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INTERSECTION SAFETY ASSIST SYSTEM CONFIRMATION TEST

(WORKING DRAFT)

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This draft test procedure provides specifications used by the National Highway Traffic Safety Administration (NHTSA) to research Intersection Safety Assist System (ISA) system performance on light vehicles with gross vehicle weight ratings (GVWR) of up to 10,000 lbs (4,536 kg). ISA is a driver assistance system designed to actively help the driver avoid an intersection-based collision with another vehicle that is approaching, or has entered into, the forward path of their vehicle. The expected operating domain for ISA includes roadway intersections supporting stopped and low speed traffic. Examples include residential and urban roads.

The test procedures described in this document use three scenarios to assess ISA operation on the test track. Each scenario is performed with different combinations of SV and Principal Other Vehicle (POV) speeds, and include both crash-imminent and near-miss test choreography.   For all tests described in this document, the POV is a strikeable object with the characteristics of a compact passenger car.

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INTERSECTION SAFETY 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
FHWA	Federal Highway Administration
GVT	Global Vehicle Target
GVWR	gross vehicle weight rating
ISA	intersection safety assist
LCC	lane centering control
lidar	light detection and ranging
NHTSA	National Highway Traffic Safety Administration
POV	principal other vehicle
radar	radio detection and ranging
SAE	formerly known as the Society of Automotive Engineers, and as SAE International since 2006
SOV	secondary other vehicle
SV	subject vehicle

1.0 PURPOSE AND APPLICATION

This draft test procedure provides specifications used by the National Highway Traffic Safety Administration (NHTSA) to research Intersection Safety Assist (ISA) 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 ISA includes roadway intersections supporting stopped and low speed traffic. Examples include residential and urban roads.

The tests contained in this document are intended for evaluation of Society of Automotive Engineers (SAE) automation level 0, 1, 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 ISA systems (e.g., vehicle-to-vehicle (V2V) 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 ISA systems, and/or (2) higher level automated vehicles.

Note: *The subject vehicle (SV) driver shall not provide manual[1] inputs to the accelerator pedal, brake pedal, or steering wheel when the tests described in this document are performed with the SV operating in SAE automation level 2 or 3 within the applicable validity periods. This provision is intended to eliminate the potential for ISA 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 three scenarios to assess ISA operation on the test track. Each scenario is performed with different combinations of SV and Principal Other Vehicle (POV) speeds, and includes both crash-imminent and near-miss test choreography.

For all tests described in this document, the POV shall be a strikeable object with the characteristics of a compact passenger car[2]. At no time shall the SV contact the POV during the conduct of any trial described in this document.

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[1] In the context of this document, manual inputs are not automatically controlled by the SV itself. Manual steering may be input by the SV driver, a robotic controller, etc.

[2] POV specifications are described in S4.6.

3.0 DEFINITIONS

In the context of this document, ISA is a driver-assistance system designed to actively help the driver avoid an intersection-based collision with another vehicle that is approaching, or has entered into, the forward path of their vehicle.

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 (PFC) of at least 0.9 when measured using an American Society for Testing and Materials (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 Intersection Geometry

