driver to keep their hands on the wheel, and to be prepared to take over at any time, temporarily appears at the bottom of the screen.

Figure 23. Tesla Model S driver display with Autopilot disabled (left) and enabled (right)

When Navigate on Autopilot determines the driver has not had their hands on the steering wheel for an extended period of time (typically between 12 to 25 seconds), the driver is warned to "Apply slight turning force to the steering wheel", as shown in the upper left-hand image of Figure 24. Two seconds later, a solid white bar begins to slowly flash across the upper portion of

the display, as shown in the upper right-hand image of Figure 24. If the driver takes no action, the flashing frequency of the white bar increases for approximately 15 seconds. After that, the hands of the "Apply slight turning force to the steering wheel" warning turn red, as shown in the lower left-hand image of Figure 24, and two audible beeps are presented in close succession. Two sets of two audible beeps are issued 10 seconds later, followed 5 seconds later by constant beeping and a large steering wheel with red hands on it, as shown in the lower right-hand image of Figure 24.

Figure 24. The escalating messages observed when the driver's hands remain off the steering wheel for an extended time

After the final message shown in Figure 24 is presented, the Traffic-Aware Cruise Control speed setting and the Autosteer steering-wheel indicator remain blue, but the vehicle begins to slow down, and lane position is not controlled. Once Autosteer becomes unavailable, any movement of the steering wheel causes the Autosteer steering-wheel indicator to disappear. Autosteer and Navigate on Autopilot will remain unavailable until the next ignition cycle. If the driver attempts to reengage the system without an ignition cycle, the message shown in Figure 25 appears.

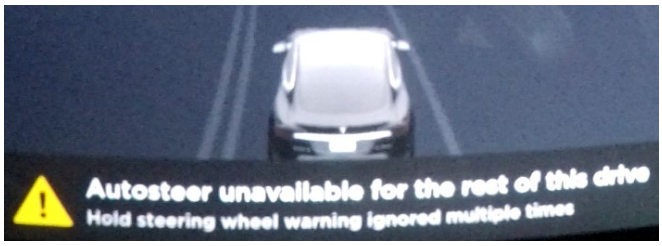

Figure 25. Message indicating Autosteer is no longer available and why

In this study, although the lane changes were typically suggested and executed by Navigate On Autopilot, there were times when the driver used the Auto Lane Change feature to pass slower vehicles if they felt an early move would minimize the chance of blocking approaching traffic in the right adjacent lane. Figure 26 shows the driver display images of the Auto Lane Change feature just as the driver signaled to move around a truck ahead (left side image), and just as the driver signaled to move back into the original travel lane (right side image). The lane where the vehicle is moving to is shaded blue when the vehicle believes the lane change can be made safely. Note: These images were captured while Navigate on Autopilot was disabled in order to capture the Auto Lane Change images; Navigate on Autopilot would have been expected to move the vehicle around the truck before slowing to 61 mph during normal operation.

