DRAFT TEST PROCEDURE. ASSEMBLED FOR DISCUSSION PURPOSES ONLY.

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Traffic Jam Assist System Confirmation Test

(Working Draft)

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16. Abstract

This draft test procedure provides specifications used by the National Highway Traffic Safety Administration to research traffic jam assist (TJA) system performance on light vehicles with gross vehicle weight ratings (GVWR) of up to 10,000 lbs (4,536 kg). The expected operating domain for TJA includes roadways supporting low speed and stop-and-go traffic. Examples include residential and urban roads, and highways during times of high congestion and reduced operating speed.

The test procedures described in this document use a series of low-speed car-following and crash-imminent driving scenarios to assess TJA operation. In this assessment, the SV shall detect and respond to a principal other vehicle (POV) and a secondary other vehicle (SOV), where applicable.

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TRAFFIC JAM ASSIST SYSTEM CONFIRMATION TEST

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GLOSSARY

ACC	adaptive cruise control
ASTM	formerly known as the American Society for Testing and Materials, and as ASTM International since 2001
GVT	Global Vehicle Target
GVWR	gross vehicle weight rating
LCC	lane centering control
lidar	light detection and ranging
LV	lead vehicle
LVDAD	lead vehicle decelerates, accelerates, then decelerates
LVLCB	lead vehicle lane change with braking
MUTCD	Manual on Uniform Traffic Control Devices
PFC	peak friction coefficient
POV	principal other vehicle
SAE	formerly known as the Society of Automotive Engineers, and as SAE International since 2006
SOV	secondary other vehicle
SRSV	suddenly revealed stopped vehicle
SV	subject vehicle
TJA	traffic jam assist

REVISION HISTORY

Date	Revision
04/09/2018	Original draft
03/22/2019	• Minor typographical corrections • The number of test speed combinations per scenario has been reduced from 4 to 2. Tests performed with the SV initially travelling at 10 or 20 mph (16.1 or 32.1 km/h) have been removed to reduce unnecessary test burden. The remaining tests are performed with the SV initially traveling at 15 or 25 mph (24.1 or 40.2 km/h). • The ACC headway specified in in S5.3.2 has been changed to the farthest setting (i.e., that which would provide the longest following distance when a lead vehicle is present ahead of the SV in its travel lane). • POV yaw rate tolerances have been removed. Extensive testing has demonstrated that satisfying a ±1 deg/s criteria with the GST does not appear to be possible. Since the POV must still satisfy a lateral tolerance of ±0.8 ft (0.25 m) during the test validity period, this change is not expected to confound the test results or affect the test outcome. • The time tolerance required by the POV to achieve the desired deceleration and acceleration magnitudes during the LVDAD tests specified in S5.3.5 has been changed to “within 0.5 s.” • The SOV-to-POV headway at the onset of the POV reveal used during the SRSV tests (i.e., when the SOV lane change is initiated) has been increased from 35 ft (10.7 m) to 40 ft (12.2 m). • An “SOV lane change onset” threshold of 0.03 g (0.3 m/s^2) has been added to the SRSV tests specified in S5.3.6.1. • A “POV lane change onset” and “completion of POV lane change” thresholds of 0.03 g (0.3 m/s^2) have been added to the LVLCB tests specified in S5.3.7.1. • The SV-to-POV longitudinal headway from the onset of the validity period to initiation of the POV lane change has been reduced from 35 ft (10.7 m) to 24.9 ft (7.5 m) for the LVLCB tests performed without POV braking during the lane change. This change is intended to eliminate the potential for the front of the POV striking the rear of the SOV during the POV lane change. • All steady state validity criteria have been changed from 5 seconds to 3 seconds. • In section 5.3.5.2 and the SV speed requirement changed from “equivalent” to “within 1 mph” to that of the POV. • In sections 5.3.6.2 and 5.3.7.2 the SV speed requirement changed from “equivalent” to “within 1 mph” to that of the SOV. • Where specified, the nominal POV deceleration used in the LVAD and LVLCB scenarios has been reduced from 0.6 to 0.5 g.

1.0 PURPOSE AND APPLICATION

This draft test procedure provides specifications used by the National Highway Traffic Safety Administration to research traffic jam assist (TJA) system performance on light vehicles with gross vehicle weight ratings (GVWR) of up to 10,000 lbs (4,536 kg). The expected operating domain for TJA includes roadways supporting low speed and stop-and-go traffic. Examples include residential and urban roads, and highways during times of high congestion and reduced operating speed.

The tests contained in this document are intended for evaluation of SAE automation level 2 or 3 vehicles that use sensors such as radar, cameras, and/or lidar to detect nearby objects. Although it is impossible to predict what technologies could be used by future TJA systems (e.g., vehicle-to-vehicle communication), it is believed that modifications to these procedures, when deemed appropriate, could be used to accommodate the evaluation of (1) alternative or more advanced TJA systems, and/or (2) higher level automated vehicles.

Note: *The subject vehicle (SV) driver shall not provide manual inputs to the accelerator pedal, brake pedal, or steering wheel when the tests described in this document are performed within the applicable validity periods. This provision is intended to eliminate the potential for TJA operation from being unintentionally affected by the SV driver while tests are being safely performed within the controlled confines of a test track, and does not constitute an endorsement by NHTSA for drivers to remove their hands from the steering wheel while operating their vehicle on public roads.*

Note: *At the time this document was written, no production vehicle was equipped with steer-to-avoid capability regardless of whether they were designed to operate in SAE automation level 2 or 3 at the speeds described herein. For this reason, the tests described in this document have not been designed to allow/accommodate this capability. However, as it becomes available on future production vehicles, NHTSA will consider revising the evaluation criteria to accommodate the additional crash avoidance functionality.*

2.0 GENERAL REQUIREMENTS

The test procedures described in this document use a series of low speed car-following and crash-imminent driving scenarios to assess TJA operation. In this assessment, the SV shall detect and respond to a principal other vehicle (POV) and a secondary other vehicle (SOV), where applicable. At no time shall the SV contact the POV and/or SOV during the conduct of any trial described in this document.

3.0 DEFINITIONS

In the context of this document, TJA is a driver assistance system capable of automatically controlling the lateral position of the SV within its travel lane while simultaneously and automatically establishing and maintaining a constant longitudinal headway behind the vehicle immediately ahead of it at speeds up to 25 mph (40 km/h).

4.0 PRETEST AND FACILITY REQUIREMENTS

4.1 Road Test Surface

The road test surface used for the tests described in this document shall be dry (without visible moisture on the surface), straight, and flat, with a consistent slope between level and one percent. The road surface shall be constructed from asphalt or concrete and shall be free of irregularities, undulations, and/or cracks that could cause the SV to pitch excessively. The surface shall be free of excessive tire skid marks, pavement seam sealer, and/or other high-contrast surface markings that could potentially confound lane line identification and/or tracking.

The road test surface must produce a peak friction coefficient of at least 0.9 when measured using ASTM E1136 standard reference test tire, in accordance with ASTM Method E 1337-90, at a speed of 64.4 km/h (40 mph), without water delivery [1]. The test track PFC shall be documented.

4.2 Line Markings

The tests described in this document are comprised of three scenarios. The lead vehicle decelerates, accelerates, then decelerates scenario requires one straight travel lane. Performing the suddenly revealed stopped vehicle and lead vehicle lane change with braking scenarios requires two straight travel lanes. The lines used to delineate each lane shall meet Federal Highway Administration standards and guidelines specified in the Manual on Uniform Traffic Control Devices (MUTCD) and be considered in "very good condition" [2].