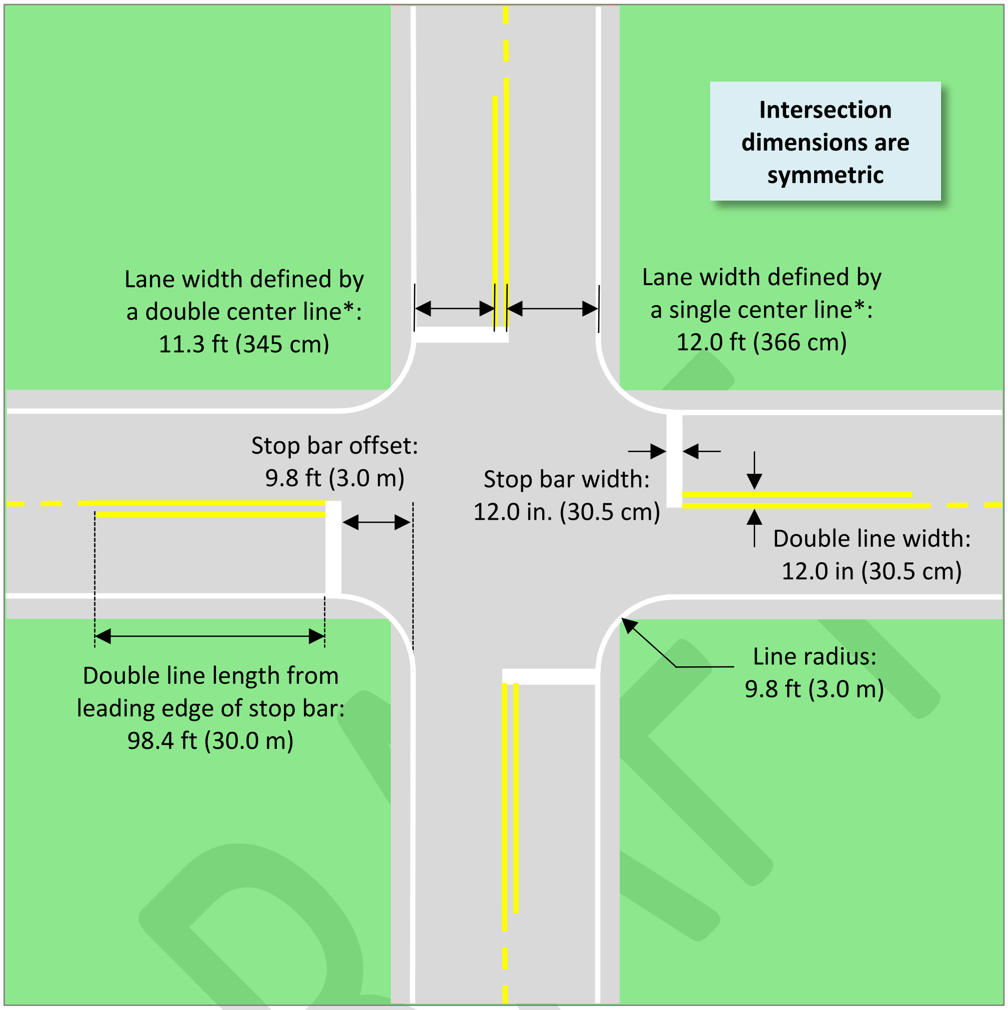
The intersection shall be comprised of a simple, four-approach, two-lane layout, shown in Figure 1.

4.3 Line Markings

The lines used to delineate each lane leading to, and extending through the intersection, shall meet the Federal Highway Administration (FHWA) specifications defined in the Manual on Uniform Traffic Control Devices (MUTCD) and be in “very good condition” [2].

4.3.1 Lane Line and Stop Bar Styles

The intersection used for the tests defined in this document shall be defined by solid white edge lines, solid white stop bars, and yellow center lines. The lanes leading up to the intersection shall be defined by solid white edge lines. The yellow center lines shall begin at the respective stop bars as double lines, and continue away from the intersection for 30 meters. The center line shall then become a single dashed line for the remainder of the test course. Details about line placement are shown in Figure 1.



*Measured from center of the 4" (102 mm) lane lines.

Figure 1. Four-way intersection used for ISA evaluations.

4.3.2 Lane Line and Stop Bar Color and Reflectivity

Lane lines, stop bar color, and reflectivity shall meet all applicable standards. These standards include those from the International Commission of Illumination (CIE) for color and the American Society for Testing and Materials (ASTM) on lane marker reflectance. Methods for determining lane marker characteristics are discussed in the Road Departure Crash Warning Systems (RDCWS) Field Operational Test (FOT) by the National Institute of Standards and Technology (NIST) [3].

4.3.3 Lane Line and Stop Bar Marker Width

The stop bars shall be 12 in. (30.5 cm) wide, as defined in Section 3B.16 of the MUTCD [2]. In accordance with Section 3A.06 of the MUTCD,

- The width of all lane lines shall be 4 to 6 in. (10.2 to 15.2 cm), and

- The sections of solid double center lines shown in Figure 1 shall be separated by 4 to 6 in (10.2 to 15.2 cm).

4.3.4 Dashed Lane Line Marker Length and Spacing

The dashed center lines shall be comprised of 10 ft (3 m) line segments and 30 ft (9 m) gaps.

4.3.5 Approach Lane and Intersection Leg Width

The width of each approach lane, measured from the center of the white edge line to the center of the dashed yellow line, shall be 12 ft (366 cm). Once the double yellow line begins, the left-side leg width shall be 12 ft (366 cm) from the center of the left lane's white edge line to the center of the nearest yellow center line, whereas the right-side width (the side with the stop bars) shall be 11.3 ft (345 cm) from the center of the right lane's white edge line to the center of the nearest (most inboard) yellow center line.

4.3.6 Longitudinal Distance to Stop Bar

To provide enough time for the SV and POV to accelerate[3] to the speeds specified in this test procedure, and to remain at them for at least three (3) seconds, the distance from the beginning of each approach lane to the leading edge of their respective stop bars is recommended to be at least 300 ft (91 m).

