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Opposing Traffic Safety Assist Draft Test Procedure Performability Validation

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16. Abstract

This report summarizes test track validation of NHTSA's September 2019 Opposing Traffic Safety Assist (OTSA) draft research test procedure. Three of the five test scenarios described in this draft procedure (Scenarios 1, 2, and 4) were used to objectively and effectively assess OTSA performance with the SV operating in automation levels 0 and 1. Since the roads used for the work described in this report were unable to support automated lane changes while the SV was being operated in automation level 2, Scenarios 3 and 5 were not used. Three speed combinations for each scenario were used for this testing. One light vehicle equipped with OTSA, a 2017 Mercedes E300, was evaluated.

Despite five OTSA system activations being observed during conduct of the crash-imminent scenarios, the OTSA system did not prevent the test vehicle from being within 1.5 ft (0.46 m) laterally of the principal other vehicle travelling in the opposite and adjacent lane. Two OTSA-based brake applications were observed during the false positive evaluations, however, they only induced a subject vehicle yaw rate great enough to briefly satisfy the false positive classification threshold during one of the applications.

The tests described in NHTSA's OTSA draft test procedure were generally found to be performable, however difficultly in satisfying some of the validity criteria due to problems related to test equipment operation was observed during some trials. Also, consideration of how best to perform tests where the subject vehicle performs automated lane changes when being operated in an automation level that enables sustained lateral control, and whether the evaluation criteria stating that the minimum lateral distance between the subject and principal other vehicles should be 1.5 ft (0.46 m) were identified as topics for further research.

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Table of Contents

List of Figures

List of Tables

Glossary

ABD	AB Dynamics
ACC	adaptive cruise control
ADAS	advanced driver assistance system
GST	guided soft target
GVT	global vehicle target
LPRV	low profile robotic vehicle
LV	lead vehicle
OTSA	opposing traffic safety assist
OxTS	Oxford Technical Solutions Ltd., Oxfordshire, UK
POV	principal other vehicle
SV	subject vehicle
TTC	time-to-collision

Executive Summary

Opposing traffic safety assist is an advanced driver assistance system whose active interventions are designed to bring a driver's vehicle back into the original travel lane in response to a path deviation towards an oncoming principal other vehicle driven in an adjacent lane. The heading adjustments provided by an OTSA intervention are typically achieved by automatically activating the vehicle's steering system or by applying differential braking.

The objective of the work discussed in this report was to validate the performability of NHTSA's September 2019 OTSA draft research test procedure (NHTSA, in press). This draft procedure defines five test scenarios: three crash imminent scenarios designed to ellicit an OTSA response, and two false positive scenarios where no OTSA intervention is expected. The crash-imminent scenarios are intended to mimic both unintentional lane deviations and intentional lane changes. Additionally, the procedure includes the provisions needed to evaluate vehicles equipped with OTSA and different levels of automation. Automation level 0 tests use no automation, automation level 1 tests use adaptive cruise control to control the subject vehicle speed and headway to a lead vehicle, and automation level 2 tests use the combination of ACC and lane centering control to control SV speed, headway, and lateral position.

Since the work described in this report was used to assess test performability (whether the tests were clearly defined, that they could be accurately performed, etc.), only one SV was used, a 2017 Mercedes E300 equipped with a brake-based OTSA system and automation level 2 capability. To ensure the tests were safely performed, a guided soft target system was used as the POV in lieu of an actual vehicle. A 2017 Volvo S90 was used as the LV ahead of the SV, and was positioned to obstruct the SV's view of the POV during the initial part of each test trial.

The SV was unable to perform automated lane changes on the roads used to facilitate the work described in this report, therefore only tests designed for automation levels 0 and 1 were used (Scenarios 1, 2, and 4). For the crash-imminent scenarios, OTSA was active during 5 of 30 trials. However, during these five trials, the OTSA interventions did not prevent the SV from being within 1.5 ft (0.46 m) laterally of the POV; a test termination condition that automatically triggers an evasive steering maneuver from the robotic steering controller installed in the SV to prevent an SV-to-POV collision from occurring. For the false positive scenarios, OTSA-based brake applications occurred during 2 of 9 trials, however, they only induced an SV yaw rate great enough to satisfy the false positive classification threshold during one of the applications.

The tests described in NHTSA's OTSA draft test procedure were generally found to be performable. However, some test validity criteria were unable to be satisfied during some trials due to equipment limitations and/or the way some of the test equipment was configured. Consideration of how best to perform tests where the SV performs automated lane changes, and whether the evaluation criteria stating the minimum lateral distance between the subject and principal other vehicles should be 1.5 ft (0.46 m) were identified as were topics for further research.

1 Introduction

An OTSA system is an advanced driver assistance technology designed to automatically bring a driver's vehicle back into the original travel lane after moving laterally towards an opposing vehicle driven in an adjacent lane. OTSA activations are intended to prevent head-on collisions and, as a general matter, are expected to occur regardless of whether the driver has activated the turn signal prior to the lane deviation. The heading adjustments provided by an OTSA intervention are typically achieved by automatically activating the vehicle's steering system or by applying differential braking.

NHTSA developed the September 2019 OTSA draft test procedure for research purposes – to provide a documented process by which system operation and effectiveness can be objectively assessed (NHTSA, in press). This report details the test track evaluations used to validate the agency's September 2019 draft research OTSA test procedure. An overview of the test protocols, results, and topics for future consideration are provided.

2 Test Protocol

This section describes the SV, POV, and LV used in this evaluation. Additionally, a brief description of the equipment used to perform the testing, and an outline of the OTSA scenarios is presented.

2.1 Subject Vehicle

A 2017 Mercedes E300 4Matic was the OTSA-equipped SV used for evaluating the draft test procedure. The Mercedes E300 OTSA system is part of the vehicle's active lane keeping assist system, and uses differential braking to return the vehicle back into the original travel lane after a certain type of lateral deviation has occurred. The operational speed range of this system, as defined by the owner's manual, is 40 to 120 mph (64.4 to 193.1 km/h) (Mercedes-Benz, 2017). One SV_POV test speed configuration specified in the OTSA draft test procedure, 25_25 mph (40.2_40.2 km/h), was lower than the operational speed of this technology for the Mercedes E300. However, since the intended purpose of this testing described in this report was primarily test procedure validation (i.e., not vehicle assessment), this speed combination was still used, albeit without an expectation that the system would activate. Finally, although the Mercedes E300 can perform automated lane changes under certain circumstances, they were unable to be performed on the road used for the evaluations described in this report. The reasons for this are not known, however an atypical lane width (approximately 14 ft or 4.3 m) and lane line marking condition (the lane line separating the SV and POV was solid white, but painted with black sections to emulate a striped white line) may be contributing factors.

The Mercedes E300 owner's manual provides full descriptions and limitations of the vehicle's ADAS. One such system, the vehicle's ACC, is known as Distance Pilot DISTRONIC. When this automation level 1 system is enabled and active, it adapts the vehicle's speed to that of the vehicle in front of it. To activate the system, the driver pulls back on the lower, left hand lever (2) shown in **Figure 2-1a**. Speed can be increased (3) or reduced (4) by moving the same lever up or down, respectively, as shown in **Figure 2-1b**. Headway can also be increased (6) or reduced (5) by rotating the end of the level, as shown in and 2-1c.

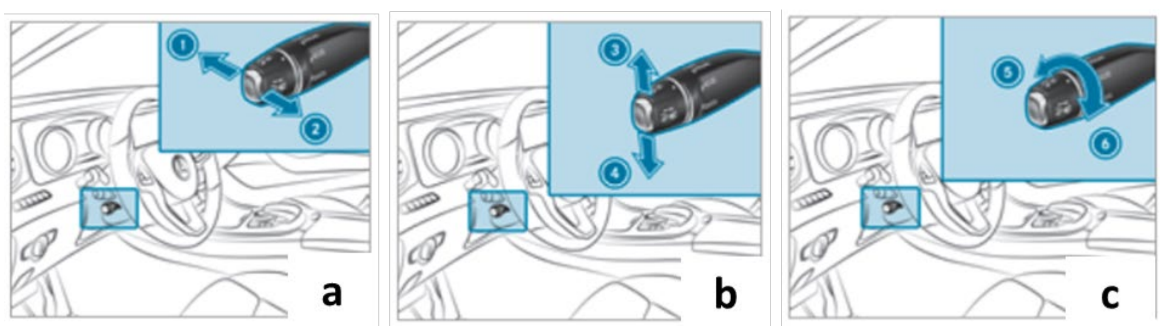

Figure 2-1. Commands used to activate and operate the Mercedes E300 ACC system.

2.2 Principal Other Vehicle

The POV used for each trial described in this report was a guided soft target. The GST system is comprised of a low Profile Robotic Vehicle that can be driven over by the SV and a global vehicle target consisting of foam panels and skins that are designed to separate upon impact, as shown in **Figure 2-2**. Extensive collaborative research was performed from 2015-2018 to ensure the GVT appears realistic to the ADAS systems designed to respond to it [3]. The LPRV provides accurate closed-loop control of the POV relative to the SV, and because the GST system is strikeable from any approach aspect it can be incorporated into nearly any pre-crash scenario. Multiple fail-safe measures are designed to ensure the safe operation of the GST.

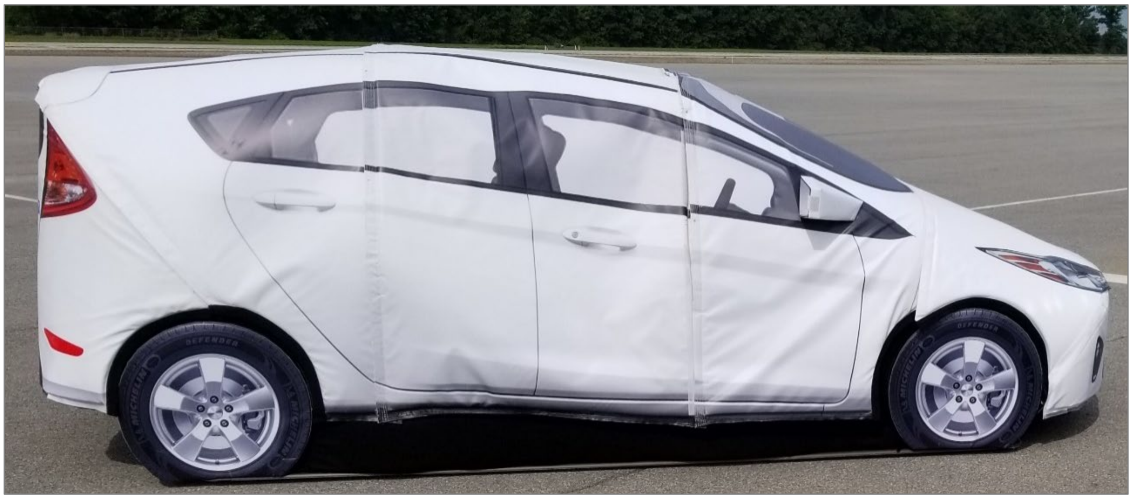

Figure 2-2. GVT Revision F, secured to the top of the LPRV.