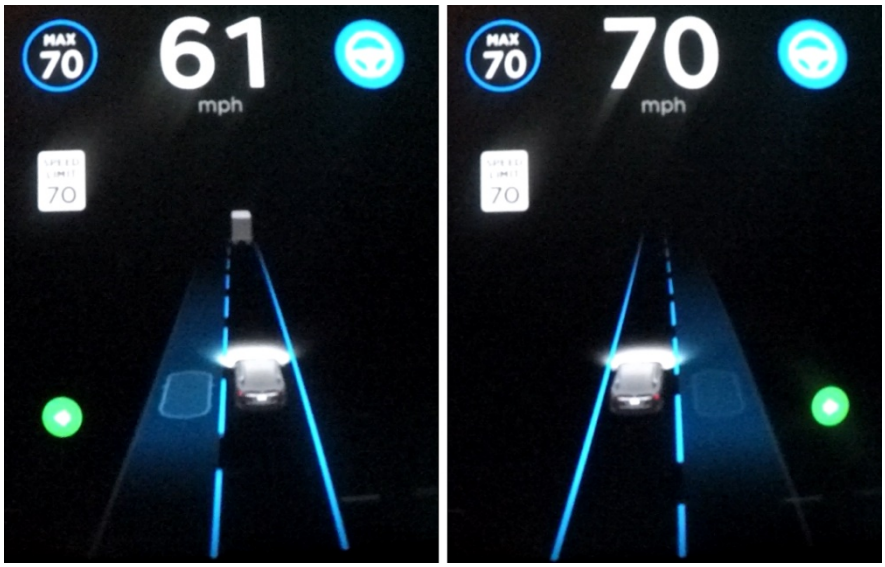

Figure 26. Auto Lane Change sequence as vehicle passes slower moving truck

The Navigate on Autopilot feature is intended to assist the driver while the vehicle is being operated on a highway and is capable of suggesting automated lane changes. The two types of lane changes that Navigate on Autopilot suggests are (1) route-based lane changes designed to keep the vehicle on the navigation route, and (2) speed-based lane changes designed to keep the vehicle moving as close to the set speed as possible. Figure 27 shows the driver display images of the Navigate on Autopilot feature in operation.

Figure 27. Messages from the Navigate on Autopilot feature while in operation

In Figure 27, the upper left-hand image shows the driver message displayed during a route-based lane change, while the upper right-hand image shows the driver message displayed during a speed-based lane change. As was the case with the Auto Lane Change feature, the lane where the vehicle is moving to is shaded blue. As the vehicle approaches the driver-specified destination programmed into the vehicle's navigation system, an audible alert such as "In 1,000 feet, your destination will be on the right" is presented to the driver. Navigate on Autopilot visually notifies the driver of the distance that remains before it turns off (i.e., is automatically switched off), as shown in the lower left-hand image of Figure 27. Upon arrival, Navigate on Autopilot issues an audible tone and notifies the driver with the message shown in the lower right-hand image of Figure 27.

In some situations, Navigate on Autopilot will issue a "Take Over" request that requires the driver to resume full manual control of the vehicle. The upper left-hand image of Figure 28

shows this image presented to the driver when the vehicle first issues a "Take Over Immediately" warning. The Autosteer steering-wheel indicator disappears shortly after that, as seen in the upper right-hand image. The lower left-hand image of Figure 28 shows the image presented to the driver at the instant the vehicle cancels Traffic-Aware Cruise Control and Autosteer due to "Reduced front radar visibility." If the driver attempts to reengage the system without an ignition cycle, a blinking, yellow Autosteer steering-wheel indicator appears, accompanied by an audible alert and the message shown in the lower right-hand image.

