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Traffic Jam Assist Draft Test Procedure Performability Validation

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16. Abstract

This report (a) summarizes the three test scenarios intended to emulate situations commonly encountered during real-world driving where a traffic jam assist (TJA) system may be expected to operate; (b) discusses the results from testing one light vehicle equipped with TJA on the test track; and (c) provides general assessments of revisions made to NHTSA's April 2018 draft research TJA test procedure. The primary goal of the work described in this report was to assess the performability of the test protocols and use of evaluation criteria described in this update to accurately and practically facilitate TJA performance assessment.

The test protocols discussed in this report were generally found to be well-defined and performable; however, some elements of the April 2018 TJA draft research test procedure were found to require further refinement. This includes some adjustments to test specifications and to the configuration settings used by the robotic controllers. These issues are believed to be reconcilable, and adjustments have been incorporated into the October 2019 version of the agency's TJA draft research test procedure.

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Table of Contents

List of Figures

List of Tables

List of Acronyms

ACC	adaptive cruise control
GST	Guided Soft Target
GVT	Global Vehicle Target
LKA	lane keeping assist
LPRV	Low Profile Robotic Vehicle
LVDAD	lead vehicle decelerates, accelerates, then decelerates
LVLCB	lead vehicle lane change with braking
NHTSA	National Highway Traffic Safety Administration
POV	principal other vehicle
SOV	secondary other vehicle
SRSV	suddenly revealed stopped vehicle
SV	subject vehicle
TJA	traffic jam assist

Executive Summary

The primary objective of the work described in this report was to validate performability improvements made to NHTSA’s April 2018 traffic jam assist (TJA) draft research test procedure (NHTSA, 2018). This draft procedure, and the October 2019 update (NHTSA, 2019), were designed to objectively assess the performance of TJA systems using three real-world driving scenarios performed within the controlled confines of a test track.

The lead vehicle decelerates, accelerates, then decelerates (LVDAD) scenario was used to evaluate the TJA system’s ability to detect and respond to a principal other vehicle (POV) that moderately brakes to a stop, pauses at rest, accelerates back to its initial speed, and then brakes aggressively to a stop ahead of the subject vehicle (SV). The suddenly revealed stopped vehicle (SRSV) scenario tested the TJA system’s ability to detect and respond to a stationary POV that is suddenly revealed after a secondary other vehicle (SOV) steers around it. The lead vehicle lane change with braking (LVLCB) scenario assessed the TJA system’s ability to detect and respond to a moving POV that braked during and/or after performing a lane change into a space between the SV and SOV.

A Japanese-specification 2018 Subaru Levorg was used as the SV for testing. One trial was performed for each scenario. The TJA system controlled longitudinal headway to a lead vehicle (at both near and far following distances) and lateral position within the travel lane at speeds ranging from 10 to 25 mph (16.1 to 40.2 km/h).

Results from the tests described in this report indicate that satisfying all validity criteria (i.e., the specifications used to define what constitutes a valid test trial) for each scenario/test condition was not always possible. When applicable, the most prominent issues included POV and SOV lane change onset timing, POV lane change completion timing, achieving the proper POV deceleration within an acceptable time, and average POV deceleration.

The test scenarios were generally able to be performed as specified. However, as the work described in this report was performed, some elements of the April 2018 draft research TJA test procedure were found to require further refinement. This includes some adjustments to the manner in which the tests were performed, and to the configuration settings used by the robotic controllers. These issues are believed to be reconcilable, but they could not be resolved due to testing time and resource constraints. Expected resolutions (i.e., more explicit lane change onset and completion definitions, and reduced maximum POV deceleration) are presented in this report, and have been incorporated into NHTSA’s October 2019 TJA draft test procedure. The robotic controller configuration adjustments are expected to require an iterative component in adjusting the programmed reveal headway used during the suddenly revealed stopped vehicle test.

1.0 INTRODUCTION

Traffic jam assist is an advanced driver assistance system capable of automatically controlling the lateral position of a vehicle 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). To provide an objective means of performing TJA performance evaluations for research purposes, NHTSA developed a draft TJA test procedure in April 2018. This report details the test track work used to validate a refined version of this protocol featuring adjustments designed to improve performability and reduce test burden (NHTSA, 2019). These changes, and additional revisions based on results from the tests discussed in this report, have been incorporated into NHTSA's latest TJA draft test procedure (dated October 2019 at the time of this report).

2.0 TEST PROTOCOL

2.1. Subject Vehicle: 2018 Subaru Levorg

The 2018 Subaru Levorg was used as the SV for this study. This vehicle, shown in **Figure 2-1** below, was a Japanese-specification light vehicle equipped with TJA system called "EyeSight Touring Assist" as well as other safety technologies (Subaru [UK] Ltd., 2016; Subaru of America, 2016). A detailed description of the Subaru Levorg TJA system capabilities are available within the vehicle's owner's manual (Subaru [UK] Ltd., 2016)

The Subaru Levorg TJA system controls longitudinal headway to a lead vehicle as well as lateral position within the lane of travel. This is accomplished using a combination of lane keeping assist (LKA) and adaptive cruise control (ACC) technologies within Subaru's EyeSight system. EyeSight uses two stereo cameras to identify vehicles, objects, and traffic lanes in front of the vehicle.

Figure 2-1. 2018 Subaru Levorg.

To use the Subaru Levorg TJA system, the operator must first enable LKA and ACC using the steering-wheel buttons (see numbers 1 and 2 in **Figure 2-2**). ACC speed can then be adjusted using the rocker switch labeled 3, and ACC following distance can be adjusted using the button labeled 4.

Figure 2-2. 2018 Subaru Levorg controls.

The green vehicle speed and steering wheel icons, shown below in **Figure 2-3**, indicate that LKA and ACC are active. In this figure, the blue lane lines indicate that the vehicle can “see” the lane lines and the blue box around the vehicle icon indicate that it can “see” a lead vehicle.

Figure 2-3. 2018 Subaru Levorg instrument cluster indicators.

2.2. Test Targets

2.2.1. Principal Other Vehicle: Guided Soft Target

To safely perform the tests described in this report, a guided soft target (GST) system, shown in **Figure 2-4**, was used as the principal other vehicle (POV) during each test trial. The GST system is comprised of two main parts: a low profile robotic vehicle (LPRV), and a global vehicle target (GVT) revision F secured to the top of the LPRV. This system provides accurate closed loop control of the GST relative to an SV, and because it is realistic-looking and 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 during test conduct.

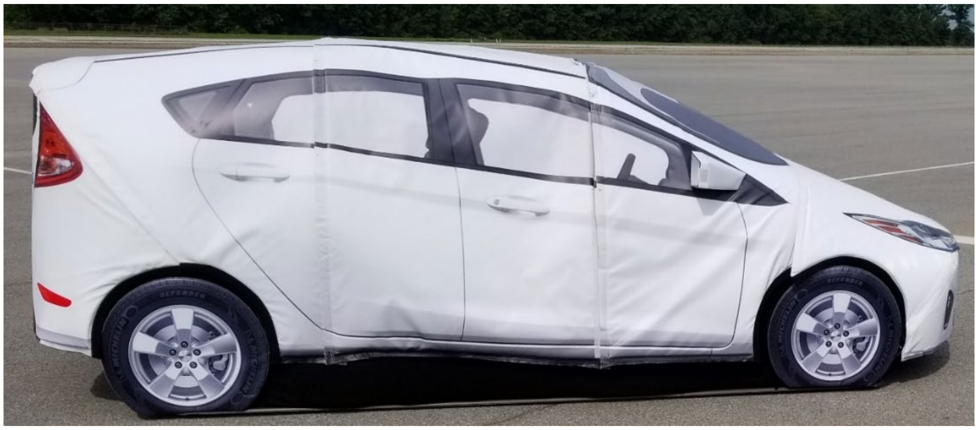


Figure 2-4. GVT Rev. E secured to the top of an LPRV.