2.3 Lead Vehicle

A 2017 Volvo S90 was used as the LV in all scenarios described in this report.

2.4 Test Equipment

Test equipment consisted of AB Dynamics steering and accelerator robots and an Oxford Technical Solutions RT and Range system. Each are briefly described in this section.

2.4.1 Robotic Steering Controller

A robotic controller was attached to the SV steering wheel to maximize the accuracy and repeatability by which the SV lateral deviations and lane changes could be performed with. For this study, an ABD SR15 Orbit was used; a lightweight, low-torque robotic controller programmed to initiate the SV lateral deviation at the desired proximity to the POV, and travel along a desired path, via closed loop control (see **Figure 2-3** for a typical installation example).

Figure 2-3. Example robotic steering controller installation.

This controller was nominally used to command the SV lane deviations (for the crash-imminent tests) or lane changes (for the false positive tests) during each test maneuver, however if the lateral proximity of the SV to the POV exceeded a threshold of 1.5 ft (0.46 m), then it was also used to quickly and automatically execute an open-loop abort maneuver designed to steer the SV away from the POV and back towards the center of its original travel lane. To avoid having the presence of the robotic steering controller potentially confound the effect of an OTSA intervention on the SV heading, it was programmed to release steering control (i.e., free wheel) at certain points within the crash-imminent test maneuvers. This was intended to allow the SV to respond to OTSA interventions as if the steering robot was not installed. Since the robotic controller was only installed around the perimeter of the steering wheel, the SV steering wheel airbag was not removed prior to performing the tests described in this report.

2.4.2 Robotic Accelerator Controllers

Robotic controllers were installed in the SV and LV to accurately and repeatedly provide longitudinal control of these vehicles, where applicable.[1] Although the controllers used in this study (ABD CBARs; see **Figure 2-4** for a typical installation example) can be configured to provide accelerator and brake inputs, only robotic control of the accelerator was used for the tests described in this report.

Figure 2-4. Example robotic brake and accelerator controller installation used in SV and LV.

2.4.3 Inertial and GPS Measurements

The SV, POV, and LV were each instrumented with Oxford Technical Solutions RT 3002 units to provide the accelerations, rotational rates, speeds, and positions of each vehicle. Differential corrections were applied to the GPS data to maximize position accuracy. Paired with an OxTS Range S system and LPRV software, relative ranges and velocities between the SV, LV, POV, and permanent lane markings were also collected.

2.5 Test Scenarios

Three of the five test scenarios described in NHTSA's September 2019 OTSA draft test procedure were used to objectively and effectively assess OTSA performance with the SV operating in automation levels 0 and 1 (Scenarios 1, 2, and 4). Since the roads used for the work described in this report were unable to support automated lane changes while the SV was being operated in automation level 2, Scenarios 3 and 5 were not used. This section describes each of the scenarios specified in the OTSA draft test procedure. For the sake of completeness, descriptions of Scenarios 3 and 5 are included in Sections 2.5.3 and 2.5.5, respectively, despite the scenarios not being used for this study.

[1] In some tests, the SV speed was controlled by its ACC, not the robotic steering controller.

Several initial conditions were common for Scenarios 1, 2, and 4:

- Each vehicle (SV, POV, and LV) initially travelled straight within their respective lane at the desired speed.
- The SV was initially positioned at a predetermined lateral offset from the left lane line, and LV was initially positioned in the center of the same travel lane. The POV was positioned such that its leftmost edge was spaced 3.3 ft (1 m) from the inboard edge of the lane line directly to its left, and oriented opposite of the SV and LV (see **Figures 2-5**, **2-8**, and **2-10**).
- Three SV-to-POV speed combinations were used for each scenario: 25_25 mph (40.2_40.2 km/h), 45_25 mph (72.4_40.2 km/h), and 45_45 mph (72.4_72.4 km/h), where the first and second numbers of each combination describe the nominal SV and POV speeds, respectively.
- For tests performed in automation level 0, the robotic accelerator controller in the SV provided closed-loop control of the desired speed, either 25 or 45 mph (40.2 and 72.4 km/h) depending on the test condition. The robotic accelerator controller installed in the LV was programmed to maintain a constant SV-to-LV headway; 65.6 ft (20 m) when the SV speed was 25 mph (40.2 km/h), and 98.4 ft (30 m) when the SV speed was 45 mph (72.4 km/h).
- For tests performed in automation level 1, the LV was programmed with closed-loop control speed of 44.3 mph (71.3 km/h), which was slightly lower than the nominal target speed of 45 mph (72.4 km/h). The SV's adaptive cruise control was set to 46 mph (74.0 km/h), and the farthest headway setting was selected. Setting the SV ACC speed higher than the tightly controlled speed of the LV ensured the ACC was actively modulating the SV-to-LV headway, something not possible if the LV speed were to exceed that of the SV.
- Since the tests described in this report were only performed with the SV operating in either automation level 0 or 1, all SV lane deviations were commanded by the robotic steering controller previously described in Section 2.4.1.

The evaluation criteria specified in NHTSA's draft OTSA research test procedure state that an OTSA system is expected to intervene in a manner that prevents any part of the SV from being within 1.5 ft (0.46 m) laterally of any part of the POV (not including the side mirrors). If this threshold was exceeded, the test was terminated and the SV automatically steered away from the POV, back into the original travel lane using an evasive maneuver preprogrammed into the robotic steering controller.

2.5.1 OTSA Scenario 1: Unintended Lateral Deviation, No Turn Signal, Manual Steering

OTSA Scenario 1, illustrated in **Figure 2-5**, was designed to evaluate the OTSA system's ability to detect and respond to an opposing POV, present in a lane adjacent to that of the SV, after the SV unintentionally deviates from its travel lane with timing that creates a crash-imminent driving situation. In this scenario, the SV lane deviation was commanded manually,[2] performed with a lateral velocity of 1.6 ft/s (0.5 m/s), and not preceded by activation of the turn signal.

[2] In the context of this report, a manual steering input is one not commanded by the SV itself. The robotically controlled steering inputs used to direct the SV into the path of the POV, and the subsequent POV avoidance maneuver (if needed) are both considered to be manual steering inputs.

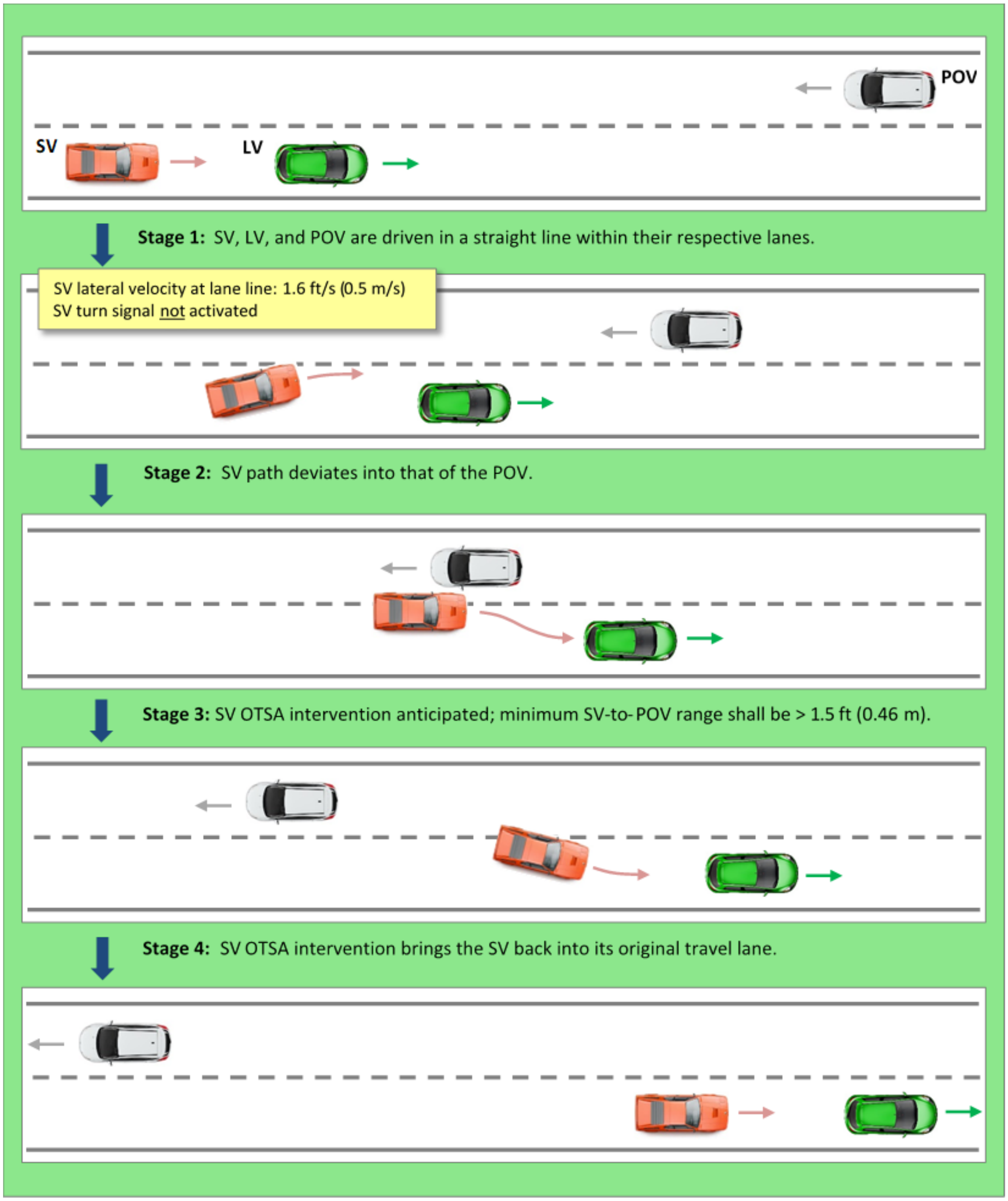

Figure 2-5. OTSA Scenario 1 overview.

Initially, the SV was driven straight behind the LV, at the lateral distance to the left lane line specified in **Figure 2-6**. This distance was calculated by adding half of the SV width to the lateral distances necessary for (1) the SV to complete the constant radius curve used to establish the desired heading angle, and (2) a short period of steady-state driving after completion of the curve.