4.2.1 Lane Line Styles

The tests described in this document use a combination of discontinuous dashed white and solid white lane lines. Details about which lines to use within a given scenario, and where they should be located, are shown in Figures 1, 2, 3, and 4 provided in S5.3.5, S5.3.6, and S5.3.7, respectively.

4.2.2 Line Marking Color and Reflectivity

Lane line marker color and reflectivity shall meet all applicable standards. These standards include those from the International Commission of Illumination for color and the ASTM on lane marker reflectance. Methods for determining lane marker characteristics are discussed in the road departure crash warning systems field operational test by the National Institute of Standards and Technology [3].

4.2.3 Line Marker Width

The width of the edge line marker shall be 4 to 6 in (10 to 15 cm). This is a normal width for longitudinal pavement markings under Section 3A.05 of the MUTCD [2].

4.3 Lane Width

Each lane required by this test procedure shall be delineated with two lane lines. Measured from inside edge to inside edge, these lines shall be spaced 12 to 14 ft (3.7 to 4.3 m) apart.

4.4 Ambient Conditions

4.4.1 Ambient Temperature

The ambient temperature shall be between 45°F (7°C) and 104°F (40°C).

4.4.2 Wind Speed

The maximum wind speed shall be no greater than 22 mph (35 km/h).

4.4.3 Inclement Weather

Tests should not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash.

4.4.4 Visibility

The tests shall be conducted during daylight hours with good atmospheric visibility defined as an absence of fog and the ability to see clearly for more than 3 miles (4.8 km). Tests shall not be conducted with the vehicle oriented into the sun during very low sun angle conditions, where the sun is oriented 15 degrees or less from horizontal and potential camera "washout" or system inoperability could result.

4.5 Principal Other Vehicle and Secondary Other Vehicle Specifications

To safely perform the tests described in this document, the POV shall be a realistic surrogate vehicle. For the tests that also require use of a SOV, the SOV may be either (1) another realistic surrogate vehicle, or (2) an actual (i.e., real) passenger car that satisfies the specifications described in S4.5.2.

4.5.1 Surrogate Vehicles

Surrogate vehicles suitable for the tests described in this document shall have the characteristics of a compact passenger car. This is intended to maximize the ability of the SV to detect the POV (and SOV, where applicable) in the most realistic manner possible without compromising SV driver safety and minimizing the potential for SV damage. An appropriate surrogate vehicle must possess the following attributes:

A. Accurate physical characteristics (e.g., visual, dimensional) when viewed from any approach angle
   i. Body panels and rear bumper shall be white in color.
   ii. Simulated body panel gaps shall be present.
   iii. The simulated rear glass and tires shall be dark gray or black.
   iv. A rear-mounted United States-specification license plate, or reflective simulation thereof, shall be installed.
B. Reflective properties representative of a high-volume passenger car when viewed from any approach angle by radar (24 GHz and 76-77 GHz bands) and lidar-based sensors.
C. Remains consistently shaped (e.g., visually, dimensionally, internally, and from a RADAR sensing perspective) within each test series.
D. Resistant to damage resulting from repeated SV-to-POV impacts.
E. Inflicts minimal to no damage to the SV, even in the event of multiple impacts.

The test conductor shall present documentation that objectively qualifies how the surrogate vehicle used to perform the tests described in this document satisfies the requirements of S4.5.1.

Note: *NHTSA intends to use the Global Vehicle Target (GVT) as the POV for the tests described in this document [4]. The GVT is a full-sized artificial vehicle designed to appear realistic to the sensors used by automotive safety systems and automated vehicles: radar, camera, and lidar. Appropriate radar characteristics are achieved by using a combination of radar reflective and radar absorbing material within the GVT's vinyl covers. The GVT is dimensionally similar to a 2013 Ford Fiesta hatchback and is secured to a robotic platform using Velcro attachment points. Internally, the GVT consists of a vinyl-covered foam structure. If a test vehicle impacts the GVT at low speed, it is typically pushed off and away from the platform, which is then pushed against the ground and stops as the test vehicle is driven over it. At higher impact speeds, the GVT breaks apart as the SV essentially drives through it. The GVT can be repeatedly struck from any approach angle without harm to those performing the tests or the vehicles being evaluated. Reassembly of the GVT occurs on top of the robotic platform and takes a team of 3 to 5 people approximately 7 to 10 minutes to complete. The robotic platform that supports the GVT is preprogrammed, and allows the GVT's movement to be accurately and repeatedly choreographed with the test vehicle and/or other test equipment required by a pre-crash scenario using closed-loop control.*

4.5.2 Actual Vehicle

If the test conductor uses an actual vehicle as the SOV, it shall be a passenger car between 175 to 197 in (445 to 500 cm) long, and 70 to 76 in (178 to 193 cm) wide measured at the widest part of the vehicle. The color the actual vehicle used as the SOV is unrestricted.

4.6 Instrumentation Required

4.6.1 Sensors and Sensor Locations

An overview of the sensor specifications required for the tests described in this document is provided in Table 1.

4.6.1.1 Vehicle Position

The position of the SV, POV, and SOV (where applicable) relative to their respective travel lanes, and the position of the SV relative to the POV and SOV (where applicable) shall be measured within the test validity period. The sensors used for these measurements are not constrained provided they meet the range, resolution, and accuracy specifications provided in Table 1.

4.6.1.2 Vehicle Speed

The lateral and longitudinal velocities of the SV, POV, and SOV (where applicable) shall be measured within the test validity period. The sensors used for this measurement are not constrained provided they meet the range, resolution, and accuracy specifications provided in

4.6.1.3 Yaw Rate

SV and SOV, where applicable, yaw rate shall be measured. Alternatively, differentially-corrected GPS data may be used to calculate yaw rate in lieu of direct measurement, provided the resulting accuracy is comparable.

4.6.1.4 Vehicle Acceleration

Lateral and longitudinal accelerations of the SV and POV shall be measured within the test validity period, and shall meet the range, resolution, and accuracy specifications provided in Table 1.

4.6.1.5 SV Brake Pedal Force

To ensure that the SV driver did not manually apply the foundation brakes during the test validity period, brake pedal force shall be measured with a single axis load cell securely attached to the SV brake pedal. If the SV driver manually applies force to the brake pedal within the validity period, the test trial is not valid and shall be repeated.

4.6.1.6 SV Accelerator Pedal Position

SV accelerator pedal position shall be measured to ensure that the driver did not manually apply an input during the test validity period. If the driver manually applies an accelerator pedal input within the validity period, the test trial is not valid and shall be repeated. SV throttle pedal position shall be expressed as a percentage of the wide-open throttle pedal position.

4.6.1.7 SV Instructions, Notifications, and/or Alerts

The data acquisition system shall record any visual/audible vehicle instructions, notifications, and/or alerts presented to the driver. Use of a high resolution digital video camera synchronized with the other recorded data channels is recommended for this purpose.

4.6.1.8 Forward Collision Warning Activation Flag

The Forward Collision Warning (FCW) activation flag shall indicate when the system has issued an alert to the SV driver. The FCW modality shall be either the auditory alert, or the alert indicated to the test conductor by a NHTSA representative. The FCW activation flag shall be recorded from a discrete signal and/or other methods that clearly indicate when the alert has been issued.