2.2.2. Secondary Other Vehicles

The following vehicles were used as SOVs.

- 2017 BMW 540i: 194.6 in (L) X 73.5 in (W); (4.94 m x 1.87 m)
- 2017 Volvo S90: 195 in (L) X 74 in (W); (4.95 m x 1.88 m)

These vehicles satisfy the test procedure specification of SOVs being 175 to 197 in (4.45 to 5.00 m) long and 70 to 76 in (1.78 to 1.93 m) wide. The BMW 540i was used as the SOV for SRSV tests, whereas the Volvo S90 was the SOV for LVLCB tests. The BMW 540i used a robotic steering controller to maintain its path during the SRSV maneuver.

2.3. Test Scenarios

Sections 2.3.1 through 2.3.4 provide an overview of the test scenarios and validity criteria used for the assessment described in this report. Additional specifications (e.g., the specific manner in which the tests are to be performed, surface and environmental conditions, etc.) can be found in the October 2019 version of NHTSA's TJA draft test procedure.

2.3.1. Lead Vehicle Decelerates, Accelerates, Then Decelerates

The objective of the "lead vehicle decelerates, accelerates, then decelerates" (LVDAD) test is to evaluate the TJA system's ability to detect and respond to a POV that (a) moderately brakes to a stop; (b) pauses while at rest; (c) accelerates back to its initial speed; then (d) brakes aggressively to a stop ahead of the SV (see **Figure 2-5**). In this test, the SV and POV remain in the same lane for the duration of each test trial. LVDAD tests were performed with SV and POV speeds of 10, 15, 20, and 25 mph (16.1, 24.1, 32.2, and 40.2 km/h), and two SV ACC settings (nearest and farthest following distances).

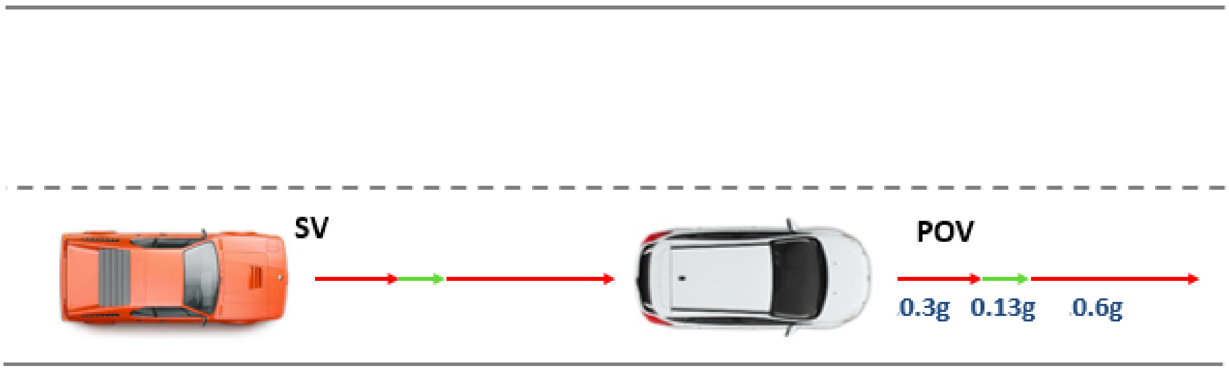


Figure 2-5. LVDAD path.

The desired POV acceleration profile for LVDAD tests is shown in **Figure 2-6**. During these trials. the POV brakes to a stop with an average deceleration 0.3 g, allows for the SV to stop for ≥3 s, accelerates back to the desired test speed at 0.127 g, allows for the SV to reach the desired test speed for ≥3 s, and then comes to a stop again with an average deceleration of 0.6 g.

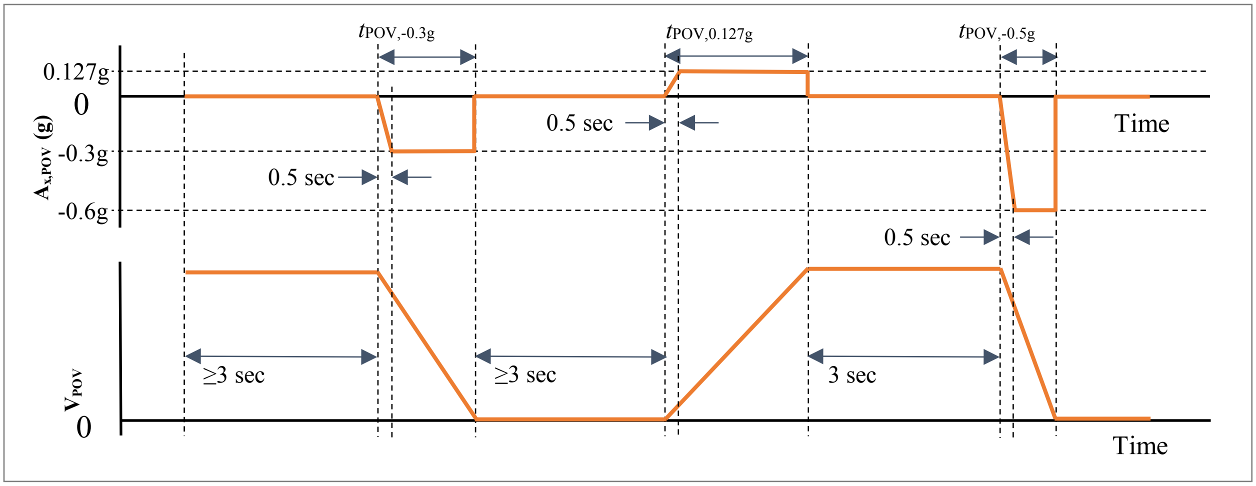


Figure 2-6. Nominal LVDAD POV velocity and acceleration profiles.

2.3.2. Suddenly Revealed Stopped Vehicle

The objective of the "suddenly revealed stopped vehicle" (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 2-7**, 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 just before colliding with the POV. The SRSV tests were performed at 10, 15, 20, and 25 mph (16.1, 24.1, 32.2, and 40.2 km/h), with the nearest and farthest SV ACC settings.