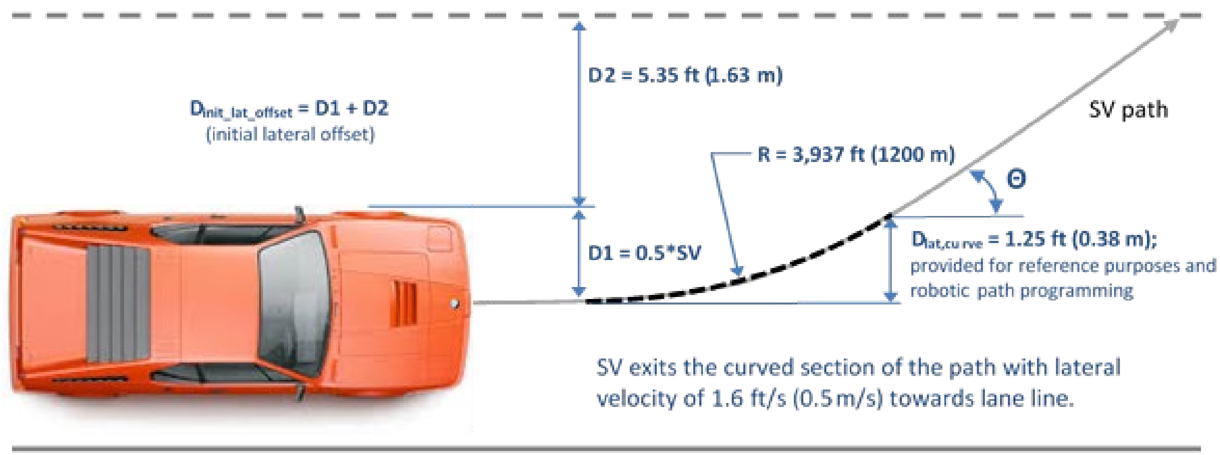

Figure 2-6. OTSA Scenario 1 SV path parameters.

More specifically, at the time-to-collision specified in **Table 2-1** for the various SV/POV speed combinations, robotically controlled inputs steered the SV into a 3,937 ft (1,200 m) radius curve until a speed-dependent heading angle (also listed in **Table 2-1**) was achieved. Once this heading angle was achieved, the SV exited the constant radius curve with a lateral velocity of 1.6 ft/s (0.5 m/s) towards the left lane line. The steering robot's closed-loop control was released within 250 ms of exiting this curve to allow for an unimpeded vehicle reaction. Additional scenario specific parameters to define the SV path deviation are given in **Figure 2-6** and **Table 2-1**.

Table 2-1. OTSA Scenario 1 Parameters

SV and LV Initial Speed	POV Initial Speed	SV-to-LV Headway	SV Path Deviation Onset TTC Range (sec)	Nominal Heading Angle, Θ (deg)[1]
25 ± 1 mph (40.2 ± 1.6 km/h	25 ± 1 mph (40.2 ± 1.6 km/h)	65.6 ± 3.3 ft (20 ± 1 m)	7.6 - 8.4	2.56
45 ±1 mph (72.4 ± 1.6 km/h)	25 ± 1 mph (40.2 ± 1.6 km/h)	98.4 ± 3.3 ft (30 ± 1 m)	6.1 - 6.5	1.43
45 ±1 mph (72.4 ± 1.6 km/h)	45 ±1 mph (72.4 ± 1.6 km/h)	98.4 ± 3.3 ft (30 ± 1 m)	6.1 - 6.5	1.43

[1] Nominal heading angle is provided for reference purposes and robotic path planning. There is no validity check performed on SV heading angle, only on lateral velocity.

For all trials, the validity period[3] ended when one of three conditions were met (**Figure 2-7**):

1. The lateral position of the SV was ≤ 1.5 ft (0.46 m) from the POV; or
2. Five seconds after the SV established a heading away from the POV and was completely within its original travel lane; or
3. One second after the SV travelled ≥ 1 ft (0.3 m) beyond the inboard edge of the lane line separating the SV travel lane from one adjacent and to the right of it.

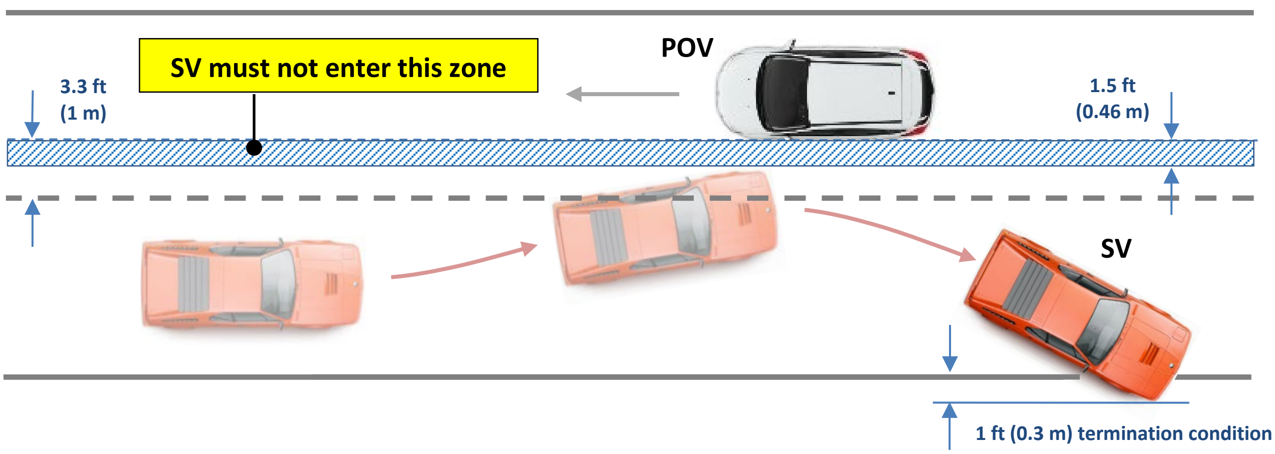

Figure 2-7. OTSA Scenario 1 test completion criteria 3.

2.5.2 OTSA Scenario 2: Intentional Lateral Deviation, Turn Signal, Manual Steering

Compared to OTSA Scenario 1, OTSA Scenario 2 differed in four ways. In OTSA Scenario 2,

- The SV lane position was initially closer to the inboard edge of the left lane line prior to the initiation of the SV lane deviation.
- The SV lane deviation process:
    - Was preceded by activation of the turn signal.
    - Was initiated at a closer SV-to-POV longitudinal TTC.
    - Occurred at a higher lateral velocity.

OTSA Scenario 2 was designed to evaluate the OTSA system's ability to detect and respond to an opposing POV, present in a lane adjacent to that of the SV, after the SV lane intentionally deviates from its travel lane with timing that creates a crash-imminent driving situation. Consistent with the performance criteria used for OTSA Scenario 1, the SV OTSA system was expected to intervene in a manner that prevented any part of the SV from being within 1.5 ft (0.46 m) of any part of the POV (less the side mirrors). An overview of OTSA Scenario 2 is shown in **Figure 2-8**.

[3] "Validity period" refers to the time when the various test tolerances defined in the OTSA draft test procedure must be satisfied for a given trial to be deemed valid.

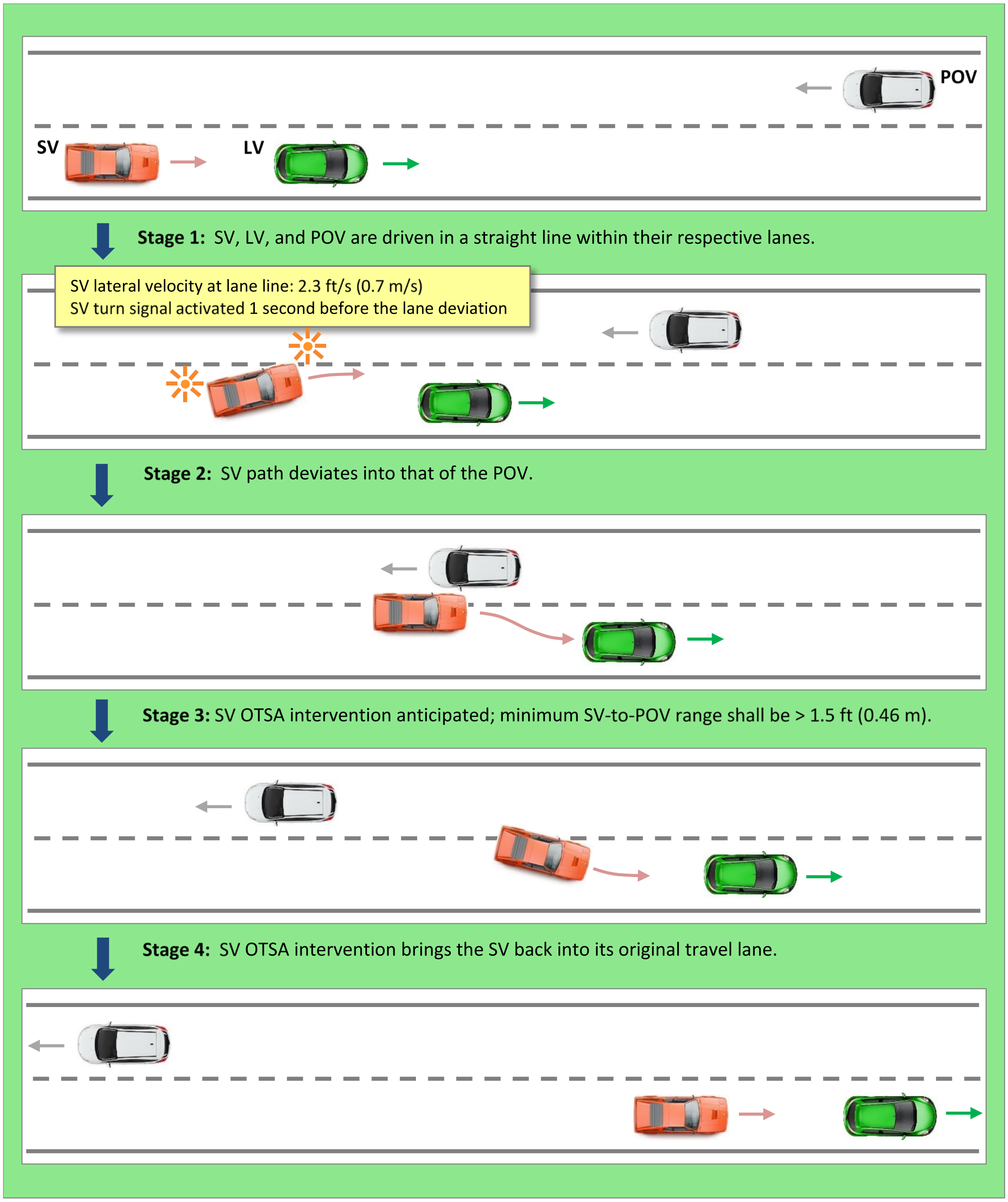

Figure 2-8. OTSA Scenario 2 overview.

To differentiate the intentional lane deviation used in OTSA scenario 2 from the unintended deviation maneuver used during OTSA Scenario 1, the SV turn signal and a higher lateral velocity of 2.3 ft/s (0.7 m/s) are used. As shown in **Figure 2-9**, this was achieved by changing the initial SV offset within its travel lane, use of a smaller 2,625 ft (800 m) constant radius curve, and ultimately, use of a larger heading angle towards the left lane line. Also, since the time needed to complete the lateral deviation was less during OTSA Scenario 2, the maneuver was initiated at a shorter TTC. A summary of these parameters is provided in **Table 2-2**.