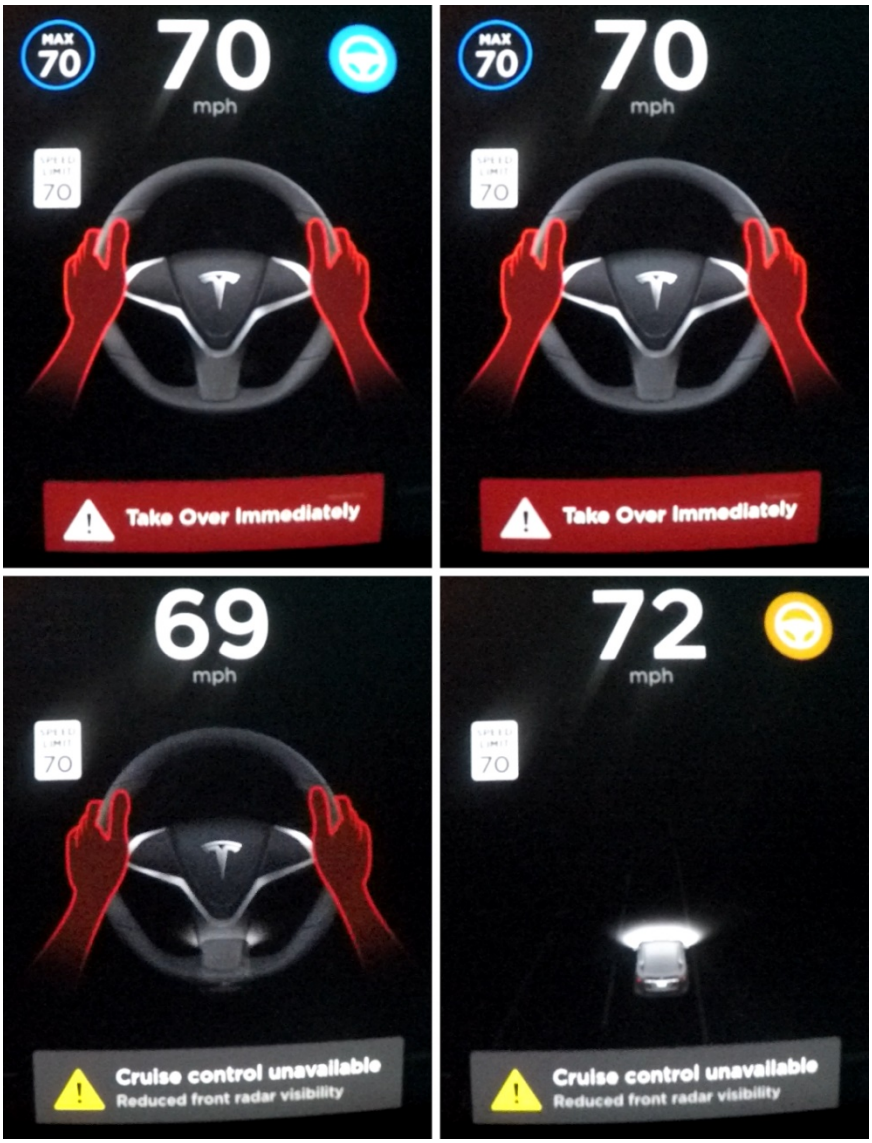

Figure 28. Take Over Request messages observed during Autopilot operation

Many factors can influence the operation and performance of Navigate on Autopilot, some of which being previously described in Section 2.1.2. In Figure 29, the left-hand image shows the situation where the vehicle has just entered a gradual right curve. The center image shows the message displayed when the vehicle is not centered in the lane when attempting to manually enable the Autosteer feature. In both these situations, the yellow Autosteer steering-wheel indicator blinks and is accompanied by an audible alert. The right-hand image shows the

situation where Navigate on Autopilot is fully engaged, but the system detected poor weather and the Navigate on Autopilot feature could not be manually enabled.