4.3 Ambient Conditions

4.3.1 Ambient Temperature

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

4.3.2 Wind Speed

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

4.3.3 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.

4.3.4 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 SV oriented into the sun during very low sun angle conditions, where the sun

[3] These dimensions assume a vehicle accelerates from rest at 0.127g (1.25 m/s^2) to a nominal speed of 25 mph (40.2 km/h). If greater acceleration can be achieved by the vehicles while having the scenario choreography remain intact, it is possible that the longitudinal distance to the stop bars could be lessened.

is oriented 15 degrees or less from horizontal and potential camera “washout” or system inoperability could result.

4.4 Principal Other Vehicle (POV) Specifications

To safely perform tests described in this document, the POV shall be a realistic surrogate vehicle with the characteristics of a compact passenger car. This is intended to maximize the ability of the SV to detect the POV 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 (e.g., 24 GHz and 76-77 GHz bands) and lidar (e.g., 905 or 1550 nm) 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 S4.6.

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 enclosed within the GVT’s vinyl covers. The GVT is dimensionally similar to a 2013 Ford Fiesta hatchback and is secured to a low-profile robotic platform using Velcro attachment points. Internally, the GVT consists of a vinyl-covered foam structure. If a test vehicle impacts the it at low speed, the GVT is designed to separate, and 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 Instrumentation Required

4.5.1 Sensors and Sensor Locations

An overview of the sensors used for the tests described in this document is provided in Table 1.

4.5.1.1 Vehicle Position

The position of the SV and POV relative to their respective travel lanes and test intersection, and the position of the SV relative to the POV, 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.

4.5.1.2 Vehicle Speed

The lateral and longitudinal velocities of the SV and POV (where applicable) shall be measured within the test validity period. The sensor(s) used for this measurement is (are) not constrained provided they meet the range, resolution, and accuracy specifications provided in Table 1.

4.5.1.3 Yaw Rate

SV 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.

4.5.1.4 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.

4.5.1.5 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.

Table 1 – Recommended Measurements and Measurement Specifications

Type	Output	Range	Resolution	Accuracy
Various	Lateral and Longitudinal position of SV and POV	650 ft (200 m)	2 in (5 cm)	At least 3.9 in (10 cm) absolute
Speed Sensors	SV and POV 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 POV 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 Sensor	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 in. lbf (56 Nm)	5 in. lbf (0.6 Nm)	5 in. lbf (0.6 Nm)
Video recorded messages	Visual/audible vehicle instructions, notifications, and/or alerts presented to the driver	N/A	At least 720p	N/A
Vehicle Dimensional Measurements	Location of SV and POV GPS antennas; SV and POV 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 center of gravity (CG)) and rear-most POV bumper position.	N/A	2 in (5 cm)	At least 3.9 in (10 cm) absolute

4.5.1.6 SV Accelerator Pedal Position

SV accelerator pedal position shall be measured to ensure that the driver did not manually apply an input within the validity period during tests performed with cruise control enabled (conventional or adaptive). 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 (WOT) pedal position.

4.5.1.7 SV Instructions, Notifications, and/or Alerts

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

4.5.1.8 Forward Collision Warning (FCW) 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.

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 0, 1, 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. ISA system performance shall be evaluated in accordance with the test procedures described in S5.3.5, S5.3.6, and 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 Gross Vehicle Weight Rating (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/s²) during each stop.

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

    B. The Initial Brake Temperature (IBT), 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 and POV 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 and POV shall be placed in "Park" or with the system brake enabled (robotic platforms).

   B. The SV and POV shall remain at rest until transmissions from least six (6) GPS satellites have been obtained and indicated by the vehicle's respective instrumentation.

2. Dynamic initialization

   A. The SV and POV 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 and POV shall be driven in three (3) figure eight patterns. The radii of the turns shall be approximately 20 ft (6 m).

   C. If necessary, steps 5.1.1.2.A and 5.1.1.2.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 to assist in resolving uncertain test data. The orientation of the POV relative to the SV used during static calibration is scenario-dependent.

1. The "crash-imminent" SV-to-POV orientation described in S5.3.6 shall be used for static calibration before the ISA Scenario 1 tests are performed. The position where the front center of the SV just contacts the POV shall be defined as the ISA Scenario 1 zero position.

2. The "crash-imminent" SV-to-POV orientation described in S5.3.7 shall be used for static calibration before the ISA Scenario 1 tests are performed. The position where the front center of the SV just contacts the POV shall be defined as the ISA Scenario 2 zero position.

3. The "crash-imminent" SV-to-POV orientation described in S5.3.8 shall be used for static calibration before the ISA Scenario 1 tests are performed. The position where the front center of the SV just contacts the POV shall be defined as the ISA Scenario 3 zero position.