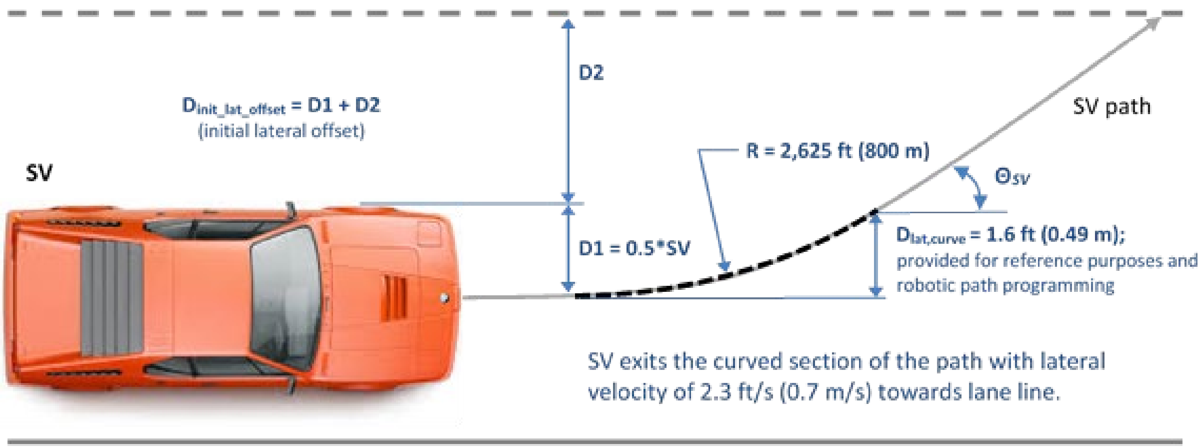

Figure 2-9. OTSA Scenario 2 SV path parameters.

Table 2-2. OTSA Scenario 2 Parameters

SV and LV Initial Speeds	POV Initial Speed	SV-to-LV Headway	SV Turn Signal Application TTC (sec)	SV Path Deviation Onset TTC Range (sec)	Nominal Heading Angle (Θ, in deg)[1]	Lateral Offset (D2)
25 ± 1 mph (40.2 ± 1.6 km/h	25 ± 1 mph (40.2 ± 1.6 km/h)	65.6 ± 3.3 ft (20 ± 1 m)	7.6 ± 0.5	6.3 - 6.9	3.61	6.23 ft (1.9 m)
45 ± 1 mph (72.4 ± 1.6 km/h)	25 ± 1 mph (40.2 ± 1.6 km/h)	98.4 ± 3.3 ft (30 ± 1 m)	5.4 ± 0.5	4.3 - 4.6	2.01	4.99 ft (1.52 m)
45 ± 1 mph (72.4 ± 1.6 km/h)	45 ± 1 mph (72.4 ± 1.6 km/h)	98.4 ± 3.3 ft (30 ± 1 m)	5.4 ± 0.5	4.3 - 4.6	2.01	4.99 ft (1.52 m)

[1] Nominal heading angle is provided for reference purposes and robotic path planning. There is not a validity check performed on SV heading angle, only on lateral velocity.

2.5.3 OTSA Scenario 3: Intentional Lateral Deviation, Turn Signal, Automated Steering

OTSA Scenario 3, which was not used in this study, is conceptionally similar to OTSA Scenario 2 (i.e., a crash-imminent scenario comprised of an intentional lane change). However, since the SV is operated at an automation level that enables sustained lateral control, its lateral position within the travel lane, during the steady state period leading up to the lane change, is controlled by SV's lane centering control system (i.e., its initial lane position was vehicle-dependent). Similarly, although the SV driver activates the turn signal at the same longitudinal TTC used for OTSA Scenario 2, the timing (i.e., when the SV physically initiates the lane change) and path are both vehicle-dependent during OTSA Scenario 3.

Note: Although the lane change itself was vehicle dependent, a robotic steering controller is still installed in the SV for OTSA Scenario 3 tests. This is to facilitate the automatically activated evasive steering maneuver to direct the SV away from the POV should the minimum lateral proximity between the vehicles fall below the 1.5 ft (0.46 m) threshold.

2.5.4 OTSA Scenario 4: False Positive Assessment, Manual Steering

Unlike the crash-imminent scenarios defined in OTSA Scenarios 1, 2, and 3, OTSA Scenario 4 is a false-positive assessment designed to evaluate whether an OTSA system detects and responds to a non-threatening POV. For these tests, the POV was driven two lanes to the left of the SV. Using the same longitudinal TTCs defined in OTSA Scenario 2, the SV driver activated the turn signal, and the robotic steering controller automatically initiated a single lane change into the left adjacent lane. However, rather than robotic steering control being released prior to the SV crossing the left lane line, a full single lane change was performed (i.e., the SV was steered from its initial travel lane to the center of the left adjacent lane). Robotic control of the SV steering was not released until the end of the validity period. A summary of these parameters is provided in **Table 2-3**. An overview of OTSA Scenario 4 is shown in **Figure 2-10**.

Table 2-3. OTSA Scenario 4 Parameters

SV and LV Initial Speeds	POV Initial Speed	SV-to-LV Headway	SV Turn Signal Application TTC (sec)	SV Path Deviation Onset TTC Range (sec)	Nominal Heading Angle (Θ, in deg)[1]	Lateral Offset (D2)
25 ± 1 mph (40.2 ± 1.6 km/h	25 ± 1 mph (40.2 ± 1.6 km/h)	65.6 ± 3.3 ft (20 ± 1 m)	7.6 ± 0.5	6.3 - 6.9	3.61	6.23 ft (1.9 m)
45 ± 1 mph (72.4 ± 1.6 km/h)	25 ± 1 mph (40.2 ± 1.6 km/h)	98.4 ± 3.3 ft (30 ± 1 m)	5.4 ± 0.5	4.3 - 4.6	2.01	4.99 ft (1.52 m)
45 ± 1 mph (72.4 ± 1.6 km/h)	45 ± 1 mph (72.4 ± 1.6 km/h)	98.4 ± 3.3 ft (30 ± 1 m)	5.4 ± 0.5	4.3 - 4.6	2.01	4.99 ft (1.52 m)

[1] Nominal heading angle is provided for reference purposes and robotic path planning. There is not a validity check performed on SV heading angle, only on lateral velocity.

To assess whether an OTSA false positive occurred, the SV yaw rate observed during baseline trials performed without the LV or POV were compared to otherwise equivalent trials performed with the LV and POV.

OTSA Scenario 4 tests were complete when one of the following conditions was met:

1. Five seconds after the SV had completed the single lane change into the left lane adjacent to the SV's original travel lane; or
2. One second after an OTSA intervention caused the SV to travel ≥ 1 ft (0.3 m) beyond the inboard edge of the lane line separating the post lane change SV travel lane and one adjacent and to the right of it (previously shown in **Figure 2-5**).

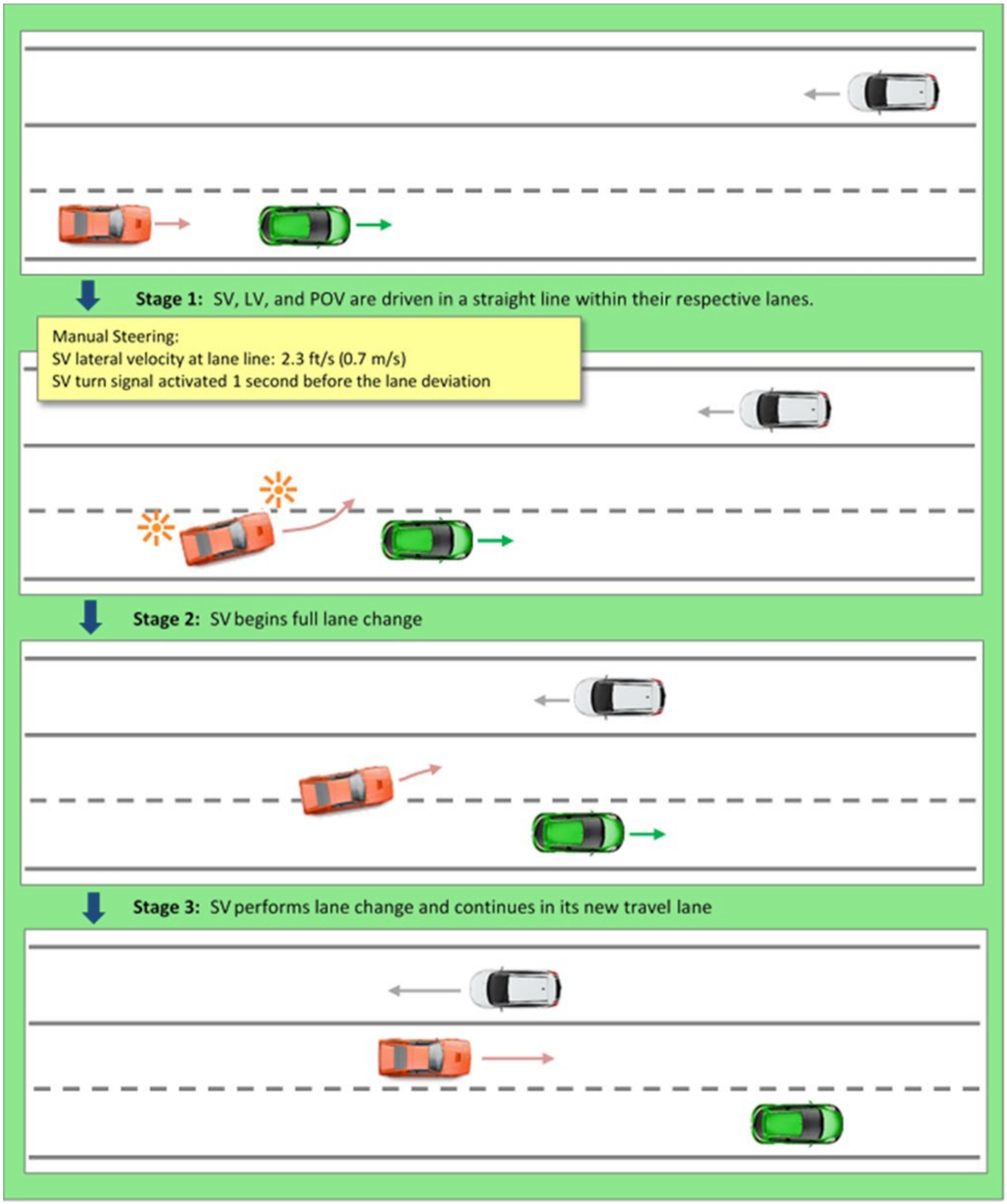

Figure 2-10. OTSA Scenario 4 overview.

2.5.4.1 Baseline Tests for OTSA Scenario 4

Baseline and evaluation OTSA scenario 4 tests were performed in an identical manner except that no POV or LV was present during the baseline condition. Three baseline trials were completed, and SV yaw rate data from each trial was synchronized and averaged to generate a composite data trace. Using this composite, upper and lower bounds of ±1 deg/s were defined to create the "acceptability corridor" shown in **Figure 2-11**.