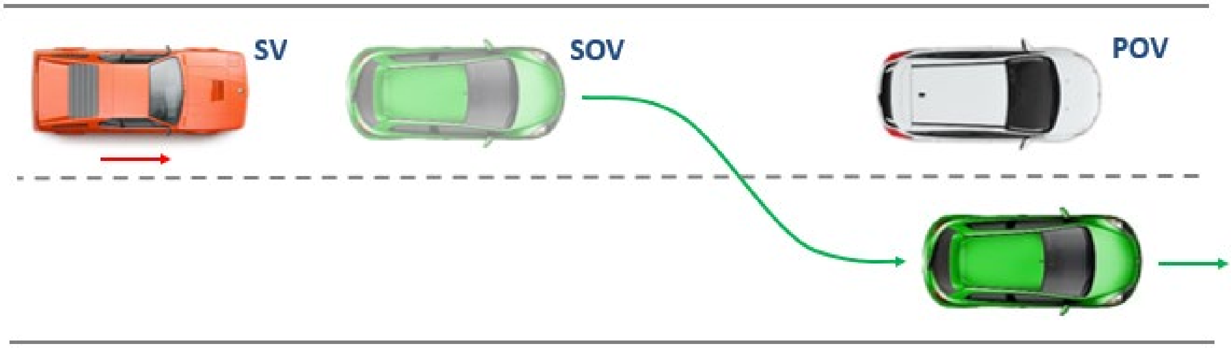
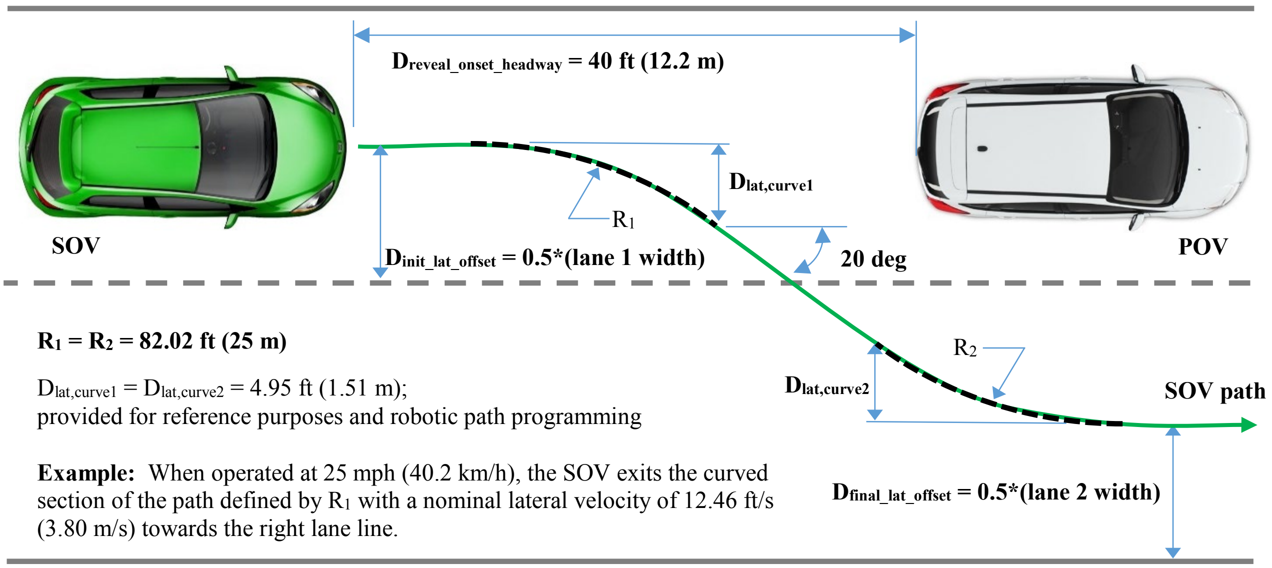


Figure 2-7. SRSV path.

Figure 2-8 shows the required SOV path, which was achieved via use of steering robot. This lane change consists of two constant radius curves connected with a straight line as the SOV crosses the right lane line. Since the curve radii and SOV-to-POV distance at the onset (40 ft or 12.2 m) of the SOV lane change remained the same regardless of SV and POV speed, overall maneuver severity increased as a function speed.



$R_1 = R_2$ = 82.02 ft (25 m)

$D_{lat,curve1} = D_{lat,curve2}$ = 4.95 ft (1.51 m);
provided for reference purposes and robotic path programming

Example: When operated at 25 mph (40.2 km/h), the SOV exits the curved section of the path defined by R_1 with a nominal lateral velocity of 12.46 ft/s (3.80 m/s) towards the right lane line.

Figure 2-8. SRSV SOV path profile.

2.3.3. *Lead Vehicle Lane Change With Braking*

The objective of the “lead vehicle lane change with braking” (LVLCB) test is to evaluate the TJA system’s ability to detect and respond to a moving POV that enters a space between the SV and an SOV (see **Figure 2-9**). In this test, the SV and the 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, and 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. The April 2018 draft TJA test procedure (NHTSA, 2018) states the LVLCB test shall nominally be performed with SV, POV, and SV speeds of 10, 15, 20, and 25 mph (16.1, 24.1, 32.2, and 40.2 km/h); however, within lane change deceleration is only specified for use during the 20 and 25 mph (32.2, and 40.2 km/h) tests since the POV is braked to a stop before completing its lane change from 10 or 15 mph (16.1 and 24.1, km/h). To allow sufficient space for the POV to perform a lane change between the SV and SOV without impacting either vehicle, the SV ACC was only set the farthest setting and the 10 mph (16.1 km/h) tests were omitted for the LVLCB tests performed with the Subaru Levorg (deviations from the April 2018 draft procedure).

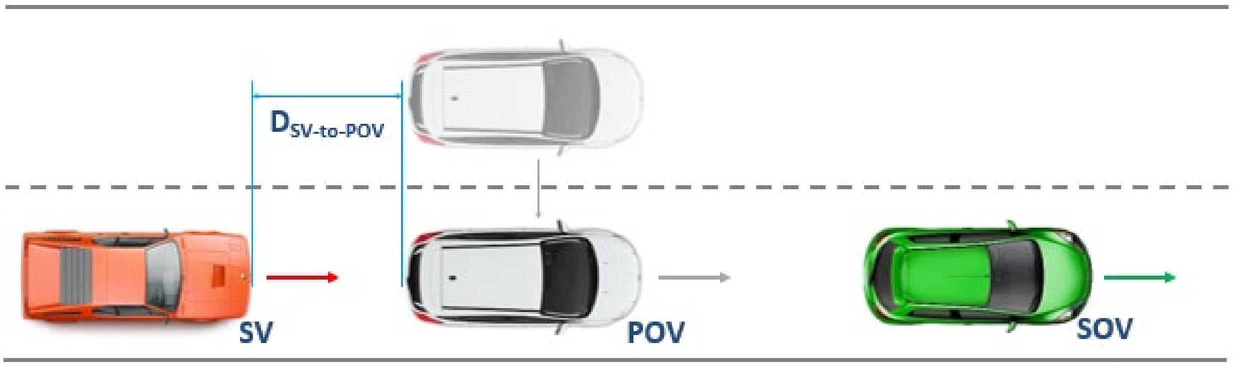
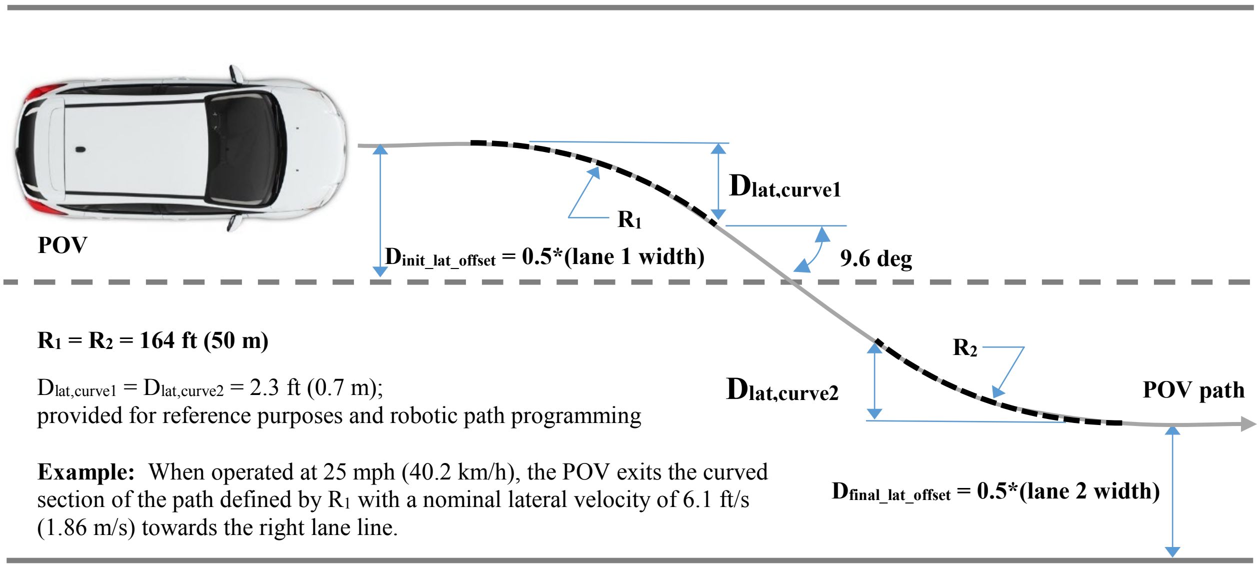


Figure 2-9. LVLCB path.