4. 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.**

5. Static data files shall be collected prior to, and immediately after, conduct of the test series described in S5.3.6, S5.3.7, and S5.3.8. 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.

5.2 ISA Pre-Test System Initialization

Some SVs may require a brief period of initialization (e.g., verification of sensor alignment and detection readiness) before their respective ISA 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, S5.3.6, and S5.3.7 of this document, the following requirements shall be satisfied unless otherwise specified:

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 shall be latched.

3. To operate the SV at constant speed in automation level 0 within the validity period, SV speed shall be maintained by (1) the SV driver manually modulating the SV accelerator pedal, or (2) use of conventional cruise control unless the SV ISA system automatically terminates its operation.

4. Operating the SV in automation level 1 requires SV ACC (i.e., not the vehicle's lane centering system) be enabled and in operation prior to the onset of the validity period. For these tests, the SV ACC shall remain in operation unless automatically terminated by an SV ISA intervention.

5. Operating the SV in automation level 2 or 3 requires the SV ACC and Lane Centering Control (LCC) systems both be enabled and in operation prior to the onset of the validity period. For these tests, the SV ACC and LCC systems shall remain in operation unless automatically terminated by an SV ISA intervention.

6. The SV driver shall not provide manual inputs to the SV accelerator and/or brake pedals while the SV is being operated in automation level 1, 2, or 3 within the validity period (i.e., while ACC is actively modulating the SV speed).

7. While the SV is operated in automation level 0 or 1 and being driven in a straight line, the SV yaw rate must not exceed ±1.0 deg/s (1) within the validity period or (2) from the onset of the validity period to the onset of an ISA system intervention.

8. The SV yaw rate produced within the validity period while the SV is operated in automation level 2 or 3 is not restricted.

9. The SV path shall be within ± 0.8 ft (0.25 m) of the nominal specification during the validity period when operated in automation level 0 or 1. SV path deviation during tests performed in automation level 2 or 3 is not restricted provided the SV remains within its travel lane.

10. The POV path shall be within ± 0.8 ft (0.25 m) of the nominal specification during the validity period.

11. To ensure the proper SV-to-POV choreography is realized, a combination of closed- and open loop control of the POV relative to the SV shall be used.

5.3.2 Adaptive Cruise Control (ACC) 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. Since none of the scenarios described in this document begin with the SV following a lead vehicle, the ACC headway setting is not expected to affect the initial conditions of any test trial. However, for the sake of test consistency, 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 (LCC) Settings

In the context of this document, LCC systems continuously provide the steering inputs needed to keep the SV centered in its travel lane. Unlike ACC (where applicable), 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.

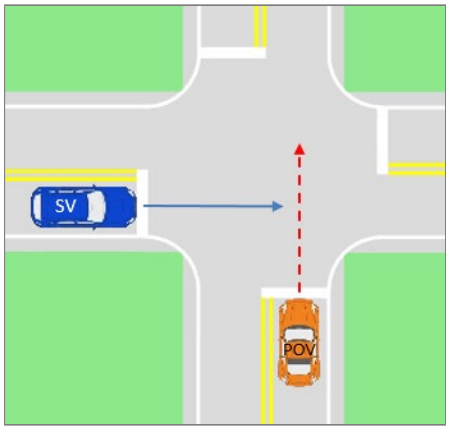
Note: *LCC system functionality differs from that provided by Lane Keeping Support (LKS) or Lane Keeping Assist (LKA) systems, as the latter are only intended to provide the brief heading corrections needed to bring the vehicle away from a lane line after it has been crossed or if a crossing has been deemed imminent.*

5.3.4 Data Collection Interval

Data collection for all trials described in this document shall be initiated at the onset of the validity period, and end at least 5 seconds after completion of any termination condition.

5.3.5 ISA Scenario 1: POV Straight Across SV Path

The objective of the ISA Scenario 1 test, shown in Figure 2, is to evaluate the ISA system's ability to detect and respond to a POV driven straight across the SV's forward path using POV approaches from both the left and right side of the SV. Three SV and POV speed combinations are used, as well as crash-imminent and near-miss timing. The specific details of how a given ISA Scenario 1 test is performed not only depends on the SV-to-POV speed combination and timing, but also what level of automation the SV is being operated in.



ISA Scenario	Vehicle Speeds	
	SV	POV
S1-A	25 mph (40.2 km/h)	25 mph (40.2 km/h)
S1-B	25 mph (40.2 km/h)	0 ⇨25 mph (0 ⇨ 40.2 km/h)
S1-C	0 ⇨25 mph (0 ⇨ 40.2 km/h)	25 mph (40.2 km/h)

Figure 2. ISA Scenario 1: POV Straight Across SV Path (right-side POV approach is shown).