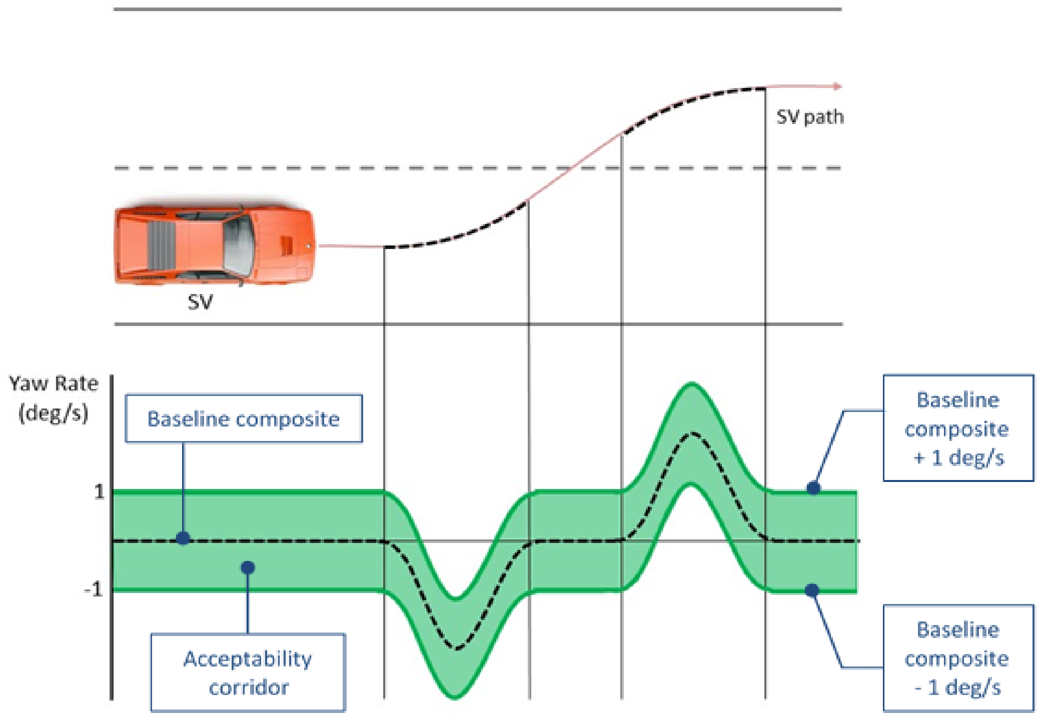

Figure 2-11. OTSA Scenario 4 acceptability corridor example.

OTSA Scenario 4 evaluation trials were compared to the acceptability corridor to determine whether a false positive OTSA intervention had occurred. Should the yaw rate data collected during an evaluation trial exceed the boundaries of the acceptability corridor, an OTSA false positive was said to have occurred. An example of what an OTSA intervention may look like is shown in **Figure 2-12**.

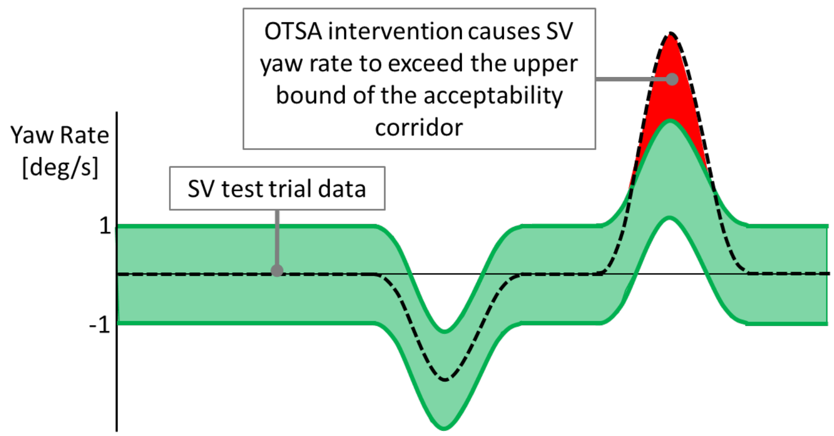

Figure 2-12. OTSA Scenario 4 intervention with acceptability corridor.

2.5.5 OTSA Scenario 5: False Positive Assessment, Automated Steering

OTSA Scenario 5, which was not used in this study, is conceptionally similar to the false positive assessment used in OTSA Scenario 4, but with the vehicle's automatic lane change function responsible for performing the commanded lane changes. Also, since the SV is operated at an automation level that enables sustained lateral control during OTSA Scenario 5, its initial lateral position within the travel lane during the steady state period leading up to the lane change was vehicle-dependent. Similarly, although the SV driver activates the turn signal at the same longitudinal TTC used for OTSA Scenario 4, the timing (i.e., when the SV physically initiated the lane change) and path are both vehicle-dependent during OTSA Scenario 5.

Note: Although lane change itself was vehicle-dependent, a robotic steering controller was still installed in the SV for OTSA Scenario 5 tests. This is to facilitate the automatically activated evasive steering maneuver to direct the SV away from the POV should the lateral proximity between the vehicles fall below the 1.5 fit (0.46 m) threshold.

2.6 Test Validity Assessment

The validity criteria described in the draft OTSA research test procedure were assessed for each trial performed in this study, and included test tolerances for the steady state approach of the vehicles prior to the lane change, the timing and path of the SV lane deviations or changes, and the SV-to-POV lateral proximity at initiation of the robotic steering controller's evasive maneuver, when applicable. More specifically, the following criteria were confirmed within the applicable validity period.

- The SV, POV, and LV speeds were ± 1 mph (± 1.6 km/h) of the desired test speed.
- The SV yaw rate was 0 ± 1 deg/s in the period preceding the lane change initiation.
- The lateral offset of the left edge of the SV to the inboard edge of the lane line immediately to the left was ± 0.8 ft (± 0.25 m) of the desired position in the period preceding the lane change initiation.
- The lateral offset of the left edge of the POV to the inboard edge of the lane line immediately to the left was ± 0.8 ft (± 0.25 m) of the desired position.
- The LV centerline was ± 0.8 ft (± 0.25 m) from the center of the LV travel lane.
- The SV-to-LV headway was ± 3.3 ft (± 1 m) of the desired headway.
- The initiation of the lane change occurred within the desired initiation TTC range.

- The lateral velocity of the SV, assessed 250 ms after exiting the curve used to define the SV path deviation, was ± 0.3 ft/s (± 0.1 m/s) of the desired lateral velocity.
- The turn signal (where applicable) was activated within ± 0.5 s of the desired SV-to-POV longitudinal TTC.
- For crash-imminent scenarios, the SV's path was ± 0.8 ft (± 0.25 m) of the desired path until steering was released.
- For false positive scenarios, the SV's path was ± 0.8 ft (± 0.25 m) of the desired path until 5 seconds after the lane change was complete.
- Should the OTSA not intervene or do so in a way that it would not prevent a collision, the steering robot abort activation occurred when the lateral position of the SV was ≤1.5 ft (0.46 m) of the POV.

2.7 OTSA System Performance Evaluation

In addition to confirming that the test validity criteria described in Section 2.6 could be satisfied, the ability of the SV's OTSA system to satisfy the performance criteria specified in NHTSA's September 2019 OTSA draft research test procedure were analyzed.

For crash-imminent scenarios:

- The lateral proximity of the SV to the POV was to be >1.5 ft (0.46 m) within the validity period.
- If an OTSA intervention occurred, it was not permitted to cause the SV to travel ≥ 1 ft (0.3 m) beyond the inboard edge of the lane line separating the SV travel lane from one adjacent and to the right of it within the validity period during any valid test.

For false positive scenarios, an OTSA system intervention was not allowed to occur within the OTSA Scenario 4 or 5 validity period.

3 Test Results

Scenarios 1, 2, and 4 test results for the Mercedes E300 are described in Sections 3.1, 3.2, and 3.3. Observations or issues pertaining to test conduct are discussed further in Chapter 4.

3.1 OTSA Scenario 1

OTSA Scenario 1 was a crash-imminent drift scenario. Tests were performed in automation level 0 for all SV-POV speed combinations, and in automation level 1 for tests performed with a nominal SV speed of 45 mph (72.4 km/h). Results for this scenario are presented in **Table 3-1**.

Of the 15 trials performed, only two had OTSA activations (indicated by the SV deceleration presented in **Figures 3-1** and **3-2**), but neither was enough to prevent the left edge of the SV from coming within 1.5 ft (0.46 m) of the left edge of the POV. In other words, the SV robotic steering controller performed evasive maneuvers to avoid the POV during all Scenario 1 trials, regardless of whether the SV OTSA system was activated.

Table 3-1. OTSA Scenario 1 Results

Automation Level	SV_POV Speed	OTSA Activations	Average TTC at OTSA Activation (sec)	SR Abort
0	25_25 mph[1] (40.2_40.2 km/h)	0/3	--	3/3
	45_25 mph (72.4_40.2 km/h)	0/3	--	3/3
	45_45 mph (72.4_72.4 km/h)	1/3	2.6	3/3
1	45_25 mph (72.4_40.2 km/h)	0/3	--	3/3
	45_45 mph (72.4_72.4 km/h)	1/3	2.6	3/3

[1] Test performed below the Mercedes E300 OTSA operational threshold speed. As such, these tests were conducted to verify the test condition could be performed, not to evaluate system performance.

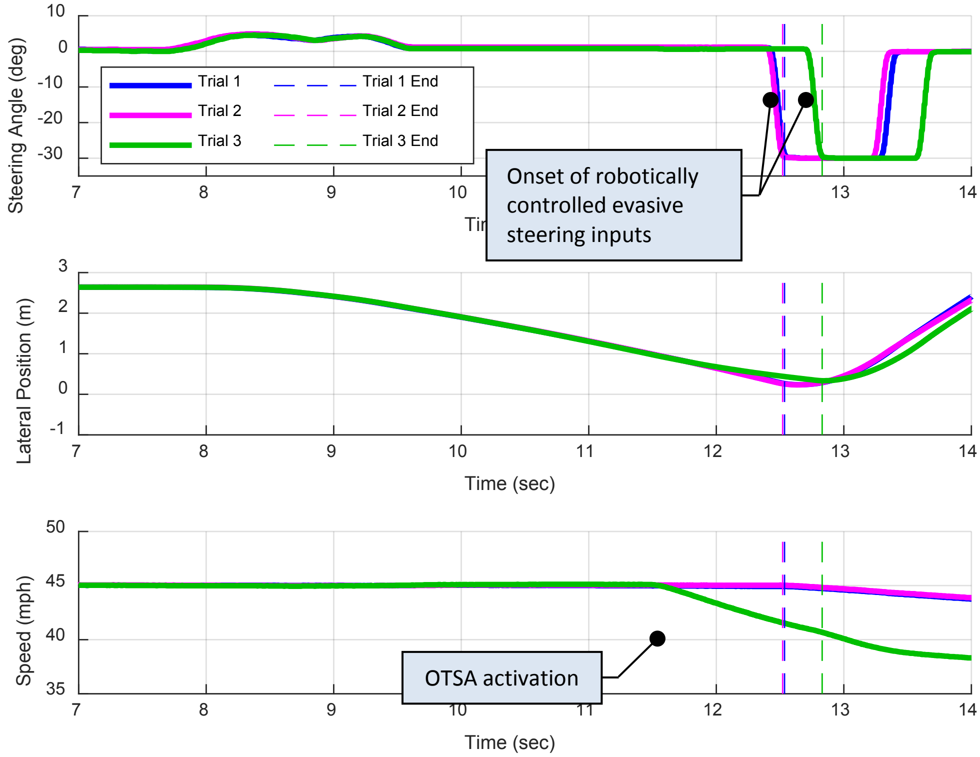

Figure 3-1. Scenario 1 automation level 0 45_45 mph (72.4_72.4 km/h) SV state comparison.