Figure 2-10 shows the required POV lane change specifications, which was achieved by having the GST execute a pre-programmed path. The lane change consists of two constant radius curves connected with a straight line to as the POV crossed the left lane line. The POV lane change was performed once the POV had matched the SV speed and was at the correct longitudinal distance from the SV: 35 and 24.6 ft (10.7 and 7.5 m) for tests performed with and without within lane change deceleration, respectively.



$R_1 = R_2$ = 164 ft (50 m)

$D_{lat,curve1} = D_{lat,curve2}$ = 2.3 ft (0.7 m);
provided for reference purposes and robotic path programming

Example: When operated at 25 mph (40.2 km/h), the POV exits the curved section of the path defined by R_1 with a nominal lateral velocity of 6.1 ft/s (1.86 m/s) towards the right lane line.

Figure 2-10. LVLCB POV path profile.

2.3.4. *Validity Criteria*

To ensure tests were properly and consistently performed, the validity criteria defined within the TJA draft test procedure were assessed for each test trial. Examples include:

- LCC and ACC must be on and active.
- SV driver shall not provide manual inputs to the SV accelerator pedal, brake pedal, or steering wheel during the test validity period. [1]
- The validity period runs from 3 seconds before the onset of the test event, until either the SV contacts the POV or 1 second after the SV stops in response to the test event.
- The POV and SOV speeds should be within ± 1 mph (± 1.6 km/h) of the given test speed.

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[1] As stated in the TJA draft research test procedure, 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. However, since the Subaru Levorg's TJA system requires confirmation that the driver is actively involved with the operation of the vehicle, very small steering wheel inputs were periodically used to prevent the system from being disabled (i.e., "timing out"), and sometimes occurred within the validity period of the test trial being performed. These inputs were brief, did not directly affect the heading of the vehicle, and were timed such that they did not occur during critical parts of the test (e.g., during, or just prior to, an automated crash avoidance maneuver).

- Where applicable, deceleration and acceleration magnitudes shall be reached within 0.5 ± 0.1 s.
- Where applicable, average POV acceleration and deceleration shall be maintained within ± 0.05 g of the desired value over the applicable interval.
- The SRSV reveal distance should be 40 ft ± 1 ft (12.2 m ± 0.3 m).
- SOV and POV path tolerances are ± 0.8 ft (± 0.24 m).
- LVLCB initial POV-SOV longitudinal offset should be within 3.3 ft (1 m) of the desired offset until the lane change occurs.
- LVLCB decelerations must be applied within 100 ms of lane change onset or completion.

2.4. Performance Criteria

The TJA system performance criteria specified in the TJA draft test procedure state that the SV shall automatically avoid a POV impact during each test trial, regardless of scenario. Since NHTSA performs its TJA evaluations for research purposes, other performance factors such as minimum range to target, impact speed, and relative impact speed are also of interest. The minimum range to target is the smallest distance between the front most point of the SV and the rear most point of the POV. If there is a collision, this value will be zero. The impact speed is the SV speed at collision. The relative impact speed is the difference between the SV and POV speed at the time of impact.

2.5. Test Facility

All tests were performed on the Skid Pad at the Transportation Research Center in East Liberty, Ohio.

2.6. Measurement and Data Acquisition Systems

All sensor data specified in the TJA draft test procedure were collected using an in-vehicle data acquisition system. Video data were recorded with GoPro Hero4 cameras. Vehicle GPS position and inertial measurements were measured using Oxford Technical Solutions (OTSX) RT3002 units. This system uses real-time kinematic corrections to improve GPS accuracy to within 0.8 in (2 cm). Relative distances and velocity between test actors were measured using an OTXS RT-Range S system.

3.0 CHANGES TO DRAFT PROCEDURE DURING TESTING

To improve performability and reduce test burden, NHTSA made several refinements to the April 2018 TJA draft test procedure before the tests described in this report were performed. Most of these refinements,[2] which are present in the October 2019 version of the draft procedure, included:

- The time tolerance required by the POV to achieve the desired deceleration and acceleration magnitudes during the LVDAD tests has been changed from "0.5 s" to "within 0.5 s."
- The SOV-to-POV headway at the onset of the POV reveal used during the SRSV tests has been increased from 35 ft (10.7 m) to 40 ft (12.2 m).
- 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 was intended to eliminate the potential for the front of the POV striking the rear of the SOV during the POV lane change.
- The SV speed requirements changed from "equivalent" to "within 1 mph" to that of the POV and SOV.
- An "SOV/POV lane change onset" threshold of 0.02 g has been added to the SRSV and LVLCB tests and a "completion of POV lane change" threshold of 0.02 g has been added to the LVLCB tests.
- 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 (0.24 m) during the test validity period, this change is not expected to confound the test results or affect the test outcome.
- All steady-state validity criteria were changed from 5 seconds to 3 seconds.

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[2] The list excludes removing tests performed with SV speeds of 10 and 20 mph (16.1 and 32.2 km/h), the ACC headway being changed to "far" only, the SOV lane change onset definition being changed to 0.03 g, and the decrease in the maximum POV deceleration used during LVLCB and LVDAD scenarios. Although these changes are also included within the October 2019 draft research TJA test procedure, they were made in response to the work described in this report, and are discussed later in Section 5 of this report.

4.0 TEST RESULTS

This section provides results from the TJA LVDAD, SRSV, and LVLCB evaluations. To expedite testing, one trial per test condition was performed.

4.1. LVDAD Results

A summary of the minimum SV-to-POV ranges, SV impact speeds, and relative SV-to-POV impact speeds observed during the LVDAD tests are shown in **Table 4-1**. Only the trial performed at the highest speed (25 mph or 40.2 km/h) and near following distance resulted in the SV impacting the POV. The SV avoided the POV during all other speed/following distance combinations.

Table 4-1. LVDAD SV Performance Summary

ACC Following Distance		**Far**		**Near**	
Deceleration		0.3 g	0.6 g	0.3 g	0.6 g
10 mph	Minimum range to POV	11.1 ft (3.4 m)	10.6 ft[1] (3.2 m)	6.5 ft (2.0 m)	5.4 ft[1] (1.6 m)
	SV impact speed	--	--	--	--
	SV-to-POV relative impact speed	--	--	--	--
15 mph	Minimum range to POV	11.0 ft (3.4 m)	9.6 ft[2] (2.9 m)	6.7 ft (2.0 m)	3.0 ft (0.9 m)
	SV impact speed	--	--	--	--
	SV-to-POV relative impact speed	--	--	--	--
20 mph	Minimum range to POV	11.8 ft (3.6 m)	11.3 ft[2] (3.4 m)	6.8 ft (2.1 m)	1.4 ft (0.4 m)
	SV impact speed	--	--	--	--
	SV-to-POV relative impact speed	--	--	--	--
25 mph	Minimum range to POV	11.5 ft (3.5 m)	10.9 ft[1,2] (3.3 m)	6.3 ft (1.9 m)	0
	SV impact speed	--	--	--	9.8 mph[2,3] (15.8 km/h)
	SV-to-POV relative impact speed	--	--	--	9.7 mph[2,3] (15.6 km/h)

[1] Test did not satisfy 0.6g deceleration average check
[2] Test did not achieve 0.6g deceleration within 0.5s
[3] Test did not satisfy steady-state criteria

All but two trials (a 15 mph (24.1 km/h) test and a 20 mph (32.2 km/h) test performed with the near following distance) were unable to satisfy all test validity criteria. The 15, 20, and 25 mph 24.1, 32.2, and 40.2 km/h) far following distance, and 25 mph (40.2 km/h) near following distance cases did not achieve the 0.6 g deceleration check within the allowed time. The 10 and 25 mph (16.1 and 40.2 km/h) far following distance, and 10 mph (16.1 km/h) near following distance, cases did not satisfy the 0.6 g average check. The 25 mph (40.2 km/h) near following distance case did not satisfy steady-state requirements. All other validity criteria were satisfied.

There was only one instance of a trial failing a validity criterion check not related to POV deceleration. During the 25 mph (40.2 km/h) test performed with a near following distance, the POV was unable to maintain steady-state speed for 3 seconds prior to its initial brake application. As this was discovered during data post processing, and since satisfying this check is generally not problematic, the test trial was not repeated.