For ISA Scenario 1 tests performed with a <u>right-side</u> POV approach:

- "Crash-imminent" timing shall be defined as the SV-to-POV choreography that results in TTC = 0 seconds occurring when the front center of the SV impacts the POV at its <u>left-side</u> longitudinal center point (see Figure 3, left).

- "Near-miss" timing shall be defined as the SV-to-POV choreography that results in the front center of the SV first breaching a vertical plane defined by the widest part of the POV along its <u>left side</u> (not considering the side mirror) at a distance of 6.6 ft (2 m) behind a perpendicular plane defined by the rearmost part of the POV (see Figure 3, right).

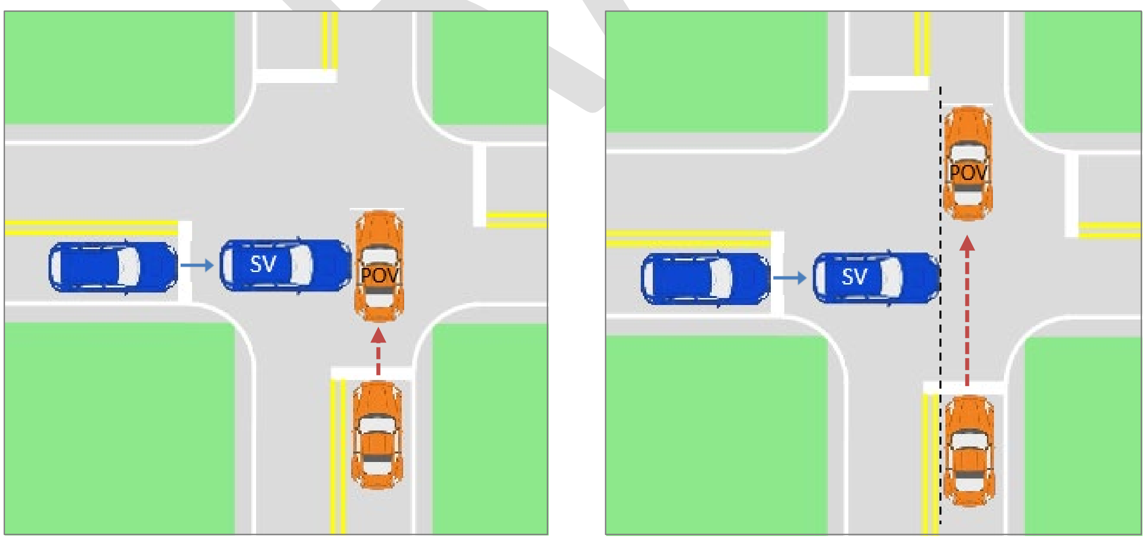


Figure 3. ISA Scenario 1 crash-imminent (left) and near-miss (right) timing. A right-side POV approach is shown.

For ISA Scenario 1 tests performed with a left-side POV approach:

- "Crash-imminent" timing shall be defined as the SV-to-POV choreography that results in TTC = 0 seconds occurring when the front center of the SV impacts the POV at its right-side longitudinal center point.

- "Near-miss" timing shall be defined as the SV-to-POV choreography that results in the front center of the SV first breaching a vertical plane defined by the widest part of the POV along its right side (not considering the side mirror) at a distance of 6.6 ft (2 m) behind a perpendicular plane defined by the rearmost part of the POV.

5.3.5.1 ISA Scenario 1-A (S1-A): Constant SV and POV Speed

In addition to the applicable general test requirements described in S5.3.1, the following requirements must also hold true throughout each ISA S1-A trial:

A. Staging

i. The SV and POV shall be staged at rest.

ii. The SV and POV shall be located behind the intersection stop bar of their respective travel lanes at a distance where they can each be accelerated to the desired test speed by the onset of the validity period. Nominal recommendations for the staging distance, which assume average SV and POV accelerations of 0.127 g (1.25 m/s) from rest, are provided in Tables 2 and 3.