Table 1 – Recommended Measurements and Measurement Specifications

Type	Output	Range	Resolution	Accuracy
Various	Lateral and Longitudinal position of SV, POV, and SOV	650 ft (200 m)	2 in (5 cm)	At least 3.9 in (10 cm) absolute
Speed Sensors	SV, POV, and SOV lateral and longitudinal velocity	0.1 - 62 mph (0.1 - 100 km/h)	0.1 mph (0.2 km/h)	± 0.25% of full scale range
Rate Sensor	SV and SOV (where applicable) yaw rate	± 100 deg/s	0.01 deg/s	± 0.25% of full scale range
Accelerometers	SV and POV lateral and longitudinal accelerations	± 2g	0.001g	± 0.01% of full scale range
Position Sensors	SV throttle and brake pedal positions	0 - 100 percent (normalized)	0.1 percent	0.1 percent
Load Cell	SV brake pedal force	0 - 300 lbf (1.3 kN)	0.1 lbf (0.4 N)	± 0.05% of full scale range
Steering Wheel Angle Sensor	SV steering wheel angle	± 360 degrees	1 degree	2 degrees
Steering Wheel Torque Sensor	SV steering wheel torque	± 500 lbf·in (56 Nm)	5 lbf·in (0.6 Nm)	5 lbf·in (0.6 Nm)

Table 2 – Recommended Measurements and Measurement Specifications (continued)

Type	Output	Range	Resolution	Accuracy
Video recorded messages	Visual/audible vehicle instructions, notifications, and/or alerts presented to the driver	N/A	At least 720p	N/A
Data Flag	Signal from SV FCW system indicating whether the alert is in operation.	0 - 10V	N/A	Output response ≤ 10 ms
Vehicle Dimensional Measurements	Location of SV, POV, and SOV GPS antennas; SV, POV, and SOV centerlines; front-most SV bumper position; and rear-most POV and SOV bumper positions.	N/A	0.04 in (1 mm)	0.04 in (1 mm)
SV-to-POV Static Range	Distance to POV reference point (typically the longitudinal CG) and rear-most POV bumper position.	N/A	2 in (5 cm)	At least 3.9 in (10 cm) absolute
SV-to-SOV Static Range	Distance to SOV reference point (typically the longitudinal CG) and rear-most SOV bumper position.	N/A	2 in (5 cm)	At least 3.9 in (10 cm) absolute

5.0 TEST EXECUTION AND TEST REQUIREMENTS

All tests performed in this document shall be performed with the SV operating in either SAE automation level 2 or 3 and the SV transmission in “drive.” For safety reasons, and to ensure the SV is properly initialized before each trial is initiated, it is anticipated a test driver will be present in the SV driver’s seat.

TJA system performance shall be evaluated in accordance with the test procedures described in S5.3.5 through S5.3.7.

5.1 General Vehicle Preparation and Pre-Test Conditioning

5.1.1 SV Brake Burnish

To achieve full brake system capability, and to ensure consistent performance, the procedure defined in S14.1.2 and S14.1.3 of FMVSS No. 135, Light Vehicle Brake Systems (i.e., TP-135-01) shall be used to burnish new SV brake components [5]:

1. Load the SV to its GVWR.

2. From a speed of 49.7 mph (80 km/h), perform 200 stops with an average deceleration of 0.31g (3.0 m/s^2) during each stop.

   A. Each stop shall be performed with the transmission in gear.

   B. The initial brake temperature, defined as the average brake pad or lining friction material temperature on the highest-temperature axle of the SV at the onset of a test trial, shall be ≤ 100°C (212°F) at the onset of each stop.

   C. The interval from the onset of one stop to the onset of the next is either the time necessary to reduce the IBT to ≤ 100°C (212°F), or the distance of 2 km (1.24 miles), whichever occurs first.

   D. Accelerate to 49.7 mph (80 km/h) after each stop and maintain that speed until initiating the next.

5.1.2 Instrumentation Initialization

All instrumentation shall be secure and properly configured. With all instrumentation off, the SV, POV, and SOV shall be driven to an outdoor location unobstructed by buildings, overpasses, or other structures capable of interfering with the ability of the GPS equipment to acquire satellite-based position information and real-time base station corrections (where applicable). At this location, the instrumentation shall be turned on, and static and dynamic GPS initializations shall be performed.

1. Static initialization

   A. Where applicable, the transmissions of the SV, POV, and SOV shall be placed in park or with the system brake enabled (robotic platforms).

   B. The SV, POV, and SOV shall remain at rest until transmissions from least six GPS satellites have been obtained and indicated by the vehicle's respective instrumentation.

2. Dynamic initialization

   A. The SV, POV, and SOV shall be driven in a straight line, at a speed of at least 35 mph (56.3 km/h) for at least 350 ft (107 m).

   B. The SV, POV, and SOV shall be driven in three figure 8 patterns. The radii of the turns shall be approximately 20 ft (6 m).

C. Steps 5.1.2.2.A and 5.1.2.2.B shall be repeated until the respective instrumentation indicates that the required accuracies for position and heading have been achieved.

5.1.3 Static Instrumentation Calibration

Calibration data shall be collected prior to the tests specified in S5.3.6 through S5.3.9 to assist in resolving uncertain test data.

1. The SV and POV shall be centered in the same travel lane with the same orientation (i.e., each must face the same direction).

2. The front-most location of the SV shall be positioned such that it just contacts a vertical plane that defines the rearmost location of the POV. This is the “zero position.”

3. The zero position shall be documented prior to, and immediately after, conduct of a test series.

   A. If the zero-position reported by the data acquisition system differs by more than ±2 in (±5 cm) from that measured during collection of the pre-test static calibration data file, the pre-test longitudinal offset shall be adjusted to output zero and another pre-test static calibration data file shall be collected.

   B. **If the zero-position reported by the data acquisition system differs by more than ±2 in (±5 cm) from that measured during collection of the post-test static calibration data file, the tests performed between collection of that post-test static calibration data file and the last valid pre-test static calibration data file shall be repeated.**

4. Static data files shall be collected prior to, and immediately after, conduct of the test series described in S5.3.5 through S5.3.7. The pre-test static files shall be reviewed prior to test conduct to confirm that all data channels are operational and have been properly configured.

5. Once the steps described in S5.1.3.1 through S5.1.3.4 have been performed using the SV and POV, they shall be repeated with the SV and SOV (i.e., using the SOV in lieu of the POV), where applicable, to verify the zero position of the SOV has also been properly defined.

5.2 Traffic Jam Assist Pre-Test System Initialization

Some vehicles may require a brief period of initialization (e.g., verification of sensor alignment and detection readiness) before their respective TJA system performance can be properly assessed. If a manufacturer-specific initialization procedure is required, NHTSA will obtain the appropriate procedure from the respective vehicle manufacturer, and provide it to the Contractor. The Contractor shall perform any NHTSA-provided initialization schedule prior to performing the tests described in this test document.

5.3 Test Scenarios

5.3.1 General Test Requirements

For tests described in S5.3.5 through S5.3.7 of this document, the following requirements shall be satisfied during the respective validity periods:

1. The SV driver seatbelt must be latched.

2. If any load has been placed on the SV front passenger seat (e.g., for instrumentation), the vehicle's front passenger seatbelt must be latched.

3. The SV ACC and lane centering systems shall both be enabled and in operation.

4. The SV driver shall not provide manual inputs to the SV accelerator or brake pedals.

5. The SV driver's hands shall not be touching the SV steering wheel.[1]

5.3.2 Adaptive Cruise Control Settings

ACC systems typically provide the operator with a range of settings to incrementally adjust the following distance from the front of the SV to the rear of the vehicle ahead of it. Each scenario described in this document begins with the SV approaching either a POV or SOV in its travel lane with the ACC enabled and active, and the ACC headway setting can have a profound effect on the initial conditions of each test trial. Each test scenario/condition combination described in this document shall be performed with the SV ACC set to its farthest setting (i.e., that which would provide the longest following distance when a lead vehicle is present ahead of the SV in its travel lane).

5.3.3 Lane Centering Control Settings

In the context of this document, an LCC system continuously provides the steering inputs needed to keep the SV centered in its travel lane. Unlike ACC, it is not anticipated the vehicles evaluated with the tests described in this document will be equipped with LCC systems that provide operator-selectable settings, modes, etc. other than on, off, and standby.