Table 4-2 reports how long it took the POV to achieve the desired decelerations (where applicable)[3], the initial POV deceleration magnitudes, and the average POV deceleration magnitudes observed during the LVDAD trials. Values outside of the +/-0.05 g allowable tolerance range are shown in red.

Table 4-2. LVDAD POV Deceleration Validity Check

Following Distance		Far		Near	
Deceleration		0.3 g	0.6 g	0.3 g	0.6 g
10 mph	Magnitude first realized (s)[1]	0.06	0.35	0.05	0.31
	Initial deceleration magnitude (g)[2]	0.26	0.55	0.26	0.55
	Average deceleration (g)[3]	0.27	0.46	0.27	0.46
15 mph	Magnitude first realized (s)[1]	0.05	0.59	0.06	0.49
	Initial deceleration magnitude (g)[2]	0.27	0.54	0.26	0.55
	Average deceleration (g)[3]	0.29	0.57	0.29	0.58
20 mph	Magnitude first realized (s)[1]	0.05	0.53	0.05	0.19
	Initial deceleration magnitude (g)[2]	0.26	0.54	0.26	0.55
	Average deceleration (g)[3]	0.30	0.57	0.29	0.57
25 mph	Magnitude first realized (s)[1]	0.05	0.54	0.05	0.86
	Initial deceleration magnitude (g)[2]	0.26	0.45	0.25	0.51
	Average deceleration (g)[3]	0.30	0.54	0.29	0.62

[1] Must occur within ±0.5s. Values outside of this tolerance are highlighted in red.

[2] Taken at the first data count after the lower threshold of the nominal magnitude is exceeded, or at a time 0.5s after the onset of braking if the lower threshold of the nominal magnitude is not exceeded. The later values are highlighted in red.

[3] From 0.5s after brake onset to 250 ms before POV stops or SV-to-POV impact occurs. Values that exceed the tolerances of the respective nominal value are highlighted in red.

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[3] This is the time from the onset of POV braking (the instant a deceleration of 0.05 g occurs) to the instant the deceleration first enters the lower threshold of the desired deceleration target.

Note that the initial deceleration magnitude reported in **Table 4-2**, and throughout the remainder of this report, is defined in one of two ways.

- For tests where deceleration exceeds the lower bound of the target magnitude tolerance, the initial deceleration magnitude is taken to be the deceleration at the first data count after the threshold is exceeded.
- If the lower bound of the target magnitude tolerance is not exceeded within 0.5 s after the braking onset, the initial deceleration magnitude is taken to be the deceleration at a time 0.5 s after the braking onset. These values are highlighted in red within the tables they are presented in.

An example of a LVDAD test nominally performed with 0.3 g POV braking is provided in **Figure 4-1**. In this figure, the cyan star indicates the onset of the POV braking (0.05 g deceleration), the cyan circle is the first instance POV braking surpasses 0.25 g (the lower bound of the nominal 0.3 g deceleration target), and the red star indicates a time 0.5 s after the onset of POV braking. Since the first instance of the POV deceleration exceeding 0.25 g occurred before the 0.5 s mark, the "magnitude first realized" time was from the braking onset to first data count after the lower threshold of the nominal magnitude was exceeded, and the deceleration magnitude at this time was taken to be the "initial deceleration magnitude."

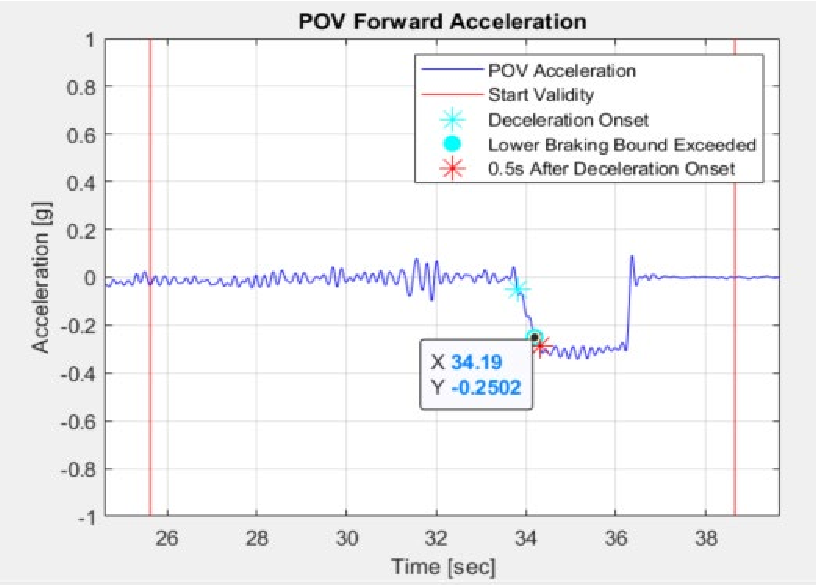

Figure 4-1. POV data used to identify "initial deceleration magnitude" and "magnitude first realized" values (LVDAD scenario, 0.3 g nominal braking test).

An example of a LVDAD test nominally performed with 0.6 g POV braking is provided in **Figure 4-2**. In this trial, first instance of the POV braking surpassing 0.55 g (the lower bound of the nominal 0.6 g deceleration target) occurred later than 0.5 s after braking was initiated. Therefore, in this case, the "initial deceleration magnitude" was the POV deceleration 0.5 s after braking was initiated, and the "magnitude first realized" time was greater than 0.5 s.
POV deceleration validity check failures occurred during six trials of the eight LVDAD trials performed. Four of the seven 0.6 g failures were because the POV was unable to achieve the

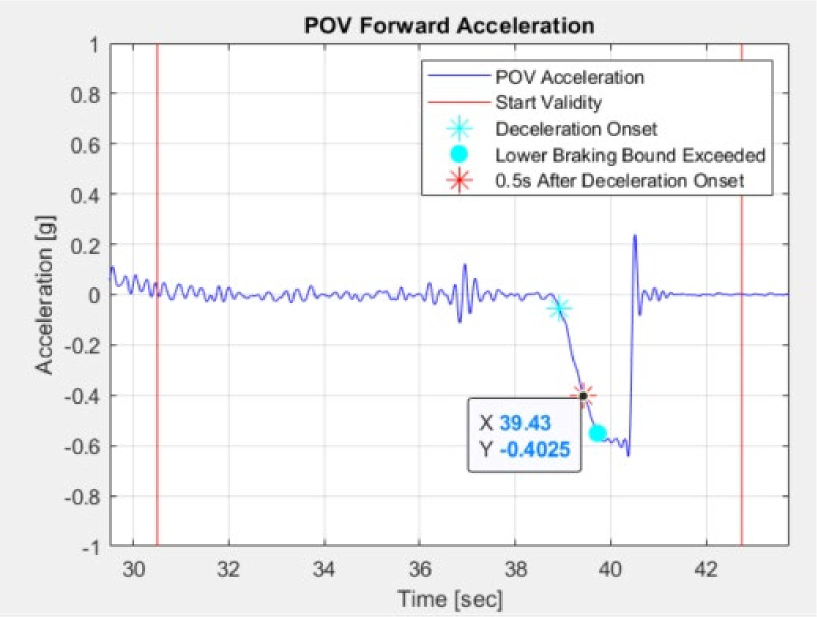

Figure 4-2. POV data used to identify "initial deceleration magnitude" and "magnitude first realized" values (LVDAD scenario, 0.6 g nominal braking test).

minimum deceleration threshold of 0.55 g. The remaining three 0.6 g failures were because the POV was unable to maintain a minimum average deceleration of at least 0.55 g.