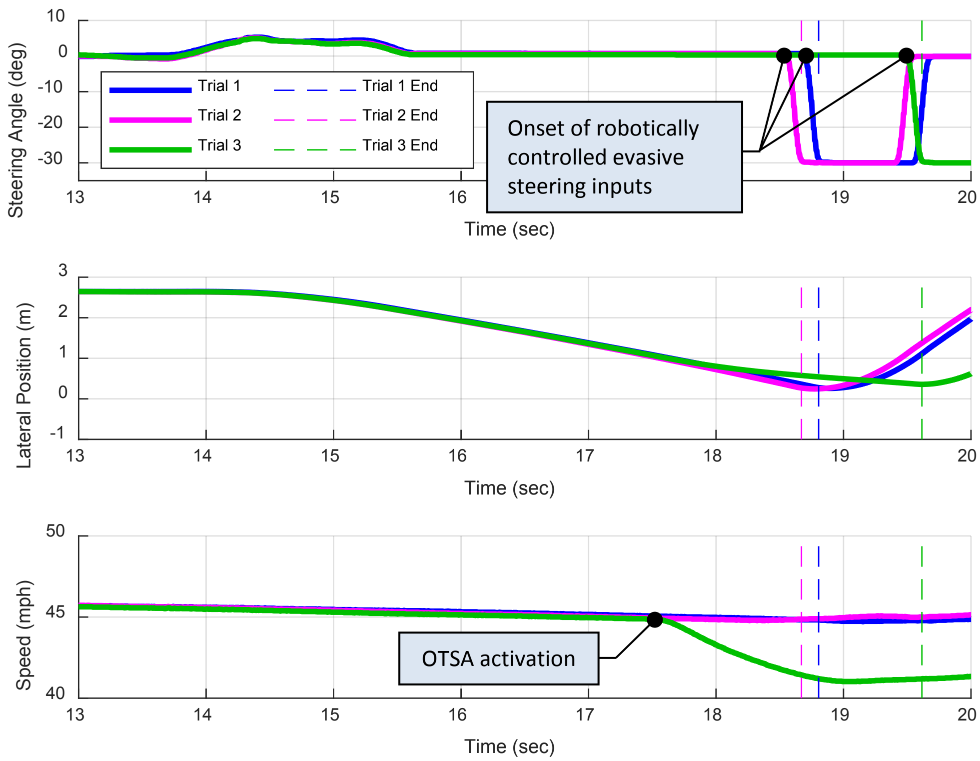

Figure 3-2. Scenario 1 automation level 1 45_45 mph (72.4_72.4 km/h) SV state comparison.

No OTSA observations were observed during trials performed with an SV speed of 25 mph (40.2 km/h), which was expected since that speed was outside the operational speed range defined in the owner's manual. The two OTSA activations occurred during the 45_45 mph (72.4_72.4 km/h) tests, once at each level of automation. The TTC for both trials with OTSA activations was consistent at 2.6 seconds.

3.2 OTSA Scenario 2

OTSA Scenario 2 was a crash-imminent, single lane change scenario with driver intent conveyed via use of the SV turn signal and a higher lateral velocity than used during OTSA Scenario 1. OTSA Scenario 2 the test results are presented in **Table 3-2**.

Tests were performed in automation level 0 for all speed combinations, and in automation level 1 for tests performed with an SV speed of 45 mph (72.4 km/h). Although NHTSA's OTSA draft research test procedure specifies that the Scenario 2 lateral deviations shall be preceded by activation of the SV turn signal, initial testing revealed it was unlikely that the OTSA system would intervene if the turn signal was activated, which was consistent with the language provided in the Mercedes E300 owner's manual. For this reason, only the 25_25 mph (40.2_40.2 km/h) tests were performed with a turn signal activation. The rationale for this was twofold: (1) the test protocol could be evaluated as stated in the test procedure, and (2) no OTSA intervention was expected to occur since the SV speed was lower than the system's operational threshold.

Since Mercedes E300 OTSA interventions are suppressed when the turn signal is used, and the 25_25 mph (40.2_40.2 km/h) tests were performed as defined in the draft test procedure, the remaining Scenario 2 speed combinations, 45_25 mph (72.4_40.2 km/h) and 45_45 mph (72.4_72.4 km/h), were performed without SV turn signal activations. Although this was a deviation from the protocol explicitly defined in the draft procedure, the adjustment was made for the work described in this report to help facilitate observation of the SV's OTSA system operation and effectiveness.

Table 3-2. OTSA Scenario 2 Results

Automation Level	SV_POV Speed	OTSA Activations	Average TTC at OTSA Activation (sec)	SR Abort
0	25_25 mph[1] (40.2_40.2 km/h)	0/3	--	3/3
	45_25 mph[2] (72.4_40.2 km/h)	1/3	1.8	3/3
	45_45 mph[2] (72.4_72.4 km/h)	2/3	1.9	3/3
1	45_25 mph[2] (72.4_40.2 km/h)	0/3	--	3/3
	45_45 mph[2] (72.4_72.4 km/h)	0/3	--	3/3

[1] Test performed below the Mercedes E300 OTSA operational threshold speed. As such, these tests were conducted to verify the test condition could be performed, not to evaluate system performance.

[2] SV turn signal not activated during these trials.

Three OTSA activations occurred during evaluations using Scenario 2, and each occurred when the SV was operated in automation level 0; during one 45_25 mph (72.4_40.2 km/h) trial (**Figure 3-3**), and during two 45_45 mph (72.4_72.4 km/h) trials (**Figure 3-4**). Despite these activations, all trials resulted with the left edge of the SV coming within 1.5 ft (0.46 m) of the left edge of the POV, therefore requiring the robotic steering controller to perform its automated evasive maneuver in each case.

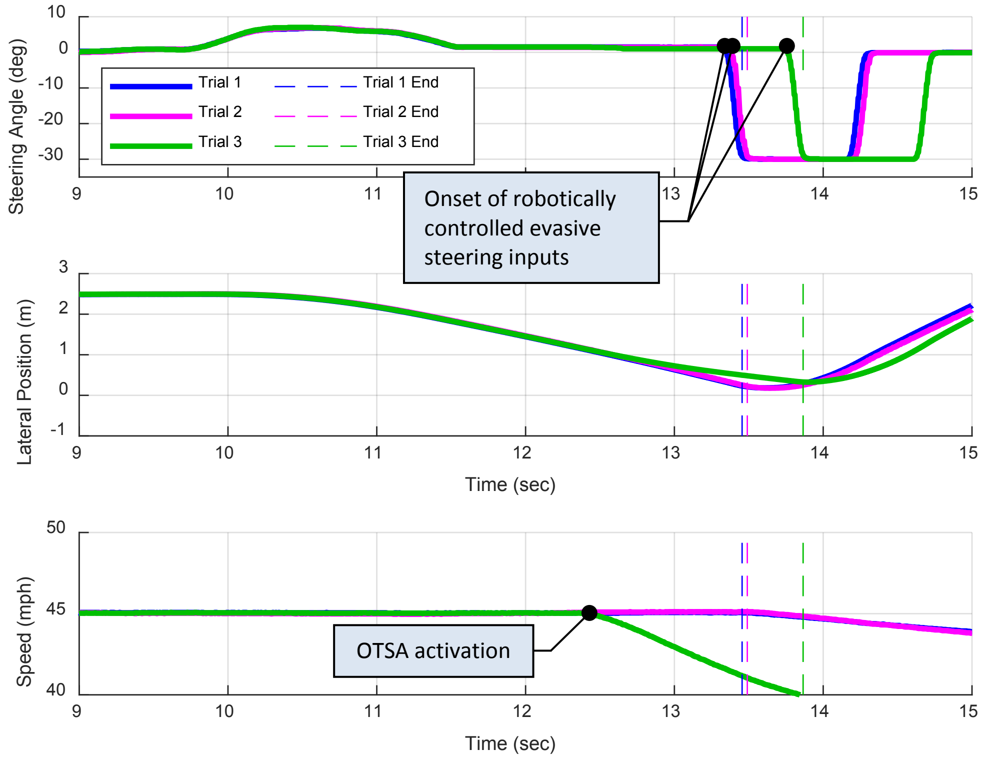

Figure 3-3. Scenario 2 automation level 0 45_25 mph (72.4_40.2 km/h) SV state comparison.

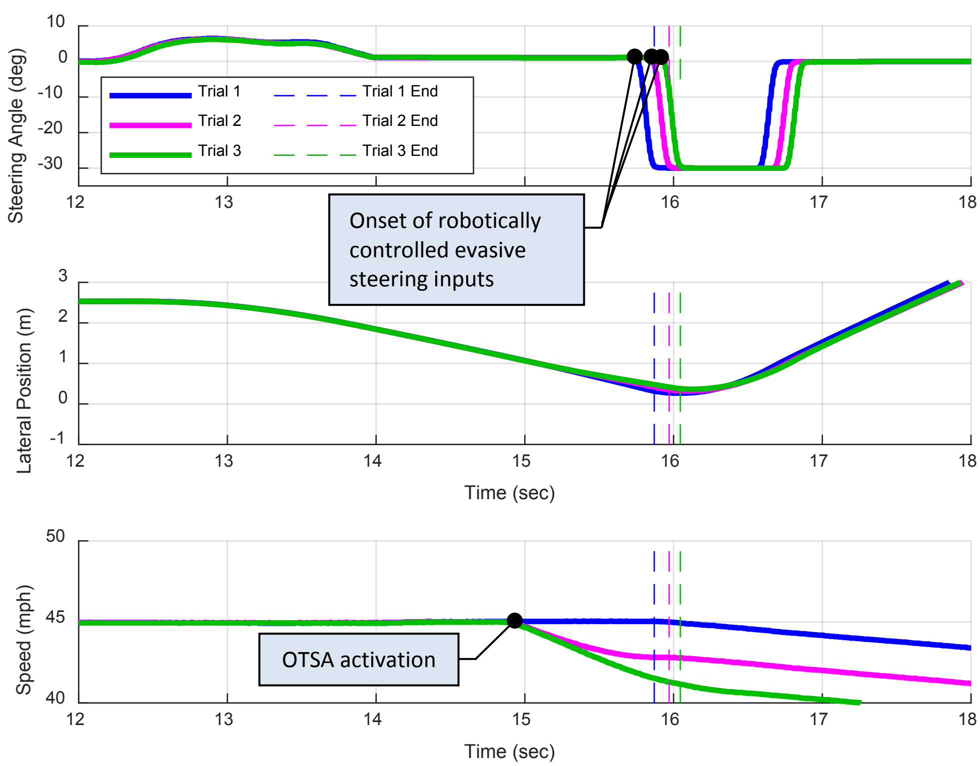

Figure 3-4. Scenario 2 automation level 0 45_45 mph (72.4_40.2 km/h) SV state comparison.