[1] Conduct of a valid TJA trial requires that the SV driver's hands not be in contact with the SV steering wheel during the applicable validity period. However, if a TJA malfunction occurs and/or the system becomes disabled during a test, the SV driver shall resume manual control of the SV steering, brake, and throttle and terminate the test.

Note: *LCC system functionality differs from that provided by lane keeping support or lane keeping assist systems, as the latter are only intended to provide the brief heading corrections needed to bring the vehicle away from a lane line after it has been crossed or if a crossing has been deemed imminent.*

5.3.4 Data Collection Interval

For all trials described in this document, data collection shall be initiated at the onset of the validity period, and end at least 3 seconds after completion of any termination condition.

5.3.5 Lead Vehicle Decelerates, Accelerates, Then Decelerates

The objective of the LVDAD test is to evaluate the TJA system's ability to detect and respond to a POV that moderately brakes to a stop, pauses, accelerates back to its initial speed, then brakes aggressively to a stop ahead of the SV (see Figure 1). In this test, the SV and POV remain in the same lane for the duration of each test trial.

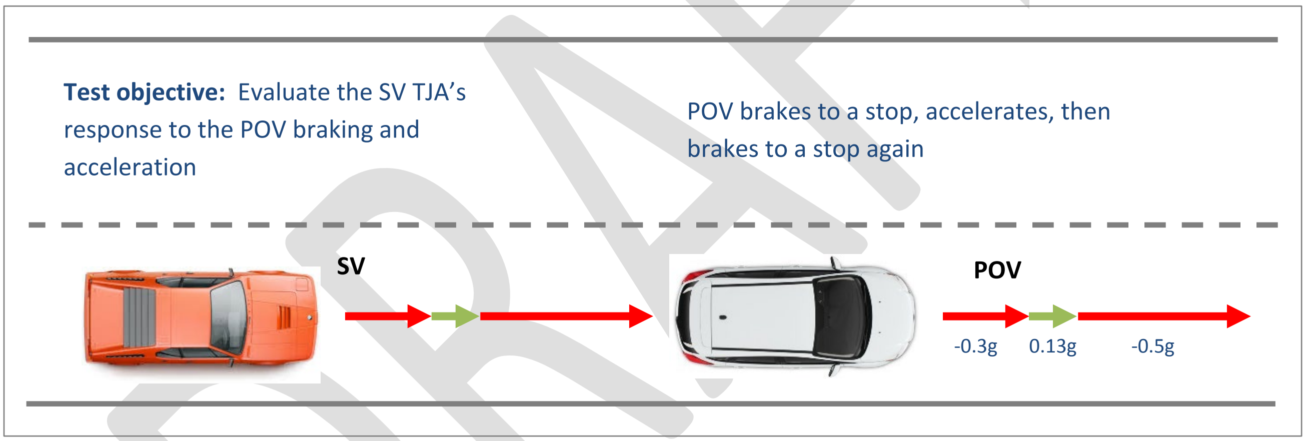

Figure 1. Lead Vehicle Decelerates, Accelerates, then Decelerates (LVDAD) scenario.

5.3.5.1 Scenario-Specific Validity Requirements

In addition to the general test requirements described in S5.3.1, the following requirements must also hold true throughout each LVDAD trial:

1. The POV shall be driven in the SV travel lane with the same orientation as the SV (i.e., the SV shall follow the rear of the POV).

2. The lateral distance between the centerline of the POV and the center of the travel lane shall not deviate more than ±0.8 ft (0.25 m) during the validity period.

5.3.5.2 Test Overview

Tests performed in the LVDAD scenario begin with initialization of the SV ACC and LCC. First, the POV is driven at constant speed in the center of the SV lane of travel. Next, the SV ACC shall be set to an indicated 30 mph, and the SV LCC enabled. With both ACC and LCC in operation, the SV is driven toward the rear of the POV in the same travel lane at a nominal speed of 30 mph (48 km/h)[2].

As the SV approaches the POV, the ACC is expected to reduce the SV speed until it matches that of the POV. At least 3 seconds after the first instance of the SV speed being within 1 mph (1.6 km/h) of that of the POV, the POV shall brake to a stop using an average deceleration of 0.3g (3 m/s^2). In response to this, the SV is also expected to stop without contacting the POV.

After the SV has been stopped for ≥3 seconds, the POV shall accelerate to the desired speed with an average acceleration of 0.127g (1.25 m/s^2) [6]. After being driven at the desired speed for ≥3 seconds, the POV shall brake to a stop using an average deceleration of 0.5g (5 m/s^2). In response to this, the SV is also expected to stop for a second time, also without impacting the POV. A summary of the LVDAD POV acceleration and velocity profile is shown in Figure 2. Note that in this figure the durations of $t_{POV,-0.3g}$, $t_{POV,0.127g}$, and $t_{POV,-0.5g}$ are dependent on V_{POV}.

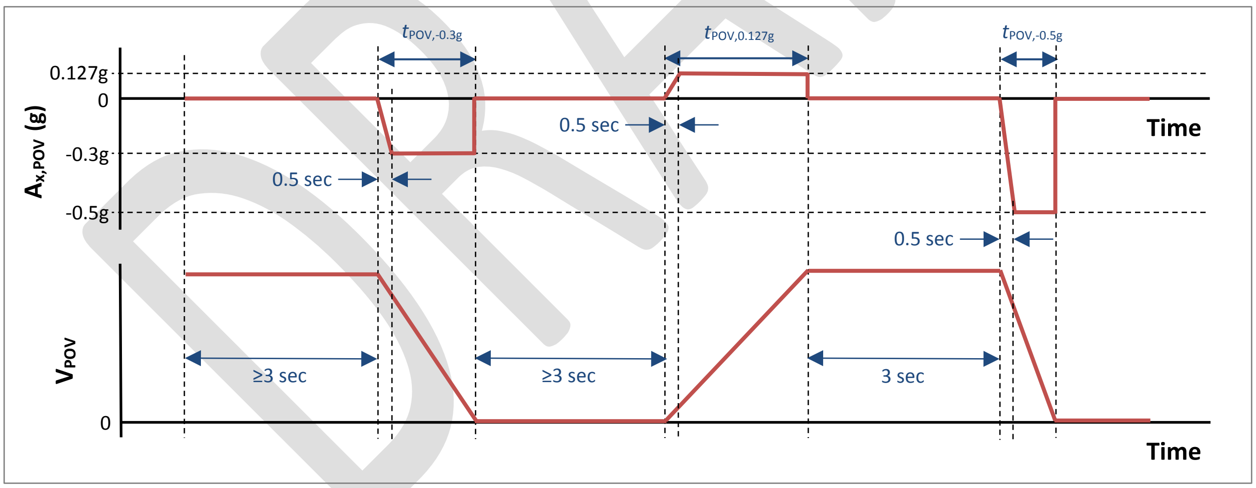

Figure 2. POV acceleration and velocity profiles used during LVDAD scenario evaluations.

Table 2 presents an overview of the SV and POV speeds, accelerations, and SV ACC settings used to perform the LVDAD scenario.

[2] The speed indicated on the SV's speedometer and/or instrument cluster may not necessarily be the actual speed of the vehicle. This is acceptable, as the SV ACC will reduce the vehicle's speed to that of the POV prior to the POV braking and accelerating events described in S5.3.3.2.

Table 3. Lead Vehicle Decelerates, Accelerates, Then Decelerates Scenario.