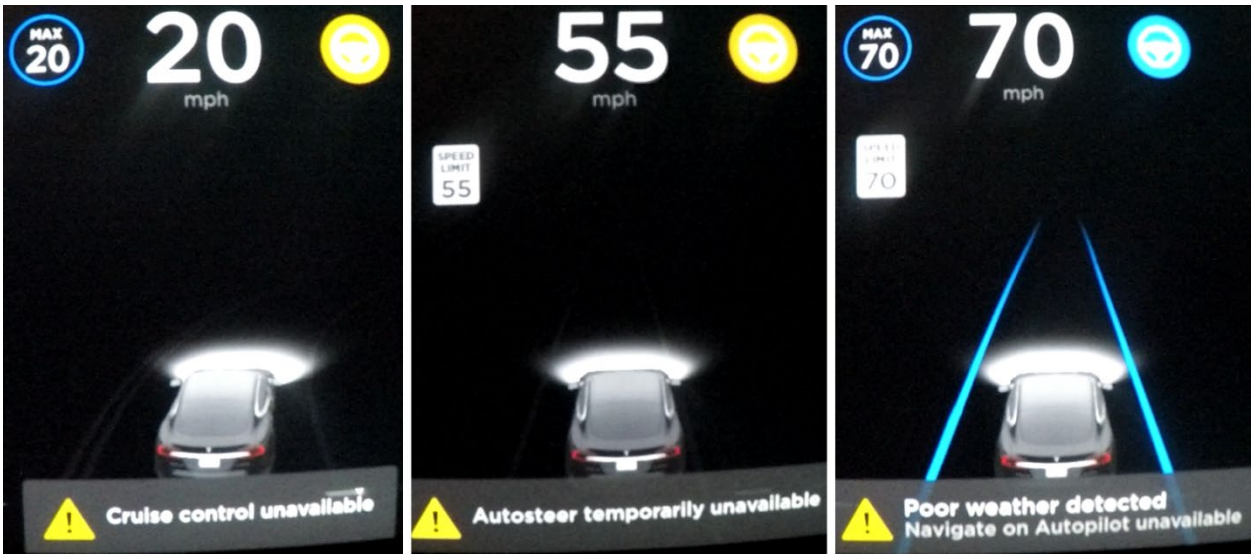

Figure 29. Messages displayed when Autopilot components are unavailable for use

In situations where the speed limit cannot be detected when Autosteer is engaged, the vehicle's speed is limited to 45 mph (70 km/h). Figure 30 shows the driver display image when the speed of Autosteer is limited (left side image). If the driver decides to manually increase the speed using the accelerator pedal, a message that indicates Traffic-Aware Cruise Control will not apply the brakes (right side image) appears.

Figure 30. Messages displayed when the speed limit is unknown and the driver increases speed

Detailed Statistics of Curve and Straight Roadways

The Hyundai Palisade Highway route data previously presented in Table 5 showed that a majority of the Type I events occurred in a curve (110 of 148 events, or 74.3%). For the sake of comparison to results observed on straight roads, and to provide a more complete event description summary, Table 29 and Table 30 break down the Type I straight and curve events,

respectively. As previously mentioned in Section 3.3.1 of this report, data were selected for detailed examination when the percentage of straight and curve roadways exceeded a 60/40 ratio and a minimum of 30 events were noted.

Table 29. Hyundai Palisade Highway Type I Events – Straight (n=38)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	2		10				**12**
	Not Flat	2						**2**
Merging Lanes	Flat	5		6		1		**12**
	Not Flat							
Exit Ramp	Flat	8		3	1			**12**
	Not Flat							
Total		**17**		**19**	**1**	**1**		**38**

Table 30. Hyundai Palisade Highway Type I Events – Curve (n=110)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	18	4	2	3			**27**
	Not Flat	9			2			**11**
Merging Lanes	Flat	11	2	1	1			**15**
	Not Flat							
Exit Ramp	Flat	41	4	5	4	1		**55**
	Not Flat	2						**2**
Total		**81**	**10**	**8**	**10**	**1**		**110**

The Hyundai Palisade Mixed route data in Table 14 showed that a majority of the Type II events occurred while on a straight roadway (201 of 277 events, or 72.6%). The overall number of "Dithering in Lane" events was 73.0 percent. Table 31 and Table 32 break down the Type II "Dithering in Lane" straight and curve events, respectively.

Table 31. Hyundai Palisade Mixed Type II Dithering in Lane Events – Straight (n=179)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	68	1	10	76		4	**159**
	Not Flat	8			9			**17**
Merging Lanes	Flat			1		1	1	**3**
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**76**	**1**	**11**	**85**	**1**	**5**	**179**

Table 32. Hyundai Palisade Mixed Type II Dithering in Lane Events – Curve (n=22)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	13			6			**19**
	Not Flat	1			1			**2**
Merging Lanes	Flat			1				**1**
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**14**		**1**	**7**			**22**

The Tesla Model S Highway route data previously presented in Table 18 showed that a majority of the Type II events occurred while on a straight roadway (310 of 350 events, or 88.6. In this section, the data are separated into Type II "Dithering in Lane" events and Type II "Other" events. The 3 "Lane Line Hugging" events mentioned in Table 18 are not further discussed here. Table 33 and Table 34 break down the Type II Dithering in Lane straight and curve events, respectively. Table 35 and Table 36 break down the Type II Other straight and curve events, respectively.