3.3 OTSA Scenario 4

OTSA Scenario 4 was a false positive scenario comprised of a single, intentional lane change performed with a lateral velocity, assessed as the SV crosses the left line of the initial travel lane, equivalent to that used in OTSA Scenario 2.

Automation level 0 was used for all speed combinations, however only the lane changes performed at 25_25 mph (40.2_40.2 km/h) were preceded by a turn signal activation. Once again, since the Mercedes E300 OTSA operational threshold speed was greater than 25 mph (40.2 km/h), no OTSA activation was expected. Therefore, these tests were only used to verify the test condition could be performed, not to evaluate system performance. Since the Mercedes E300 owner's manual indicated the system would not operate if the turn signal was activated, it (the turn signal) was not used during the OTSA Scenario 4 tests performed with the 45_25 mph (72.4_40.2 km/h) and 45_45 mph (72.4_72.4 km/h) speed combinations. **Table 3-3** shows the results for OTSA Scenario 4.

Table 3-3. OTSA Scenario 4 Results

Automation Level	SV_POV Speed	OTSA Activations	OTSA False Positives
0	25_25 mph[1] (40.2_40.2 km/h)	0/3	0/3
	45_25 mph[2] (72.4_40.2 km/h)	0/3	0/3
	45_45 mph[2] (72.4_72.4 km/h)	2/3	1/3[3]

[1] Test performed below the Mercedes E300 OTSA operational threshold speed. As such, these tests were conducted to verify the test condition could be performed, not to evaluate system performance.

[2] SV turn signal not activated during these trials.

[3] Two trials observed brake applications by the Mercedes E300, however, only one was deemed a false positive activation.

Two OTSA-based brake applications were observed during the false positive evaluations, however, only one induced an SV yaw rate great enough to satisfy the false positive classification threshold.

OTSA activations were not anticipated during the conduct of OTSA Scenario 4 trials, as the scenario was designed to be a false positive assessment. The tests performed at 25_25 mph (40.2_40.2 km/h) and 45_25 mph (72.4_40.2 km/h) did not have any apparent OTSA activations. The third speed configuration, 45_45 mph (72.4_72.4 km/h), had OTSA brake applications during 2 of the 3 trials performed, however, they only induced an SV yaw rate great enough to satisfy the false positive classification threshold, described previously in Section 2.5.4.1, during one trial (albeit by only one data count, as shown in **Figure 3-5**).

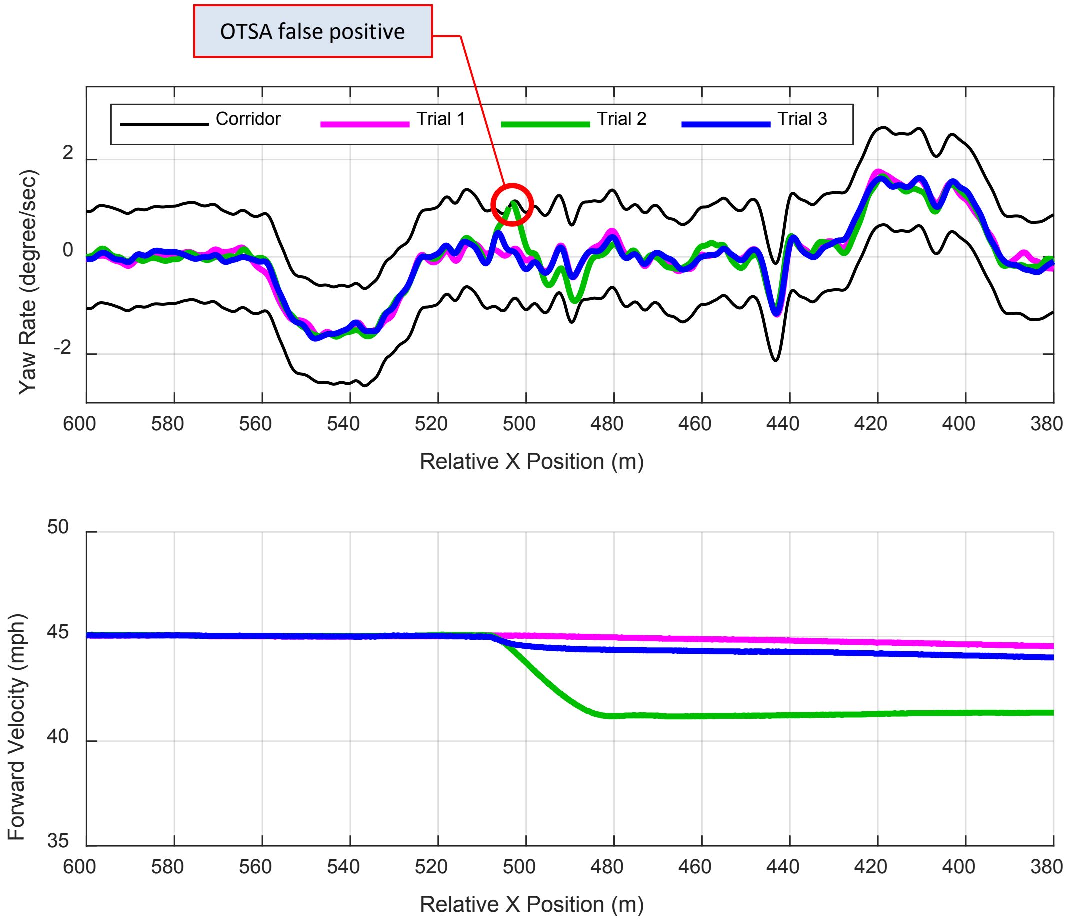

Figure 3-5. SV yaw rates used for OTSA false positive assessment. SV forward velocity is provided for reference purposes.

4 Test Validity Criteria and Other Testing Issues

Satisfying all validity criteria listed in Section 2.6, for each scenario/automation level/speed condition, was not always possible for each trial. **Table 4-1** presents an overview of the validity check failures observed during data post processing, while the Appendix provides results from the complete validity assessment. The ability to satisfy all validity criteria, and some of the other the issues pertaining to test conduct described in this section, are believed to be reconcilable, but could not be resolved during the test effort described in this report due to testing time and resource constraints.

Table 4-1. Test Validity Check Failures

Scenario	Automation Level	SV_POV Speed	Validity Criteria
1	0	25_25 mph (40.2_40.2 km/h)	None
		45_25 mph (72.4_40.2 km/h)	LV speed, SV-LV headway
		45_45 mph (72.4_72.4 km/h)	POV and LV speeds, SV-LV headway
	1	45_25 mph (72.4_40.2 km/h)	LV speed
		45_45 mph (72.4_72.4 km/h)	POV speed, SR abort distance
2	0	25_25 mph (40.2_40.2 km/h)	None
		45_25 mph (72.4_40.2 km/h)	LV speed, SV-LV headway
		45_45 mph (72.4_72.4 km/h)	SR abort distance, LV speed, SV-LV headway
	1	45_25 mph (72.4_40.2 km/h)	None
		45_45 mph (72.4_72.4 km/h)	POV speed
4	0	25_25 mph (40.2_40.2 km/h)	LV speed, SV-LV headway
		45_25 mph (72.4_40.2 km/h)	POV speed
		45_45 mph (72.4_72.4 km/h)	None

4.1 Achieving Steady State Speeds During High-Speed Trials

One of the challenges observed while completing test trials performed with high longitudinal speeds was the distance required to allow for the SV, POV, and the LV to achieve and maintain steady state speeds. This required a significant length of the test track, over 2,500 ft (762 m). Also, a clear line of sight was needed to facilitate synchronized system communication among the various robotic controllers and the LPRV, and the higher speed trials tested the limit of the communication equipment's range.

Due to these communication issues, achieving three seconds of steady state POV speed prior to the initiation of the SV lane change did not occur for several tests, as shown in **Table 4-1**. The 45_45 mph (72.4_72.4 km/h) Scenario 1 trials, the 45_45 mph (72.4_72.4 km/h) Scenario 2 trials performed in automation level 1, and the 45_25 mph (72.4_40.2 km/h) Scenario 4 trials all had POV speed validity failures.

4.2 Early Evasive Steering Trigger

Other validity criteria failures involved the automated evasive maneuver performed by the robotic steering controller. As described in Section 2.6, this maneuver was to be automatically executed if the lateral distance between the SV and POV fell below 1.5 ft (0.46 m). However, for two of the five trials with OTSA activations, the evasive maneuver began too early. For Scenario 1, this occurred once during the 45_45 mph (72.4_72.4 km/h) test performed in automation level 1, where the evasive steering was initiated approximately 8 in. (20.3 cm) earlier than programmed. This resulted in the SV not achieving the minimum SV-to-POV lateral distance by 2 in. (5.1 cm). For one 45_45 mph (72.4_72.4 km/h) Scenario 2 test performed in automation level 0, the evasive steering maneuver occurred 7 in. (17.8 cm) too early, which resulted in the SV not achieving the minimum SV-to-POV lateral distance by 1 in. (2.5 cm). At the time this report was written, it was unclear why these anomalies occurred.

4.3 SV-LV Synchronization

For tests performed with the SV operating in automation level 0, the LV was equipped with a robotic throttle controller intended to establish and maintain the desired SV-to-LV headway via closed loop control. However, during test trials performed at the higher speeds, it was observed that the LV had difficulty maintaining this parameter. Additionally, the LV also had difficulty maintaining the desired speed.

Testing revealed LV drive mode was one contributing factor to this problem. Early tests were performed with the LV operating in "Comfort" mode, whereas later tests used a more responsive "Dynamic" mode. While this difference alone did not fully resolve the occurrence of SV-to-LV headway and LV speed validity check failures, it did reduce the magnitude of the validity violation. **Figure 4-1** demonstrates this by presenting a sample of six SV-to-LV headway traces, three with the LV in Comfort mode, three in Dynamic mode. In this example, the Comfort mode tests were performed in Scenario 2 with automation level 0 and SV-LV speeds of 45_25 mph (72.4_40.2 km/h), and the Dynamic mode tests were performed in Scenario 4 with automation level 0 and SV-LV speeds of 45_45 mph (72.4_72.4 mph). The trials performed in Dynamic mode were more accurately and consistently able to maintain the desired headway of 98.4 ft (30 m).