Extensive PID tuning efforts related to GST brake applications were made in an attempt to rectify these problems; however, adjusting the GST brake apply velocity parameters (i.e., not PID adjustment) ultimately seemed to have the greatest effect on achieving the desired braking characteristics. Ultimately, these adjustments were still unable to consistently satisfy the test tolerances associated with the 0.6 g POV deceleration part of the LVDAD test. A recommendation to reduce the maximum nominal POV deceleration from 0.6 g to 0.5 g for future testing is discussed in Section 5.3.

4.2. SRSV Results

Table 4-3 provides a summary of the SOV-to-POV reveal headway, minimum SV-to-POV ranges, and SV-to-POV impact speeds observed during the SRSV tests. Only trials performed with the two highest SV and POV speeds (20 and 25 mph, or 32.2 and 40.2 km/h) and nearest SV ACC setting concluded with the SV impacting the POV. The SV avoided the POV by automatically braking to a stop when all other speed/following distance combinations were used.

An acceptable reveal headway was only realized during only one trial (a 15 mph, or 24.1 km/h, test performed with a far following distance). As previously indicated in Section 2.3.2, reveal headway is defined as the distance between the beginning of the SOV lane change, taken to be the instant when the SOV reaches 0.02 g, and the rear-most point of the POV. According to the TJA draft test procedure this instant should occur when the POV-to-SOV headway is between 39 and 41 ft (11.9 m to 12.5 m) during an otherwise valid test. Since the measured reveal headway was too close to the POV during the 10 mph (16.1 km/h) tests, headway setting specified in the test configuration file was increased beyond the nominal the 40 ft (12.2 m) value in an attempt to achieve the desired value. The same adjustment was used for each of the four test speeds, and it

Table 4-3. SRSV Test Conduct and SV Performance Summary

Following Distance		Far	Near
10 mph	SOV-to-POV reveal headway[1]	35.0 ft[2] (10.7 m)	35.3 ft[2] (10.8 m)
	SV-to-POV minimum range	12.7 ft (3.9 m)	6.5 ft (2.0 m)
	SV-to-POV impact speed	--	--
15 mph	SOV-to-POV reveal headway[1]	39.1 ft (11.9 m)	39.0[2] (11.9 m)
	SV-to-POV minimum range	11.6 ft (3.5 m)	3.7 ft (1.1 m)
	SV-to-POV impact speed	--	--
20 mph	SOV-to-POV reveal headway[1]	38.2 ft[2] (11.6 m)	38.2 ft[2] (11.6 m)
	SV-to-POV minimum range	9.2 ft (2.8 m)	0
	SV-to-POV impact speed	--	16.8 mph (27.0 km/h)
25 mph	SOV-to-POV reveal headway[1]	37.3 ft[2] (11.4 m)	37.5 ft[2] (11.4 m)
	SV-to-POV minimum range	3.9 ft (1.2 m)	0
	SV-to-POV impact speed	--	24.2 mph (38.9 km/h)
Total Impacts		2/8	

[1] Yaw rate was used to identify the onset of lane change. Lateral acceleration was unavailable.

[2] The desired reveal headway is between 39 and 41 ft.

improved the results. However, these trials also indicated that each test speed will likely require its own iterative tuning to ultimately achieve the desired reveal headway. Confirmation of this is process recommended for future testing. All other SRSV validity criteria described in the were satisfied.

4.3. LCLVB Results

A summary of the SV's minimum range to the POV, SV speed at the time POV impact, and the SV-to-POV relative impact speeds observed during the LVLCB tests are shown in **Table 4-4**.

Table 4-4. LVLCB SV Performance Summary

Post LC Deceleration		**0.3 g**		**0.6 g**	
In-Turn Deceleration		0 g	0.1 g	0 g	0.1 g
10 mph	Minimum range to POV	--[1]		--[1]	
	SV impact speed	--		--	
	SV-to-POV relative impact speed	--		--	
15 mph	Minimum range to POV	9.6 ft[2,3] (2.9 m)		2.6 ft[4,5] (0.8 m)	
	SV impact speed	--		--	
	SV-to-POV relative impact speed	--		--	
20 mph	Minimum range to POV	3.4 ft[2,6] (1.0 m)	0[7,8]	0.2 ft[2,3,4,5] (0.06 m)	0[7]
	SV impact speed	--	20.0 mph (32.2 km/h)	--	15.5 mph (24.9 km/h)
	SV-to-POV relative impact speed	--	10.1 mph (16.3 km/h)	--	5.9 mph (9.5 km/h)
25 mph	Minimum range to POV	5.0 ft[2] (1.5 m)	0.9 ft[2,7] (0.3 m)	0[2,5]	0[2,7]
	SV impact speed	--	--	18.0 mph (29.0 km/h)	16.5 mph (26.6 km/h)
	SV-to-POV relative impact speed	--	--	17.2 mph (27.7 km/h)	3.7 mph (6.0 km/h)
Total Impacts		**4/10**			

[1] 10 mph (16.1 km/h) tests without in-turn deceleration were not performed; the headway between the SV and SOV was not great enough to support a POV lane change between them.

[2] Test did not satisfy the second POV deceleration start time.

[3] Test did not satisfy POV path error limits.

[4] Test did not satisfy the second POV average deceleration check.

[5] Test did not satisfy second POV initial deceleration magnitude check.

[6] Test did not satisfy longitudinal POV range requirements.

[7] Test did not satisfy POV in-turn deceleration start time criteria.

[8] Test did not satisfy POV steady-state criteria.

With regards to the SV-to-POV impacts observed during these tests:

- The SV automatically braked to a stop to avoid the POV during the tests nominally performed from 15 mph (24.1 km/h).
- When the SV and POV speed was nominally 20 mph (32.2 km/h), impacts occurred during both tests performed with within-lane change POV deceleration. When no within-lane change deceleration was used, the SV avoided the POV by automatically braking to a stop.
- When the SV and POV speed was nominally 25 mph (40.2 mph), impacts occurred during tests performed with nominal post-lane change decelerations of 0.6g, regardless of whether POV within-lane change deceleration was used or not. No SV-to-POV impacts occurred when the post-lane change POV deceleration was nominally 0.3g. When no SV-to-POV impact occurred, crash avoidance was achieved by the SV automatically braking to a stop.

Each LVLCB trial failed at least one validity criteria. The in-turn and final deceleration start times criteria were not satisfied during four of ten, and seven of ten trials respectively. Other validity criteria unable to be satisfied are noted in **Table 4-4**. Consistent validity check failures beyond those related to POV deceleration were not observed. Since satisfying these checks was generally not problematic (e.g., having the POV achieve steady-state speed for at least 3 seconds), affected trials were not repeated due to testing time constraints.

Table 4-5 provides POV deceleration start times (relative to the completion of the POV lane change); (b) the time taken to reach the desired initial POV deceleration magnitude; (c) initial POV deceleration magnitudes (threshold values from the draft test procedure if satisfied, and actual values if not); and (d) average POV deceleration values used to assess test validity. Values exceeding their respective target value tolerances are shown in red. In summary:

- POV deceleration did not begin ≤ 0.1 s after the lane change was completed during 5 of 6 trials performed with no in-turn deceleration, and during each of the four trials performed with in-turn deceleration.
- The time taken to achieve the desired deceleration magnitude was > 0.5 s three times.
- All LVLCB initial magnitude and average deceleration validity violations occurred during the 0.6 g deceleration portion of the respective test.
- Each of three non-impacting 0.6 g tests failed to meet the minimum initial POV deceleration magnitude of 0.55 g.
- Two out of three non-impacting tests did not meet the minimum average POV deceleration magnitude of 0.55 g.