Table 33. Tesla Model S Highway Type II Dithering in Lane Events – Straight (n=112)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	52	2	1	5			**60**
	Not Flat							
Merging Lanes	Flat	9	4	36				**49**
	Not Flat							
Exit Ramp	Flat	1		2				**3**
	Not Flat							
Total		**62**	**6**	**39**	**5**			**112**

Table 34. Tesla Model S Highway Type II Dithering in Lane Events – Curve (n=15)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	3						**3**
	Not Flat							
Merging Lanes	Flat	1		6				**7**
	Not Flat							
Exit Ramp	Flat	4		1				**5**
	Not Flat							
Total		**8**		**7**				**15**

Table 35. Tesla Model S Highway Type II Other Events – Straight (n=195)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	115	2	2	1			**120**
	Not Flat							
Merging Lanes	Flat	43	9	6	1	2		**61**
	Not Flat							
Exit Ramp	Flat	10	2	2				**14**
	Not Flat							
Total		**168**	**13**	**10**	**2**	**2**		**195**

Table 36. Tesla Model S Highway Type II Other Events – Curve (n=25)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	10						**10**
	Not Flat							
Merging Lanes	Flat	6	2	5				**13**
	Not Flat							
Exit Ramp	Flat	2						**2**
	Not Flat							
Total		**18**	**2**	**5**				**25**

The Tesla Model S Highway route data previously presented in Table 19 showed that a majority of the Type III events occurred while on a straight roadway (61 of 93 events, or 65.6%). In this section, these data are separated into Type III "Lateral Intervention" events and Type III "Longitudinal Intervention" events. Table 37 and Table 38 break down the Type III "Lateral Intervention" straight and curve events, respectively. Table 39 and Table 40 break down the Type III "Longitudinal Intervention" straight and curve events, respectively.

Table 37. Tesla Model S Highway Type III Lateral Intervention Events – Straight (n=42)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	20		2				**22**
	Not Flat							
Merging Lanes	Flat	6	3[1]	6[2]				**15**
	Not Flat							
Exit Ramp	Flat	2	1	2				**5**
	Not Flat							
Total		**28**	**4**	**10**				**42**

[1] 1 of the 3 events involved a lane departure.
[2] 4 of the 6 events involved a lane departure.

Table 38. Tesla Model S Highway Type III Lateral Intervention Events – Curve (n=26)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	4		2[1]				**6**
	Not Flat							
Merging Lanes	Flat	2			1			**3**
	Not Flat							
Exit Ramp	Flat		1	15[2]				**16**
	Not Flat		1					**1**
Total		**6**	**2**	**17**	**1**			**26**

[1] Both events involved a lane departure.
[2] 10 of the 15 events involved a lane departure.

Table 39. Tesla Model S Highway Type III Longitudinal Intervention Events – Straight (n=19)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	11			2			**13**
	Not Flat							
Merging Lanes	Flat	4						**4**
	Not Flat							
Exit Ramp	Flat	2						**2**
	Not Flat							
Total		**17**			**2**			**19**

Table 40. Tesla Model S Highway Type III Longitudinal Intervention Events – Curve (n=6)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	2						**2**
	Not Flat	1			2			**3**
Merging Lanes	Flat							
	Not Flat							
Exit Ramp	Flat	1						**1**
	Not Flat							
Total		**4**			**2**			**6**

The Tesla Model S Rural route data in previously presented in Table 22 showed that a majority of the Type II events occurred while on a straight roadway (96 of 122 events, or 78.7%). The data in this section are separated into Type II "Dithering in Lane" events and Type II "Other" events (the two "Lane Line Hugging" events shown in Table 22 are not included). Table 41 and Table 42 break down the Type II Dithering in Lane straight and curve events, respectively. Table 43 and Table 44 break down the Type II "Other" straight and curve events, respectively.