B. Test Conduct

i. Using closed-loop control of the POV relative to the SV, both vehicles shall begin driving at the same time using the same acceleration profile until the desired speed is achieved.

ii. The SV shall remain centered in its travel lane within the validity period, or up to the onset of an ISA intervention that occurs within the validity period, when operated in automation level 0 or 1.

iii. The POV shall remain centered in its travel lane within the validity period.

iv. The POV forward velocity shall be maintained via:

a. Closed loop control relative to the SV from the beginning of the test (i.e., not just the onset of the validity period) to a time $t = t_{pov\_stop\_bar} - 1$ second, where $t_{pov\_stop\_bar}$ is the time when the front most part of the POV first reaches the leading edge of the intersection stop bar located in the POV travel lane, and

b. Open loop control from a time $t > t_{pov\_stop\_bar}$ – 1 second.[4]

v. For S1-A tests performed with manual control of the SV speed,

a. The driver shall maintain the SV speed within the validity period, or up to the onset of an ISA intervention that occurs within the validity period.

b. If an ISA intervention occurs, the driver shall release the SV accelerator pedal within 500 ms of the ISA intervention onset.

vi. For S1-A tests that use cruise control to maintain SV speed,

a. The SV driver shall enable the SV cruise control before onset of the validity period.

b. The SV cruise control shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

vii. For S1-A tests performed with level 1 automation,

a. The SV driver shall enable the SV ACC before onset of the validity period.

b. The SV ACC shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

viii. For S1-A tests performed with level 2 or 3 automation,

a. The SV driver shall enable the SV ACC and LCC before onset of the validity period.

b. The SV ACC shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

C. Scenario 1-A test synchronization check (see Appendix A Section 8.1 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. Right-side POV Approach

a. For tests performed with crash-imminent timing, the front center of the POV shall nominally be 3.34 ft (1.02 m) before the leading edge of the POV stop bar

[4] The transition from closed- to open-loop control is necessary so that POV speed is not affected by the SV speed reductions resulting from ISA braking.

at the instant the front center of the SV crosses the leading edge of the SV stop bar.

b. For tests performed with near-miss timing, the rear center of the POV shall nominally be 3.22 ft (0.98 m) past the leading edge of the POV stop bar at the instant the front center of the SV crosses the leading edge of the SV stop bar.

ii. Left-side POV Approach

a. For tests performed with crash-imminent timing, the front center of the POV shall nominally be 21.99 ft (6.70 m) past the leading edge of the POV stop bar at the instant the front center of the SV crosses the leading edge of the SV stop bar.

b. For tests performed with near-miss timing, the rear center of the POV shall nominally be 35.08 ft (10.69 m) past the leading edge of the POV stop bar at the instant the front center of the SV crosses the leading edge of the SV stop bar.

5.3.6.1 ISA Scenario 1-B (S1-B): Constant SV Speed, POV Accelerates from Rest

In addition to the applicable general test requirements described in S5.3.1, the following requirements must also hold true throughout each ISA S1-B trial:

A. Staging

i. The SV and POV shall be staged at rest.

ii. The SV shall be located behind the intersection stop bar of its travel lane at a distance where it can be accelerated to the desired test speed by the onset of the validity period. Tables 2 and 3 provide nominal staging distance recommendations, which assumes an average POV acceleration of 0.127 g (1.25 m/s) from rest.

iii. The front-most part of the POV shall be located at the leading edge of the intersection stop bar of its travel lane by the onset of the validity period.

B. Test Conduct

i. The driver shall accelerate the SV to the desired speed. SV acceleration is not restricted; however, the SV speed must be within the tolerance shown in Table 2 during the validity period.

ii. The SV shall remain centered in its travel lane within the validity period, or up to the onset of an ISA intervention that occurs within the validity period, when operated in automation level 0 or 1.

iii. For S1-B tests performed with manual control of the SV speed,

a. The driver shall maintain the SV speed within the validity period, or up to the onset of an ISA intervention that occurs within the validity period.

b. If an ISA intervention occurs, the driver shall release the SV accelerator pedal within 500 ms of the ISA intervention onset.

iv. For S1-B tests that use cruise control to maintain SV speed,

a. The SV driver shall enable the SV cruise control before onset of the validity period.

b. The SV cruise control shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

v. For S1-B tests performed with level 1 automation,

a. The SV driver shall enable the SV ACC before onset of the validity period.

b. The SV ACC shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

vi. For S1-B tests performed with level 2 or 3 automation,

a. The SV driver shall enable the SV ACC and LCC before onset of the validity period.

b. The SV ACC shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

vii. The POV shall remain centered in its travel lane within the validity period.

viii. The POV shall use an average acceleration of 0.127 g (1.25 m/s) from rest at its stop bar until it achieves the desired speed or is struck by the SV. Open-loop control shall be used to achieve and maintain POV speed.