Extensive PID tuning efforts were made to in an attempt to rectify the braking-related validity violations. Adjusting the apply velocity (i.e., not PID adjustment) seemed to have the greatest positive affect on achieving the desired braking characteristics. Since this test did not require 0.3 and 0.6 g decelerations to occur within the same test trial, each application magnitude was tuned separately. This allowed the 0.3 g decelerations to be executed with less overshoot, but did not significantly improve the ability to achieve the desired magnitude during tests performed with a 0.6 g target deceleration. Also, after examining all data collected, it was determined that 0.02 g was not the most accurate point for determining the onset (or completion) of the lane change, which in turn, made it difficult to accurately and consistently assess whether the POV was able

Table 4-5. LVLCB POV Deceleration Validity Check

Test Type		No In-Turn Deceleration		With In-Turn Deceleration			
Deceleration		0.3 g	0.6 g	0.1 g	0.3 g	0.1 g	0.6 g
15 mph	Onset after lane change (s)[1]	-0.33	0.01				
	Magnitude first realized (s)[2]	0.39	0.80				
	Initial Deceleration Magnitude (g)[3]	0.25	0.40				
	Average deceleration (g)[4]	0.31	0.53				
20 mph	Onset after lane change (s)[1]	-0.42	-0.52	-0.2	-	-0.29	-
	Magnitude first realized (s)[2]	0.26	0.81	0	-	0	-
	Initial Deceleration Magnitude (g)[3]	0.25	0.39	0.05	-	0.05	-
	Average deceleration (g)[4]	0.31	0.55	0.10	-	0.10	-
25 mph	Onset after lane change (s)[1]	-1.11	-0.62	-0.18	-0.34	-0.02	0.15
	Magnitude first realized (s)[2]	0.31	0.61	0	0.18	0	-
	Initial Deceleration Magnitude (g)[3]	0.25	0.44	0.05	0.25	0.05	-
	Average deceleration (g)[4]	0.32	0.64	0.10	0.32	0.10	-

[1] Braking to be initiated within ±0.1s of POV lane change.

[2] Must occur within ±0.5s. Values outside of this tolerance are highlighted in red.

[3] Taken at the first data count after the lower threshold of the nominal magnitude is exceeded, or at a time 0.5s after the onset of braking if the lower threshold of the nominal magnitude is not exceeded. The later values are highlighted in red.

[4] From 0.5s after brake onset to 250 ms before POV stops or SV-to-POV impact occurs. Values that exceed the tolerances of the respective nominal value are highlighted in red.

to satisfy the validity criteria requiring the POV begin its deceleration within 0.1 s after initiating its lane change.

To more accurately and consistently identify the onset and completion of the POV lane change, it was recommended that the related threshold be increased from 0.02 to 0.03 g. To address the concern of being unable to accurately and consistently achieve a deceleration of 0.6 g, it was recommended the maximum POV used during the LVLCB tests be reduced to 0.5 g. Both recommendations are discussed in greater detail in Sections 5.2 and 5.3, respectively.

5.0 POST-TEST CHANGES TO NHTSA'S DRAFT TJA PROCEDURE

As previously explained in Section 1, the test procedures used for the evaluations described in this report were based on a revision of NHTSA's April 2018 TJA draft test procedure. Based on observations made during these test, and review of the subsequent results, additional revisions were deemed appropriate. These revisions, which are discussed in Sections 5.1, 5.2, and 5.3, have been incorporated into the October 2019 release of NHTSA's TJA draft test procedure.

5.1. Test Burden Reduction

The number of test speed combinations per scenario has been reduced from four to two. Tests performed with the SV initially travelling at 10 or 20 mph (16.1 or 32.1 km/h) have been removed to ensure all the tests described in the draft test procedure can actually be performed and to reduce test burden. Tests performed with the SV operating at 10 mph (16.1 km/h), when performed, did not produce results markedly different than those performed at 15 mph (24.1 km/h). A similar trend was often observed for tests performed at 20 and 25 mph (32.1 and 40.2 km/h), and when differences in test outcome were present, the 25 mph (40.2 km/h) tests appeared to be more challenging. Therefore, the test speeds included within the October 2019 TJA draft test procedure are limited to 15 and 25 mph (24.1 and 40.2 km/h).

A second significant change present in the October 2019 TJA draft test procedure is the specification that all tests must be performed with the SV ACC set to the farthest setting only (i.e., the setting that provides the longest following distance when a lead vehicle is present ahead of the SV in its travel lane). The LVLCB tests performed in the work described in this report indicate that, for some vehicle models, this change ensures sufficient room between the SV and SOV for the POV to change lanes between them. In the case of the SRSV, the combination of the highest speed (25 mph or 40.2 km/h) and shortest SV-to-SOV headway (achieved with the nearest SV ACC setting) did not always provide sufficient time for the SV to avoid an impact with the stopped POV. For LVDAD tests, it is less clear that the SV ACC should be set to its farthest setting. However, since the maneuver requires moderately high POV braking, maneuver severity still is expected to be sufficiently high. Also, consistently specifying the same ACC setting for all test conditions minimizes the potential for an incorrect setting being used during test conduct.

5.2. Test Burden Reduction

The "SOV lane change onset" threshold in the SRSV and LVLCB tests, and the "completion of POV lane change" threshold in the LVLCB test, have been increased from 0.02 to 0.03 g. This was done to more accurately and reliably define the onset/completion of the lane change during data post processing by using a threshold less affected by the signal noise present in the lateral acceleration channel, and is a change recommended for future testing.[4] These points must be properly identified to assess the validity check stating that each stage of POV deceleration shall be initiated within 0.1 s after the onset/completion of the POV lane change, as shown in **Figure 5-1**.

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[4] Use of a threshold closer to zero is desirable from the perspective of best identifying the instant a lane change is initiated or completed, but if this threshold is below the data channel's noise floor, it is nearly impossible to accurately and consistently determine the true initiation/completion point.

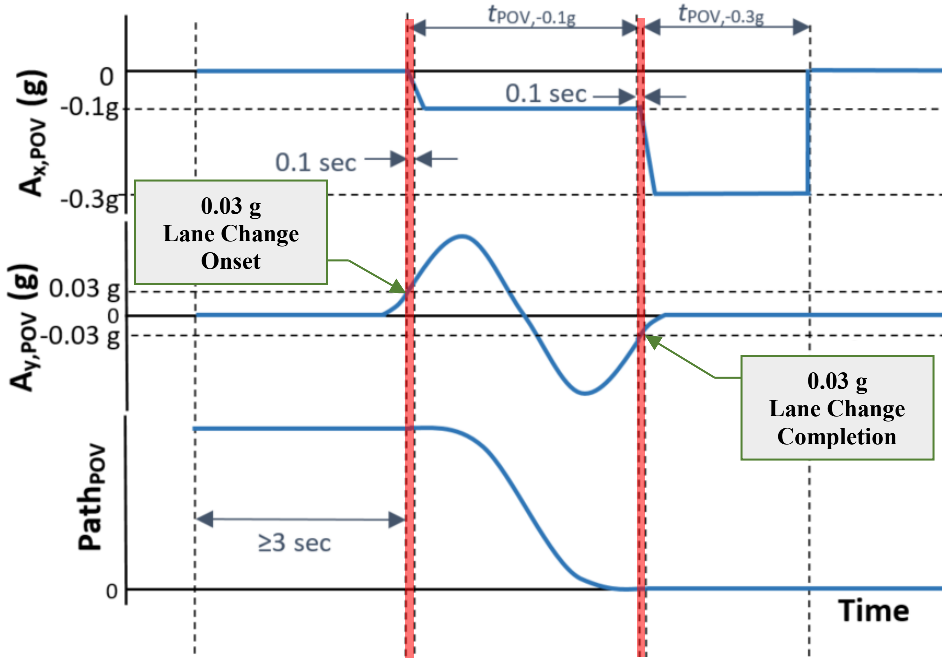

Figure 5-1. Example POV lane change onset and completion.

5.3. Maximum POV Deceleration

The maximum POV deceleration used in the LVDAD and LVLCB scenarios has been reduced from a nominal value of 0.6 g to 0.5 g. **Figure 5-2** shows examples of four attempts to establish and maintain constant POV decelerations of 0.3 and 0.6 g. One trial per initial test speed is shown, and are offset in time for ease of comparison.