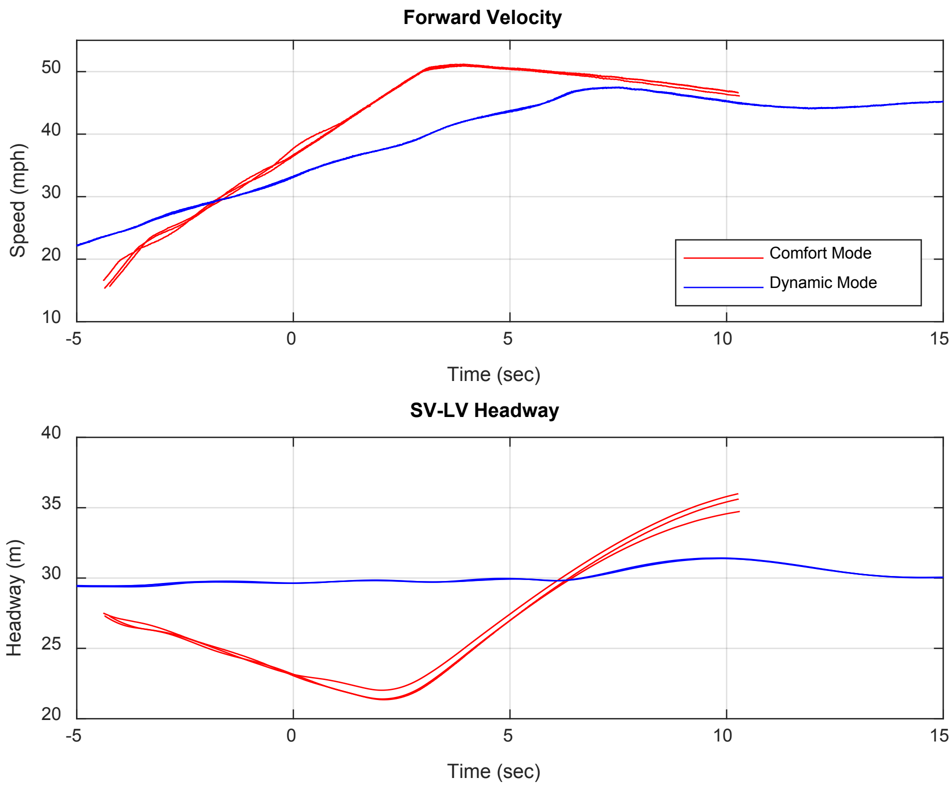

Figure 4-1. SV-LV speed and headway comparison: LV operating in comfort vs. dynamic mode.

That said, the second set of trials performed with the LV operating in Dynamic mode, Scenario 2 45_45 mph (72.4_72.4 km/h) tests performed in automation level 0, were still unable to have LV speed and SV-LV headway meet the validity criteria as outlined in Section 2.6. In an attempt to practically resolve this without affecting maneuver severity, these parameters were averaged over the validity period, and then compared to the applicable test tolerances (i.e., rather than considering individual data points).

- When LV speed was averaged over the validity period, the average value was within the valid range for each trial.
- When the averaging process was applied to SV-LV headway data, it was still unable to meet the desired value of 98.4 ± 3.3 ft (30 ± 1 m) within the validity period, although the reported error was less.
- The best SV-LV headway result was achieved using the combination of the LV operating in Dynamic mode and averaging the data channel over the validity period. Using this process, the average headways from 45_45 mph (72.4_72.4 km/h) tests performed in Dynamic mode ranged from 102.7 to 104.0 ft (31.3 to 31.7 m), versus the average 108.3 to 110.9 ft (33.0 to 33.8 m) headways observed during 45_25 mph (72.4_40.2 km/h) tests performed in Comfort mode.

5 Other OTSA Draft Test Procedure Considerations

Some questions regarding OTSA test conduct and system operation arose while the work described in this study was performed. Consideration of how best to resolve these questions may be an opportunity for further OTSA research. Some of these topics are discussed in this section.

5.1 Subject Vehicle Turn Signal Application

NHTSA's draft OTSA research test procedure assumes the system will operate with or without a turn signal application. However, this was not the case for the Mercedes E300. Additional research may be needed to determine whether specifying that an OTSA system shall operate after the turn signal has been activated (e.g., when a driver signals they are about to overtake a vehicle traveling ahead of them) is too prescriptive. Should this be the case, a potential revision could be to allow OTSA tests be performed with, or without, the turn signal being activated during conduct of the tests described in draft OTSA research test procedure.

5.2 Automation Level 2 and 3 Test Timing

Compared to those performed in automation levels 0 or 1, tests performed in automation levels 2 or 3 present unique challenges. In the context of OTSA test conduct, this becomes apparent when considering the time between SV turn signal activation and when the SV initiates its heading deviation (OTSA Scenario 3) or lane change (OTSA Scenario 5). Although the SV turn signal is activated by its driver with the same timing regardless of automation level, the response parameters are vehicle dependent. Importantly, these include:

- The time between turn signal activation and when the SV physically initiates lateral motion (which may, or may not, impose crash-imminent timing relative to the POV).
- The SV path during its lateral deviation from its initial travel lane (which also affects maneuver severity since the automated SV path towards the POV may, or may not, be crash-imminent).

Assessing the extent to which these factors may affect test outcome was not possible due to the Mercedes E300 operational constraints (the vehicle would not perform automated lane changes at the test track location where the OTSA evaluations were performed), however if the topic is of interest to the agency, it may be a topic of future research.

5.3 LV Selection and Synchronization

Challenges in satisfying headway and speed validity criteria highlighted the need for careful selection and tuning of the LV. To achieve the SV-to-LV headway and LV speed necessary for these tests, an LV that is responsive to quick inputs by throttle applications appears to be important. This was demonstrated by the improvement in test performability realized by switching from Comfort to Dynamic mode in the Volvo S90 LV, as discussed in Section 4.3.

Adjustments to the draft test procedure could also be used to improve the ability to satisfy SV-to-LV headway and LV speed within the validity period without profoundly affecting maneuver severity. Specifically,

- Average LV speed could be used over the validity period, and/or
- The SV-to-LV headway tolerance could be increased slightly.

5.4 Interaction Between the Robotically Controlled Evasive Maneuver and OTSA Interventions

Though necessary for safe test conduct, the robotically controlled and automatically initiated evasive steering maneuver away from the POV may potentially impede observation of the SV's OTSA operation and/or effectiveness if the system is designed to only react to the POV at a proximity that occurs after the evasive maneuver initiation criteria of <1.5 ft (0.46 m) is satisfied. In other words, it may not be possible to accurately evaluate the SV's OTSA system capabilities if the robotic evasive steering maneuver occurs before the system is designed to intervene. For this reason, better understanding the interaction between the SV steering robot's automatically controlled evasive maneuver and the vehicle's OTSA operation may be of interest.

6 Conclusion

The work described in this report was performed to confirm that the test methodology specified in NHTSA's September 2019 OTSA draft test procedure is well-defined, capable of eliciting OTSA activations, and able to be accurately performed.

Of the 30 crash-imminent test trials, 5 had OTSA activations. However, since none of these activations could prevent the SV from being within 1.5 ft (0.46 m) laterally from the POV, an evasive steering maneuver was automatically (and successfully) executed by the SV's robotic steering controller during each of these test trials. For false positive tests, OTSA-based brake applications were observed during 2 of the 9 trials performed, however, they only induced an SV yaw rate great enough to satisfy the false positive classification threshold during one.

Difficultly in satisfying some of the validity criteria specified in the September 2019 OTSA draft test procedure due to problems related to the test equipment operation was observed during some trials.

- Poor SV-to-POV communication, which was particularly apparent during trials performed with 45_45 mph (72.4_72.4 km/h) test speeds, sometimes occurred due to the long distance initially present between the vehicles. Bringing the vehicles closer to one another helped alleviate this condition, however the adjustment also prevented at least 3 seconds of steady state operation being realized before the SV lateral deviation had to be initiated.
- The robotic steering controller initiated the evasive maneuver prior to the SV reaching the desired activation threshold of 1.5 ft (0.46 m) away from the POV during 2 trials.
- When configured to operate with a less responsive LV accelerator pedal, the robotic accelerator controller was unable to consistently deliver the desired SV-to-LV headway and LV speed within the validity period up to the onset of the SV lateral deviation.

Although additional time and resources were unavailable to demonstrate resolution of these issues in this report, NHTSA expects they are reconcilable, and may be the subject of future research and documentation.

The work discussed in this study identified several considerations for further OTSA research. First, exploration into better understanding the safety considerations of having turn signal activation suppressing an OTSA intervention is needed (although from a testing perspective, minor revisions to the draft test procedure could be made to accommodate such systems). Second, evaluations performed with SVs capable of performing automated lane changes when operating in automation levels 2 or 3 are needed to better understand how the vehicle-dependent parameters of lateral deviation onset timing and path affect maneuver severity. Third, adjustments to the tolerances pertaining to SV-to-LV headway and LV speed validity requirements may be explored. Finally, a discussion about the appropriateness of automatically initiating a robotically controlled evasive steering maneuver when the lateral distance between the SV and POV becomes less than 1.5 ft (0.46 m), even if the OTSA system has been activated, is needed.

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8 Appendix

The following sections contain validity checks for the testing described in this report.

8.1 Scenario 1 Validity Checks

Auto. Level	SV-POV Speeds	Trial	SV Speed	POV Speed	LV Speed	SV Yaw Rate	SV Lateral Offset	POV Lateral Offset	LV Center	SV-LV Headway	Lane Change TTC	Lateral Velocity	Turn Signal	SV Path	SR Abort
0	25_25	1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass
		2	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass
		3	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass
	45_25	1	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
		2	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
		3	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
	45_45	1	Pass	Fail	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
		2	Pass	Fail	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
		3	Pass	Fail	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
1	45_25	1	Pass	Pass	Fail	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass
		2	Pass	Pass	Fail	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass
		3	Pass	Pass	Fail	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass
	45_45	1	Pass	Fail	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Fail
		2	Pass	Pass	Pass	Pass	Pass	Pass	Fail	n/a	Pass	Pass	n/a	Pass	Pass
		3	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass

8.2 Scenario 2 Validity Checks

Auto. Level	SV-POV Speeds	Trial	SV Speed	POV Speed	LV Speed	SV Yaw Rate	SV Lateral Offset	POV Lateral Offset	LV Center	SV-LV Headway	Lane Change TTC	Lateral Velocity	Turn Signal	SV Path	SR Abort
0	25_25	1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
		2	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
		3	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
	45_25	1	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
		2	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
		3	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
	45_45	1	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	False
		2	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
		3	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	n/a	Pass	Pass
1	45_25	1	Pass	Fail	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass
		2	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass
		3	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass
	45_45	1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass
		2	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass
		3	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	Pass	n/a	Pass	Pass

8.3 Scenario 4 Validity Checks

Auto. Level	SV-POV Speeds	Trial	SV Speed	POV Speed	LV Speed	SV Yaw Rate	SV Lateral Offset	POV Lateral Offset	LV Center	SV-LV Headway	Lane Change TTC	Lateral Velocity	Turn Signal	SV Path	SR Abort
0	25_25	1	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a
		2	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a
		3	Pass	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass	Pass	n/a
	45_25	1	Pass	Fail	Pass	Pass	Pass	Pass	Fail	Pass	Pass	Pass	n/a	Pass	n/a
		2	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	n/a
		3	Pass	Fail	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	n/a
	45_45	1	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	n/a
		2	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	n/a
		3	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	n/a	Pass	n/a

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