Nominal SV Speed[1]	POV Speed[2]	POV Deceleration and Acceleration Magnitudes			POV Lateral Path Tolerance	SV ACC Setting	Number of Trials
		First POV Braking Event	POV Acceleration	Second POV Braking Event			
15 mph (24.1 km/h)	15 ± 1 mph (24.1 ± 1.6 km/h)	0.3 ± 0.05g within 0.5s of braking onset	0.127 ± 0.05g within 0.5s of acceleration onset	0.5 ± 0.05g within 0.5s of braking onset	± 0.8 ft (± 0.25 m)	Far	1
25 mph (40.2 km/h)	25 ± 1 mph (40.2 ± 1.6 km/h)	0.3 ± 0.05g within 0.5s of braking onset	0.127 ± 0.05g within 0.5s of acceleration onset	0.5 ± 0.05g within 0.5s of braking onset	± 0.8 ft (± 0.25 m)	Far	1

[1] The actual SV speeds realized during the Accelerating and Decelerating POV tests will depend on the vehicle's ACC performance and how closely the system matches the POV speed.

[2] When not accelerating, braking, or at rest.

5.3.5.3 POV Brake Applications

1. The onset of POV braking is taken to be the instant when the POV achieves a deceleration of 0.05g.

2. The specified POV deceleration magnitude (i.e., 0.3 ± 0.05g or 0.5 ± 0.05g) shall be achieved within 0.5s from the onset of the respective POV brake application.

3. For the first POV deceleration event, the average POV deceleration shall not deviate from 0.3g by more than ±0.05g from 0.5 seconds after the onset of POV braking to the time one of the following two conditions is satisfied:

   A. 250 ms prior to the POV coming to a stop.

   B. The SV contacts the POV.

4. For the second POV deceleration event, the average POV deceleration shall not deviate from 0.5g by more than ±0.05g from 0.5 seconds after the onset of POV braking to the time one of the following two conditions is satisfied:

   A. 250 ms prior to the POV coming to a stop.

   B. The SV contacts the POV.

5.3.5.4 POV Acceleration

1. The onset of POV acceleration is taken to be the instant the POV achieves an acceleration of 0.05g.

2. The POV shall achieve an acceleration of at least 0.127 ± 0.05g within 0.5s from the onset of POV acceleration.

3. The average POV acceleration shall remain at 0.127 ± 0.05g from a time 0.5 seconds after the onset of POV acceleration to a time 250 ms prior to the POV achieving its desired test speed.

5.3.5.5 Validity Period

1. The valid test interval begins 3 seconds before the onset of the first POV braking event.

2. The valid test interval ends when either:

   A. The SV contacts the POV; or

   B. 1 second after the SV stops in response to the second POV deceleration event.

5.3.5.6 End-of-Test Instructions

1. After the validity period is complete, the SV driver shall manually apply force to the brake pedal, bring the vehicle to a stop (if necessary), and place the transmission in park.

2. The LVDAD test trial is complete.

5.3.6 Suddenly Revealed Stopped Vehicle

The objective of the SRSV test is to evaluate the TJA system's ability to detect and respond to a stationary POV that is suddenly revealed after an SOV steers around it. In this test, shown in Figure 3, the SV and POV remain in the same lane for the duration of each test trial. The SOV begins in the same lane as the SV and POV, but performs a single lane change into an adjacent lane before colliding with the POV.

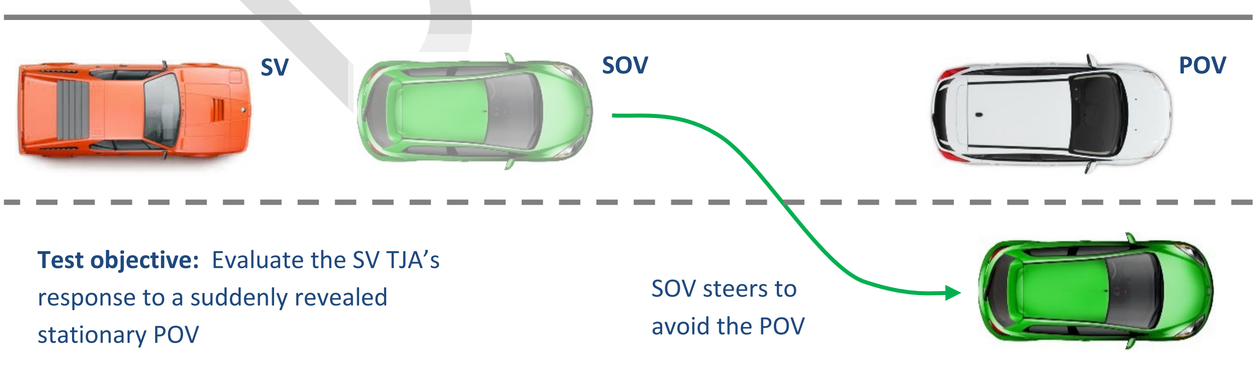

Figure 3. Suddenly Revealed Stopped Vehicle scenario.

5.3.6.1 Scenario-Specific Validity Requirements

In addition to the general test requirements described in S5.3.1, the following requirements must also hold true throughout each SRSV trial:

1. The [stationary] POV shall be oriented in the same direction as the SV (i.e., the SV shall approach the rear of the POV).

2. The centerline of the POV shall be placed within ±0.5 ft (±152 mm) of the center of the SV travel lane. The POV shall remain at this location throughout the validity period.

3. If the test is performed using an actual vehicle (defined in S4.5.2) as the SOV, SOV yaw rate shall not exceed ±1.0 deg/s from the onset of the validity period until the initiation of the SOV lane change.

4. The lateral distance between the centerline of the SOV and the center of the travel lane shall not deviate more than ±0.8 ft (0.25 m) from the onset of the validity period until the initiation of the SOV lane change.

5. The front most center position of the SOV shall not deviate more than ±0.8 ft (0.25 m) from the SOV path shown in Figure 4 from the instant when the SOV lane change begins until the end of the validity period.

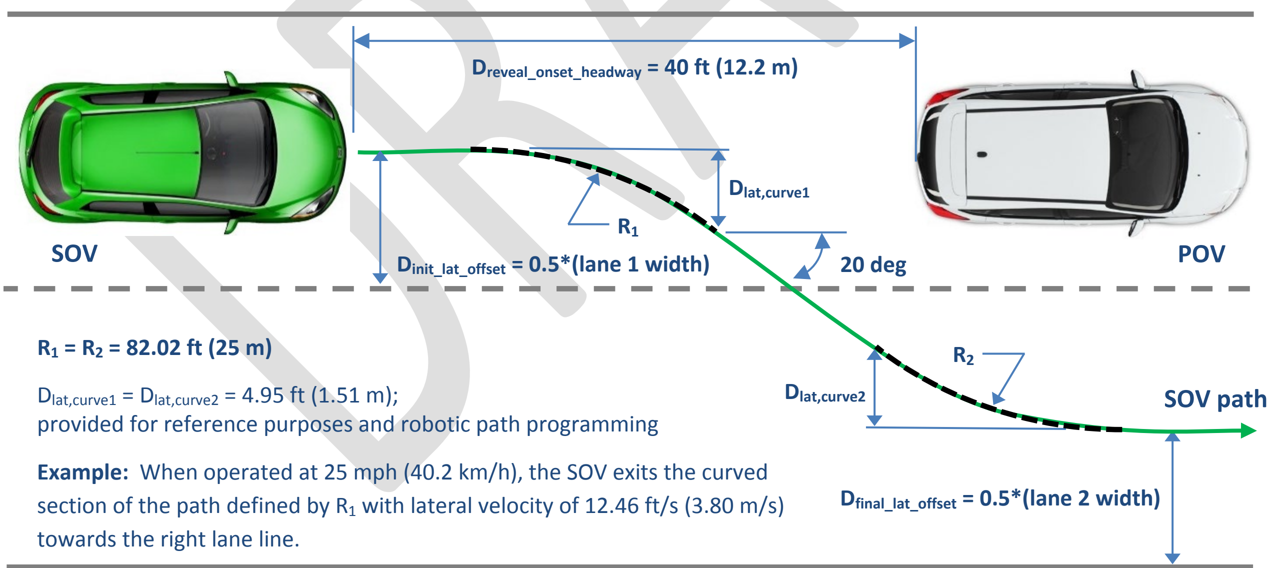

Figure 4. SOV lane change path used during the SRSV scenario.