C. Scenario 1-B test synchronization check (see Appendix A Section 8.2 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. Right-side POV Approach

a. For tests performed with crash-imminent timing, the onset of the POV acceleration shall occur when the front center of the SV is 96.52 ft (29.42 m) before the leading edge of the SV stop bar.

b. For tests performed with near-miss timing, the onset of the POV acceleration shall occur when the front center of the SV is 127.52 ft (38.87 m) before the leading edge of the SV stop bar.

ii. Left-side POV Approach

a. For tests performed with crash-imminent timing, the onset of the POV acceleration shall occur when the front center of the SV is 139.29 ft (42.45 m) before the leading edge of the SV stop bar.

b. For tests performed with near-miss timing, the onset of the POV acceleration shall occur when the front center of the SV is 165.14 ft (50.34 m) before the leading edge of the SV stop bar.

5.3.6.2 ISA Scenario 1-C (S1-C): SV Accelerates from Rest, Constant POV Speed

Note: For the reasons described in S5.3.12, ISA S1-C tests shall only be performed with the SV operating in automation level 0 and manual control of SV speed.

In addition to the applicable general test requirements described in S5.3.1, the following requirements must also hold true throughout each ISA S1-C trial:

A. Staging

i. The SV and POV shall be staged at rest.

ii. The front-most part of the SV shall be located at the leading edge of the intersection stop bar of its travel lane by the onset of the validity period.

iii. The POV shall be located behind the intersection stop bar of its travel lane at a distance where it can be accelerated to the desired test speed by the onset of the validity period. Tables 2 and 3 provide nominal staging distance recommendations, which assumes an average POV acceleration of 0.127 g (1.25 m/s) from rest.

B. Test Conduct

i. The POV shall accelerate to the desired speed. POV acceleration is not restricted, however the POV speed must be within the tolerance shown in Table 2 during the validity period. POV forward velocity shall be maintained via open loop control from a time $t < t_{pov\_stop\_bar}$ – 1 second until SV strikes the POV or the end of the validity period.

ii. The POV shall remain centered in its travel lane within the validity period.

iii. The SV shall use an average acceleration of 0.127 g (1.25 m/s) from rest at its stop bar until the it achieves the desired speed, an ISA intervention occurs, or the SV strikes the POV. Manual control shall be used to achieve and maintain the desired SV speed. If an ISA intervention occurs, the driver shall release the SV accelerator pedal within 500 ms of the ISA intervention onset [6].

iv. The SV shall remain centered in its travel lane within the validity period, or up to the onset of an ISA intervention that occurs within the validity period.

C. Scenario 1-C test synchronization check (see Appendix A Section 8.3 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. Right-side POV Approach

a. For tests performed with crash-imminent timing, the onset of the SV acceleration shall occur when the front center of the POV is 108.47 ft (33.06 m) before the leading edge of the POV stop bar.

b. For tests performed with near-miss timing, the onset of the SV acceleration shall occur when the front center of the POV is 95.38 ft (29.07 m) before the leading edge of the SV stop bar.

ii. Left-side POV Approach

a. For tests performed with crash-imminent timing, the onset of the SV acceleration shall occur when the front center of the POV is 59.11 ft (18.02 m) before the leading edge of the POV stop bar.

b. For tests performed with near-miss timing, the onset of the SV acceleration shall occur when the front center of the POV is 46.02 ft (14.03 m) before the leading edge of the POV stop bar.

5.3.6.3 ISA Scenario 1 Test Tolerances and Specifications

An overview of the ISA Scenario 1 test tolerances and specifications are shown in Tables 2 and 3, for tests performed with right- and left-side POV approaches, respectively.

Table 2. ISA Scenario 1 Test Specifications (Right-Side POV Approach).

Scenario	Initial Distance to Intersection Stop Bars[1]		Acceleration from Rest	Speed Within Validity Period	Lateral Path Tolerance Within Validity Period			Yaw Rate Within Validity Period[3]	Number of Trials Per Automation Level
	Crash-Imminent Timing	Near-Miss Timing			SV (Automation Level 0 and 1[2])	SV (Automation Level 2 and 3)	POV		
S1-A	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 276.6 ± 1 ft (84.3 ± 0.3 m)	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 270.0 ± 1 ft (82.3 ± 0.3 m)	Unrestricted from staging point	SV: 25 ± 1 mph (40.2 ± 1.6 km/h) POV: 25 ± 1 mph (40.2 ± 1.6 km/h)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3 3
S1-B	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 0 ft	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 0 ft	SV: Unrestricted from staging point POV: 0.127g (1.25 m/s^2) from stop bar	SV: 25 ± 1 mph (40.2 ± 1.6 km/h) POV: 0 ⇨25 ± 1 mph (0 ⇨ 40.2 ± 1.6 km/h)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3 3
S1-C	SV: 0 ft POV: 273.9 ± 1 ft (83.5 ± 0.3 m)	SV: 0 ft POV: 273.9 ± 1 ft (83.5 ± 0.3 m)	SV: 0.127g (1.25 m/s^2) from stop bar POV: Unrestricted from staging point	SV: 0 ⇨25 ± 1 mph (0 ⇨ 40.2 ± 1.6 km/h) POV: 25 ± 1 mph (40.2 ± 1.6 km/h)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3 3

[1] The non-zero distances are coarse approximations that assume the vehicle(s) achieve the desired steady state speed quickly after the acceleration from rest is complete.