Table 41. Tesla Model S Rural Type II Dithering in Lane Events – Straight (n=27)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	4		3				**7**
	Not Flat	11		2				**13**
Merging Lanes	Flat			7				**7**
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**15**		**12**				**27**

Table 42. Tesla Model S Rural Type II Dithering in Lane Events – Curve (n=12)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	4		5				**9**
	Not Flat	2		1				**3**
Merging Lanes	Flat							
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**6**		**6**				**12**

Table 43. Tesla Model S Rural Type II Other Events – Straight (n=68)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	33		5				**38**
	Not Flat	27		3				**30**
Merging Lanes	Flat							
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**60**		**8**				**68**

Table 44. Tesla Model S Rural Type II Other Events – Curve (n=13)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	5		1				**6**
	Not Flat			7				**7**
Merging Lanes	Flat							
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**5**		**8**				**13**

The Tesla Model S Rural route data previously presented in Table 23 showed that a majority of the Type III events occurred in a curve (43 of 56 events, or 76.8%). In this section, the data are separated into Type III "Lateral Intervention" events and Type III "Longitudinal Intervention" events (the 10 Lane Departure with System Recovery events shown in Table 23 are not included). Table 45 and Table 46 break down the Type III "Lateral Intervention" straight and curve events, respectively. Table 47 and Table 48 break down the Type III "Longitudinal Intervention" straight and curve events, respectively.

Table 45. Tesla Model S Rural Type III Lateral Intervention Events – Straight (n=7)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	7						**7**
	Not Flat							
Merging Lanes	Flat							
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**7**						**7**

Table 46. Tesla Model S Rural Type III Lateral Intervention Events – Curve (n=32)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	18[1]		7[3]				**25**
	Not Flat	2[2]		1[4]				**3**
Merging Lanes	Flat			4				**4**
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**20**		**12**				**32**

[1] 7 of the 18 events involved a lane departure.
[2] 1 of the 2 events involved a lane departure.
[3] 6 of the 7 events involved a lane departure.
[4] Event involved a lane departure.

Table 47. Tesla Model S Rural Type III Longitudinal Intervention Events – Straight (n=6)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	4						**4**
	Not Flat	2						**2**
Merging Lanes	Flat							
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**6**						**6**

Table 48. Tesla Model S Rural Type III Longitudinal Intervention Events – Curve (n=1)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	1						**1**
	Not Flat							
Merging Lanes	Flat							
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**1**						**1**

The Tesla Model S Mixed route data previously presented in Table 26 showed that a majority of the Type II events occurred while on a straight roadway (87 of 111 events, or 78.4%). In this section, these data are separated into Type II "Dithering in Lane" events and Type II "Other" events (the single "Lane Line Hugging" event shown in Table 26 is not included). Table 49 and Table 50 break down the Type II Dithering in Lane straight and curve events, respectively. Table 51 and Table 52 break down the Type II Other straight and curve events, respectively.

Table 49. Tesla Model S Mixed Type II Dithering in Lane Events – Straight (n=38

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	8		10			1	**19**
	Not Flat	5		2				**7**
Merging Lanes	Flat	2		8				**10**
	Not Flat							
Exit Ramp	Flat	2						**2**
	Not Flat							
Total		**17**		**20**			**1**	**38**

Table 50. Tesla Model S Mixed Type II Dithering in Lane Events – Curve (n=14)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	2		2	1		1	**6**
	Not Flat	6			1			**7**
Merging Lanes	Flat	1						**1**
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**9**		**2**	**2**		**1**	**14**

Table 51. Tesla Model S Mixed Type II Other Events – Straight (n=48)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	13		1	2		1	**17**
	Not Flat	10		1	8			**19**
Merging Lanes	Flat	8	2		1			**11**
	Not Flat							
Exit Ramp	Flat	1						**1**
	Not Flat							
Total		**32**	**2**	**2**	**11**		**1**	**48**

Table 52. Tesla Model S Mixed Type II Other Events – Curve (n=10)

Roadway		Lane Markings, Dry Road			Lane Markings, Wet Road			Total
Type	**Level**	**Good**	**Degraded**	**Missing**	**Good**	**Degraded**	**Missing**	
Normal	Flat	5			3			**8**
	Not Flat	1						**1**
Merging Lanes	Flat	1						**1**
	Not Flat							
Exit Ramp	Flat							
	Not Flat							
Total		**7**			**3**			**10**

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