6. Initiation of the SOV lane change is taken to be the instant when the SOV first achieves a lateral acceleration of ≥0.03g (0.3 m/s^2) during the lane change maneuver.

7. The SOV-to-POV headway at initiation of the SOV lane change shall be 40 ft (12.2 m).

5.3.6.2 Test Overview

Tests performed in the SRSV scenario begin with initialization of the SV ACC and LCC. First, the SOV is driven at constant speed in the center of the SV lane of travel. Next, the SV ACC shall be set to an indicated 30 mph, and the SV LCC enabled. With both ACC and LCC in operation, the SV shall be driven toward the rear of the SOV in the same travel lane at a nominal speed of 30 mph (48 km/h).

As the SV approaches the SOV, the ACC is expected to reduce the SV speed until it matches that of the SOV. At least 3 seconds after the first instance of the SV speed being within 1 mph of that of the SOV, the SOV shall initiate a single lane change into an adjacent travel lane along the path defined in Figure 4. This will expose a stationary POV in the forward path of the SV. In response to this, the SV is expected to automatically brake to a stop without contacting the POV.
Table 3 presents an overview of the SV and POV speeds, SV initialization headways, and SOV-to-POV headways up to the onset of the SOV lane change around the stopped POV (i.e., the reveal onset) used to perform the SRSV scenario.

5.3.6.3 Validity Period

1. The valid test interval begins 3 seconds before the onset of the SOV lane change.

2. The valid test interval ends when either:

   A. The SV contacts the POV; or

   B. 1 second after the SV stops in response to the stopped POV.

Table 4. Suddenly Revealed Stopped Vehicle Scenario.

Initial Speed			SOV-to-POV Distance at Reveal Onset	SOV Lateral Path Tolerance	SV ACC Setting	Number of Trials
SV[1]	SOV	POV				
15 mph (24.1 km/h)	15 ± 1 mph (24.1 ± 1.6 km/h)	0	40 ± 1 ft (12.2 ± 0.3 m)	± 0.8 ft (± 0.25 m)	Far	1
25 mph (40.2 km/h)	25 ± 1 mph (40.2 ± 1.6 km/h)	0	40 ± 1 ft (12.2 ± 0.3 m)	± 0.8 ft (± 0.25 m)	Far	1

[1] Initial SV speeds are nominal values. The actual SV speeds realized during the SRSV tests will depend on how the vehicle's ACC performance and how closely the system matches the POV speed.

5.3.6.4 End-of-Test Instructions

1. After the validity period is complete, the SV driver shall manually apply force to the brake pedal, bring the vehicle to a stop (if necessary), and place the transmission in park.

2. The SRSV test trial is complete.

5.3.7 Lead Vehicle Lane Change With Braking

The objective of the LVLCB test is to evaluate the TJA system's ability to detect and respond to a moving POV that brakes during or after performing a lane change into a space between the SV and SOV (see Figure 5). In this test, the SV and SOV remain in the same lane for the duration of each test trial. The POV begins in a lane adjacent to the SV and SOV, but performs a single lane change into the SV and SOV travel lane. The POV deceleration during or after the lane change (or both) varies depending on the test conditions.

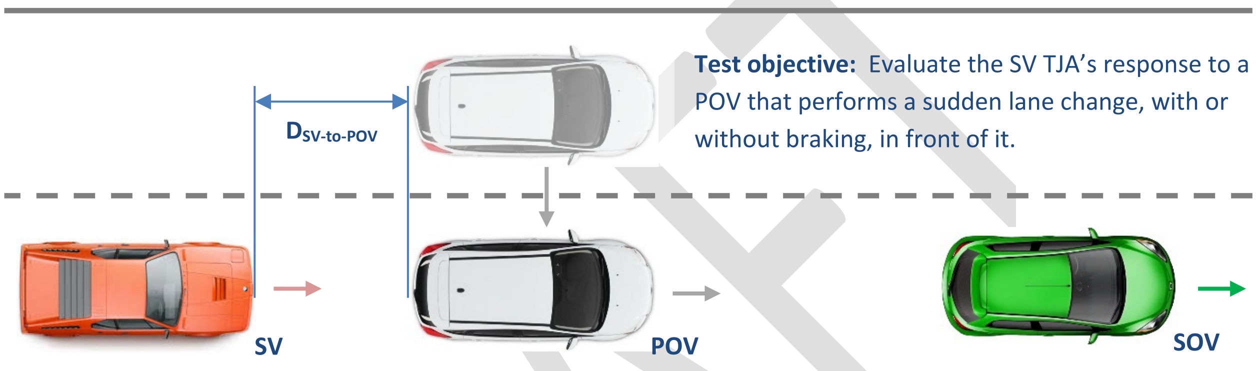

Figure 5. Lead Vehicle Lane Change With Braking (LVLCB) scenario.

5.3.7.1 Scenario-Specific Validity Requirements

In addition to the general test requirements described in S5.3.2, the following requirements must also hold true throughout each LVLCB trial:

1. The SOV shall be driven at constant speed in the SV travel lane with the same orientation as the SV (i.e., the SV shall follow the rear of the SOV) during the entire validity period.

2. If the test is performed using an actual vehicle (defined in S4.5.2) as the SOV, SOV yaw rate shall not exceed ±1.0 deg/s from the onset of the validity period until the initiation of the SOV lane change.

3. The lateral distance between the centerline of the SOV and the center of its travel lane shall not deviate more than 0.8ft (0.25 m) during the entire validity period.

4. The POV shall be driven at constant speed from the onset of the validity period until the initiation of the POV lane change.

5. Initiation of the POV lane change is taken to be the instant when the POV first achieves a lateral acceleration of ≥0.03g (0.3 m/s^2) during the lane change maneuver.

6. The lateral distance between the centerline of the POV and the center of its travel lane shall not deviate more than 0.8 ft (0.25 m) from the onset of the validity period until the initiation of the POV lane change.

7. Completion of the POV lane change is taken to be the instant when the POV lateral acceleration produced by the final steering input (i.e., that used to establish the POV path in the center of the SV and SOV travel lane) first becomes ≤0.03g (0.3 m/s^2).

8. The front most center position of the POV shall not deviate more than 0.8 ft (0.25 m) laterally from the applicable POV path from initiation of the POV lane change until the end of the validity period.

5.3.7.2 Test Overview

LVLCB scenario tests begin with initialization of the SV ACC and LCC. First, the SOV is driven at constant speed in the center of the SV lane of travel. Next, the SV ACC shall be set to an indicated 30 mph, and the SV LCC enabled. With both ACC and LCC in operation, the SV is driven toward the rear of the SOV in the same travel lane at a nominal speed of 30 mph (48 km/h).

As the SV approaches the SOV, the ACC is expected to reduce the SV speed until it matches that of the SOV. At least 3 seconds after the first instance of the SV speed being within 1 mph (1.6 km/h) of the SOV speed, the POV shall initiate a single lane change from an adjacent travel lane along the path defined in Figure 6 to a position in between the SV and SOV. Depending on the specific scenario, the POV shall either complete the lane change then brake, or brake during (Stage 1) and after (Stage 2) the lane change. Regardless of whether the POV uses single- or two-stage braking, the POV shall brake to a stop after crossing completely into the SV travel lane. In response to this, the SV is expected to stop without contacting the POV.