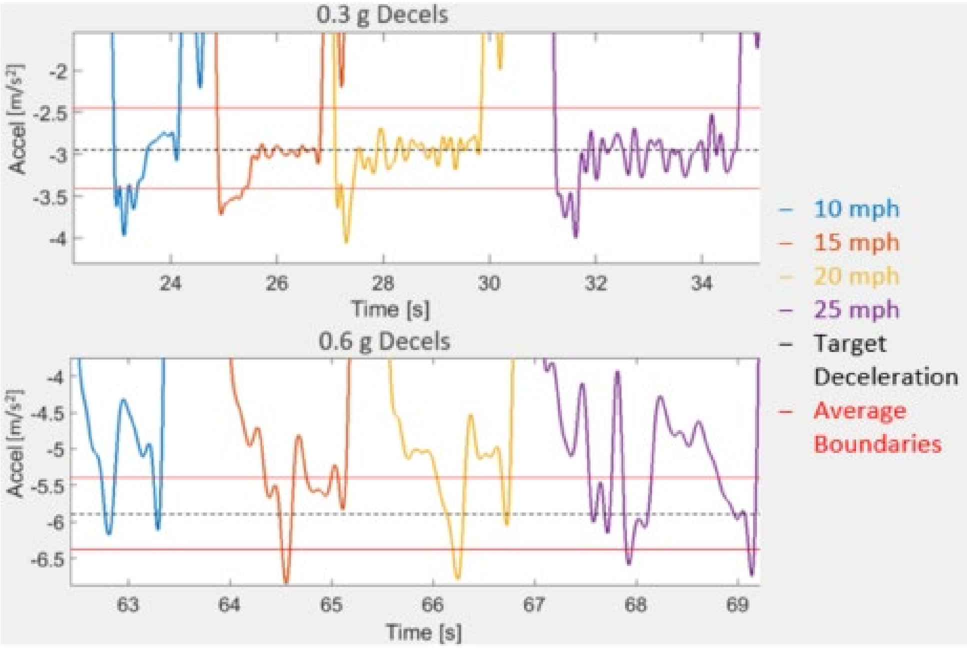

Figure 5-2. Example POV decelerations.

The 0.3 g POV decelerations shown in **Figure 5-2** overshoot the maximum range (greater than 0.35 g) just after completion of the POV brake application; however, average steady-state deceleration within the required range (tolerance) of 0.25 to 0.35 g is achieved shortly thereafter. POV deceleration exhibited greater oscillations during the attempt to achieve 0.6 g braking, and did not settle into a steady-state the way the lesser braking magnitude did.

Figure 5-3 presents examples from experimental tests performed after those described earlier in this report. While additional work remains, comparison of the deceleration results from tests with a target deceleration of 0.6 g (**Figure 5-2**) to those with a 0.5 g target (**Figure 5-3**) indicate some improvements in consistency throughout the braking event.

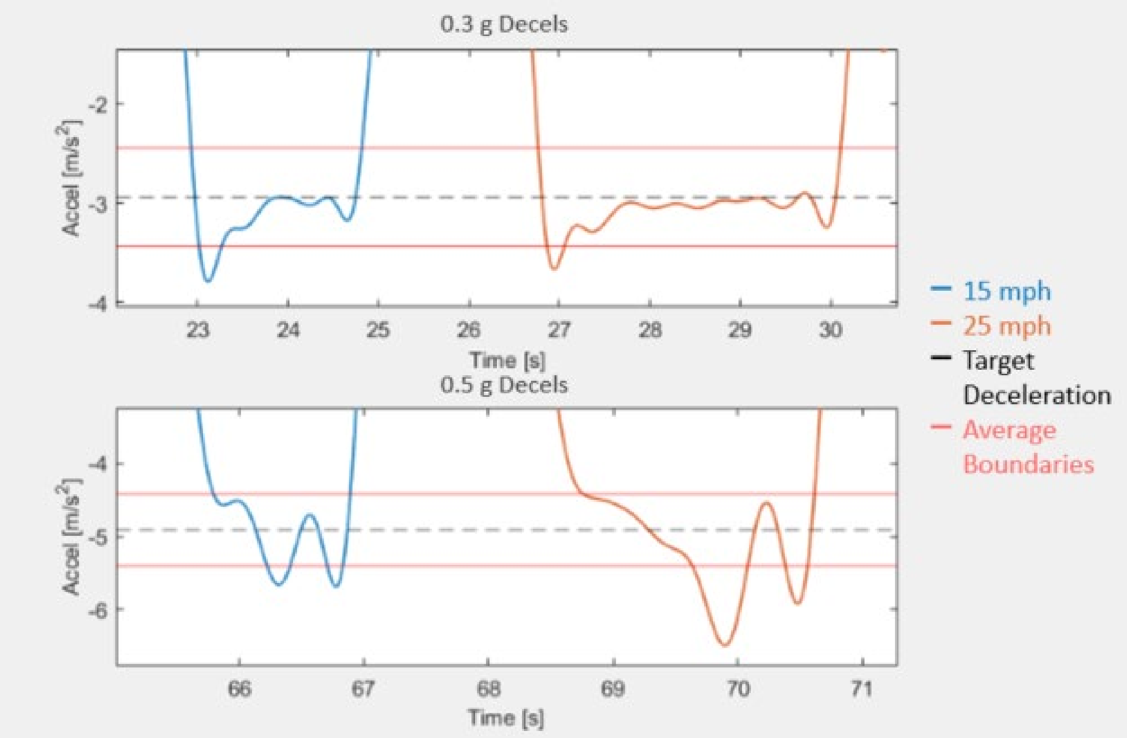

Figure 5-3. Improved POV decelerations.

The decrease in maximum POV deceleration is also expected to reduce equipment wear. Not only is a deceleration of 0.6 g at the maximum braking capability of the LPRV, it is also the default magnitude used by the LPRV during an emergency stop (i.e., severe braking designed to bring the platform to rest as rapidly as possible, typically activated for safety considerations). Therefore, staying below the LPRV's maximum capability is expected to help increase component longevity, particularly for tires and braking components.

6.0 SUMMARY AND CONCLUSIONS

The work described in this report demonstrates that the tests defined in the revised version of the April 2018 version of NHTSA's draft TJA test procedure were generally able to be performed as specified. However, some additional adjustments are recommended since satisfying all validity criteria, for each scenario/test condition, was not always possible. Where applicable, (a) POV and SOV lane change onset timing; (b) POV lane change completion timing; (c) initiating and achieving the proper POV deceleration within an acceptable time, and (d) average POV deceleration proved to be the most problematic. However, recommendations as how to address these issues have been provided, and they have been incorporated into NHTSA's October 2019 TJA draft research test procedure.

- For the LVDAD tests, the POV was unable to consistently achieve the desired initial and average deceleration magnitudes for each test speed. However, this was primarily an issue during the 0.6 g deceleration portion of the test, and reducing the specified magnitude to 0.5 g is expected to improve test execution and bring the tests within specifications. The same adjustment is expected to improve the ability of the POV to achieve the highest deceleration specified for the LVLCB tests.
- Achieving the desired 40 ft (12.2 m) POV reveal headway during the SRSV tests is expected to be possible via iterative adjustments of the GST configuration settings available within the software used to control it.
- Adjusting the lane change onset/completion threshold values from 0.02 to 0.03 g is expected to more accurately and consistently define the onset and completion of the POV lane changes performed during the LVLCB scenario. These data points indicate if the POV was able to begin braking within the desired "POV lane change onset" and the "completion of POV lane change" times.
- Adjusting the time when the POV must begin braking after initiating (when required) and completing its lane change from 100 ms to 250 ms is expected to more consistently allow the GST-based POV to satisfy the applicable validity criteria during the LVLCB scenario.

In addition to the adjustments needed to further improve test performability, other adjustments are recommended to reduce test burden. They include removing the 10 and 20 mph (16.1 or 32.1 km/h) tests from each scenario and only using the farthest SV ACC headway setting. The adjustments to reduce test burden have been incorporated into NHTSA's October 2019 TJA draft research test procedure.

7.0 REFERENCES

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