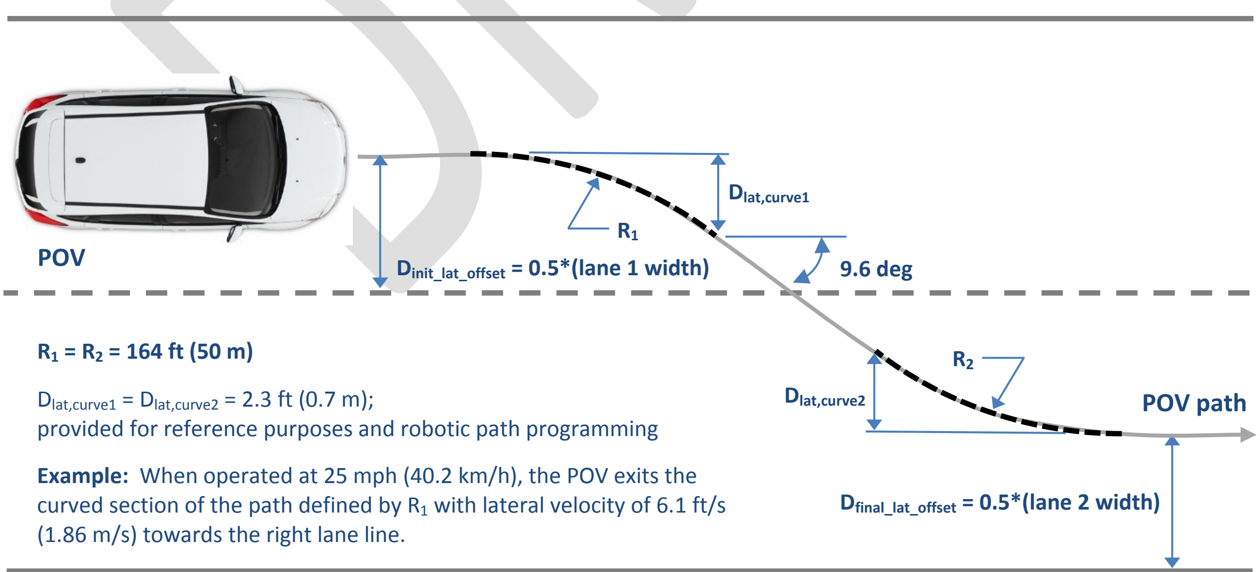

Figure 6. POV lane change path used during the LVLCB scenario (with or without POV braking).

Note: The longitudinal position of the POV is directly related to that of the SV, not to the SOV. For this reason, the longitudinal position of the POV relative to that of the SOV is not defined. Table 4, presented at the end of S5.3.7, includes an overview of the (1) SV, POV, and SOV speeds; (2) the SV-to-POV longitudinal and lateral offsets; (3) the POV brake application timing and magnitudes; and (4) the ACC settings used to perform the LVLCB scenario.

5.3.7.3 POV Brake Applications

1. For tests where the POV completes the lane change prior to braking (i.e., where no braking occurs during the POV lane change), the following criteria shall be realized:

    A. The longitudinal distance from the rear most center position of the POV shall not deviate more than 24.6 ± 3.3 ft (7.5 ± 1 m) from a vertical plane defined by the front most position of the SV, perpendicular to the SV longitudinal centerline, from onset of the validity period to initiation of the POV lane change.

    B. The onset of POV braking shall occur within 100 ms of the POV completing its lane change.

    C. The onset of POV braking is taken to be the instant when the POV achieves a deceleration of 0.05g.

    D. The specified POV deceleration magnitude (i.e., either 0.3 ± 0.05g or 0.5 ± 0.05g) shall be achieved within 0.5s from the onset of POV braking.

    E. For tests where the nominal POV deceleration magnitude is 0.3g, the average POV deceleration shall not deviate from 0.3g by more than ± 0.05g from 0.5 seconds after the onset of POV braking to the time one of the following two conditions is satisfied:

        i. 250 ms prior to the POV coming to a stop.

        ii. The SV contacts the POV.

    F. For tests where the nominal POV deceleration magnitude is 0.5g, the average POV deceleration shall not deviate from 0.5g by more than ± 0.05g from 0.5 seconds after the onset of POV braking to the time one of the following two conditions is satisfied:

        i. 250 ms prior to the POV coming to a stop.

        ii. The SV contacts the POV.

2. For tests where the POV brakes during (Stage 1) <u>and</u> after (Stage 2) the lane change, the following criteria shall be realized.

   A. Stage 1 POV braking

      i. The longitudinal distance from the rear most center position of the POV shall not deviate more than 35 ± 3.3 ft (10.7 ± 1 m) from a vertical plane defined by the front most position of the SV, perpendicular to the SV longitudinal centerline, from onset of the validity period to initiation of the POV lane change.

      ii. The onset of Stage 1 POV braking shall occur within 100 ms of the POV beginning its lane change.

      iii. The onset of Stage 1 POV braking is taken to be the instant when the POV achieves a deceleration of 0.05g.

      iv. The Stage 1 POV deceleration magnitude of 0.1 ± 0.05g shall be achieved within 0.5s from the onset of POV braking.

      v. Average Stage 1 POV deceleration shall be 0.1 ± 0.05g s during an interval beginning 0.5s after the onset of POV braking until one of the following two conditions is satisfied:

         a. The onset of Stage 2 POV braking occurs

         b. The SV contacts the POV.

   B. Stage 2 POV braking; 0.3g deceleration

      i. The onset of Stage 2 POV braking shall occur within 100 ms of the POV completing its lane change.

      ii. The onset of Stage 2 POV braking is taken to be the instant when the POV achieves a deceleration of 0.05g more than the nominal Stage 1 deceleration value used for that particular test trial.

      iii. The Stage 2 POV deceleration magnitude of 0.3 ± 0.05g shall be achieved within 0.5s from the onset of POV braking.

      iv. The average POV deceleration shall not deviate from 0.3g by more than ±0.05g from 0.5 seconds after the onset of Stage 2 POV braking to the time one of the following two conditions is satisfied:

a. 250 ms prior to the POV coming to a stop.

b. The SV contacts the POV.

C. Stage 2 POV braking; 0.5g deceleration

i. The onset of Stage 2 POV braking shall occur within 100 ms of the POV completing its lane change.

ii. The onset of Stage 2 POV braking is taken to be the instant when the POV achieves a deceleration of 0.05g more than the nominal Stage 1 deceleration value used for that particular test trial.

iii. The Stage 2 POV deceleration magnitude of 0.5 ± 0.05g shall be achieved within 0.5s from the onset of POV braking.

iv. The average POV deceleration shall not deviate from 0.5g by more than ±0.05g from 0.5 seconds after the onset of Stage 2 POV braking to the time one of the following two conditions is satisfied:

a. 250 ms prior to the POV coming to a stop.

b. The SV contacts the POV.

5.3.7.4 Validity Period

1. The valid test interval begins 3 seconds before the onset of the POV lane change.

2. The valid test interval ends when either:

A. The SV contacts the POV; or

B. 1 second after the SV stops in response to the braked to-a-stop POV.

5.3.7.5 End-of-Test Instructions

1. After the validity period is complete, the SV driver shall manually apply force to the brake pedal, bring the vehicle to a stop (if necessary), and place the transmission in park.

2. The LVLCB test trial is complete.

Table 5. Lead Vehicle Lane Change With Braking Scenario.

Initial Speed			SV-to-POV Longitudinal Offset up to POV Lane Change	POV and SOV Lateral Path Tolerance	POV Braking During Lane Change		POV Braking After Lane Change		ACC Setting	Number of Trials
SV[1]	POV	SOV			Timing	Magnitude	Timing	Magnitude		
15 mph (24.1 km/h)	15 ± 1 mph (24.1 ± 1.6 km/h)	15 ± 1 mph (24.1 ± 1.6 km/h)	24.6 ± 3.3 ft (7.5 ± 1 m)	± 0.8 ft (± 0.25 m)	N/A	0	Applied within 100 ms of lane change completion; magnitude realized within 0.5s of braking onset	0.3g ± 0.05g	Far	1
								0.5g ± 0.05g	Far	1
25 mph (40.2 km/h)	25 ± 1 mph (40.2 ± 1.6 km/h)	25 ± 1 mph (40.2 ± 1.6 km/h)	24.6 ± 3.3 ft (7.5 ± 1 m)	± 0.8 ft (± 0.25 m)	N/A	0	Applied within 100 ms of lane change completion; magnitude realized within 0.5s of braking onset	0.3g ± 0.05g	Far	1
								0.5g ± 0.05g	Far	1
			35.0 ± 3.3 ft (10.7 ± 1 m)	± 0.8 ft (± 0.25 m)	Applied within 100 ms of lane change onset; magnitude realized within 0.5s of braking onset	0.1 ± 0.05g	Applied within 100 ms of lane change completion; magnitude realized within 0.5s of braking onset	0.3g ± 0.05g	Far	1
								0.5g ± 0.05g	Far	1

[1] Initial SV speeds are nominal values. The actual SV speeds realized during the LVLCB tests will depend on how the vehicle's ACC performance and how closely the system matches the SOV and POV speeds before and after the POV lane change, respectively.

6.0 REFERENCES

1. ASTM International. (2011). *ASTM Standard E 1337-90 (2008) Standard test method for determining longitudinal peak braking coefficient of paved surfaces using a standard reference test tire.* West Conshohocken, PA: Author.

2. Federal Highway Administration. (2012, May). *Manual on uniform traffic control devices for streets and highways, 2009 edition*. Washington, DC: Author. https://mutcd.fhwa.dot.gov/pdfs/2009r1r2/pdf_index.htm.

3. Szabo, S., & Norcross, R. (2006, February). *Recommendations for objective test procedures for road departure crash warning systems.* (Report No. NISTIR 7288). Gaithersburg, MD: National Institute of Standards and Technology.

4. Forkenbrock, G. J., Snyder, A. C., Davis, I. J., & O'Harra, B. C. (2019, May). *A test track comparison of the global vehicle target and NHTSA's strikeable surrogate vehicle*. (Report No. DOT HS 812 698). Washington, DC: National Highway Traffic Safety Administration.

5. National Highway Traffic Safety Administration. (2005, December). *Laboratory Test Procedure for Federal Vehicle Motor Safety Standard (FMVSS) No. 135 Light Vehicle Brake Systems, TP-135-01*. www.nhtsa.gov/DOT/NHTSA/Vehicle%20Safety/Test%20Procedures/Associated%20Files/TP-135-01.pdf

6. Wang, J., Dixon, K. K., Li, H., & Ogle, J. (2014). *Normal acceleration behavior of passenger vehicles starting from rest at all-way stop-controlled intersections*. *Transportation Research Record, 1883*, pp. 158–166, ISSN: 0361-1981.

7.0 DATA SHEETS

SUBJECT VEHICLE (SV) INFORMATION	
NHTSA Vehicle No.	Vehicle Identification Number (VIN)
Vehicle Make/Model/Body Style	Date of Manufacture
Vehicle Width (in. or mm)	Vehicle Length (in. or mm)

Vehicle Test Weight (lbs or kg)	GVWR (lbs or kg)	Front GAWR (lbs or kg)	Rear GAWR (lbs or kg)

Driver Seatbelt Buckled?	Front Passenger Seatbelt Buckled?	Airbags Disabled?

Adaptive Cruise Control (ACC)		
Operational Speed Range (mph or km/h)	Method to Engage (stalk, button, etc.)	Number of Headway Settings

Lane Centering Control (LCC)	
Operational Speed Range (mph or km/h)	Method to Engage (stalk, button, etc.)

SAE Automation Level 1 or 3 Driving
Process to engage automation level 2 or 3 driving

PRINCIPAL OTHER VEHICLE (POV) INFORMATION	
POV Description (e.g., surrogate design)	POV Construction Type / Materials (e.g., carbon fiber shell)
POV Moving Platform Description (if applicable)	POV Moving Platform Material (if applicable)

SECONDARY OTHER VEHICLE (SOV) INFORMATION	
SOV Description (e.g., surrogate design, actual vehicle make/model)	SOV Construction Type / Materials (if applicable)
SOV Moving Platform Description (if applicable)	SOV Moving Platform Material (if applicable)

GENERAL TEST FACILITY INFORMATION	
Facility Designation (e.g., "VDA west edge")	Test Surface (e.g., asphalt, concrete)
Test Surface Condition	Test Surface PFC
Lane Line Description	
Vehicle Orientation During LVDAD tests (e.g., "North")	Vehicle Orientation During SRSV tests
Vehicle Orientation During LVLCB tests (braking after lane change)	Vehicle Orientation During LVLCB tests (braking during lane change)

PRETEST CONDITIONS (complete before each test scenario is evaluated)			
Time	Ambient Temperature (°F or °C)	Wind Speed (mph or km/h)	Wind Direction
Ambient Condition Description (e.g., "overcast")			
Test Vehicle-to-POV Distance During Static Cal, Measured (in. or mm)		Test Vehicle-to-POV Distance During Static Cal, Displayed (in. or mm)	

POST-TEST CONDITIONS (complete before each test scenario is evaluated)			
Time	Ambient Temperature (°F or °C)	Wind Speed (mph or km/h)	Wind Direction
Ambient Condition Description (e.g., "overcast")			
Test Vehicle-to-POV Distance During Static Cal, Measured (in. or mm)		Test Vehicle-to-POV Distance During Static Cal, Displayed (in. or mm)	

Lead Vehicle Decelerates, Accelerates, Then Decelerates (LVDAD) Scenario Performance Summary.

Vehicle Speeds		SV ACC Setting	Forward Collision Warning TTC (s)*	Crash Avoidance (Y/N)	SV-to-POV Impact Speed* (mph or km/h)
SV	POV				
15 mph (24.1 km/h)	15 mph (24.1 km/h)	Far			
25 mph (40.2 km/h)	25 mph (40.2 km/h)	Far			

*If applicable

Suddenly Revealed Stopped Vehicle (SRSV) Scenario Performance Summary.

Vehicle Speeds			SV ACC Setting	Forward Collision Warning TTC (s)*	Crash Avoidance (Y/N)	SV-to-POV Impact Speed* (mph or km/h)
SV	SOV	POV				
15 mph (24.1 km/h)	15 mph (24.1 km/h)	0	Far			
25 mph (40.2 km/h)	25 mph (40.2 km/h)	0	Far			

*If applicable

Lead Vehicle Lane Change With Braking (LVLCB) Scenario Performance Summary.

Vehicle Speeds			POV Deceleration (g)		SV ACC Setting	FCW TTC (s)*	Crash Avoidance (Y/N)	SV-to-POV Impact Speed* (mph or km/h)
SV	POV	SOV	During LC	After LC				
15 mph (24.1 km/h)	15 mph (24.1 km/h)	15 mph (24.1 km/h)	0	0.3	Far			
				0.5	Far			
25 mph (40.2 km/h)	25 mph (40.2 km/h)	25 mph (40.2 km/h)	0	0.3	Far			
				0.5	Far			
			0.1	0.3	Far			
				0.5	Far			

*If applicable

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July 2019

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National Highway
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