[2] Where applicable.

[3] Yaw rate specifications are applicable only when the desired path of the SV is a straight line. Additionally, SV yaw rate specifications are only valid during tests performed in automation level 0 or 1.

[4] LCC actively controls the SV lateral path during tests performed in automation level 2 or 3.

Table 3. ISA Scenario 1 Test Specifications (Left-Side POV Approach).

Scenario	Initial Distance to Intersection Stop Bars[1]		Acceleration from Rest	Speed Within Validity Period	Lateral Path Tolerance Within Validity Period			Yaw Rate Within Validity Period[3]	Number of Trials Per Automation Level
	Crash-Imminent Timing	Near-Miss Timing			SV (Automation Level 0 and 1[2])	SV (Automation Level 2 and 3)	POV		
S1-A	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 252.6 ± 1 ft (77.0 ± 0.3 m)	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 239.5 ± 1 ft (73.0 ± 0.3 m)	Unrestricted from staging point	SV: 25 ± 1 mph (40.2 ± 1.6 km/h) POV: 25 ± 1 mph (40.2 ± 1.6 km/h)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3
									3
S1-B	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 0 ft	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 0 ft	SV: Unrestricted from staging point POV: 0.127g (1.25 m/s²) from stop bar	SV: 25 ± 1 mph (40.2 ± 1.6 km/h) POV: 0 ⇨25 ± 1 mph (0 ⇨ 40.2 ± 1.6 km/h)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3
									3
S1-C	SV: 0 ft POV: 273.9 ± 1 ft (83.5 ± 0.3 m)	SV: 0 ft POV: 273.9 ± 1 ft (83.5 ± 0.3 m)	SV: 0.127g (1.25 m/s²) from stop bar POV: Unrestricted from staging point	SV: 0 ⇨25 ± 1 mph (0 ⇨ 40.2 ± 1.6 km/h) POV: 25 ± 1 mph (40.2 ± 1.6 km/h)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3
									3

[1] The non-zero distances are coarse approximations that assume the vehicle(s) achieve the desired steady state speed quickly after the acceleration from rest is complete.

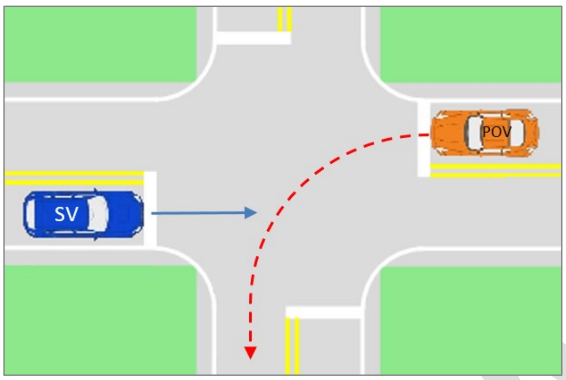
[2] Where applicable.

[3] Yaw rate specifications are applicable only when the desired path of the SV is a straight line. Additionally, SV yaw rate specifications are only valid during tests performed in automation level 0 or 1.

[4] LCC actively controls the SV lateral path during tests performed in automation level 2 or 3.

5.3.7 ISA Scenario 2: POV Left Turn Across SV Path

The objective of the ISA Scenario 2 test, shown in Figure 4, is to evaluate the ISA system's ability to detect and respond to a POV that turns left across the SV's forward path. Three SV and POV speed combinations are used, as well as crash-imminent and near-miss timing. The specific details of how a given ISA Scenario 2 test is performed not only depends on the SV-to-POV speed combination and timing, but also what level of automation the SV is being operated in.



ISA Scenario	Vehicle Speeds	
	SV	POV
S2-A	25 mph (40.2 km/h)	25 ⇨15 mph (40.2 ⇨ 24.1 km/h)
S2-B	25 mph (40.2 km/h)	0 ⇨25 mph (0 ⇨ 40.2 km/h)
S2-C	0 ⇨25 mph (0 ⇨ 40.2 km/h)	25 ⇨15 mph (40.2 ⇨ 24.1 km/h)

Figure 4. ISA Scenario 2: POV Left Turn Across SV Path.

For ISA Scenario 2:

- "Crash-imminent" timing shall be defined as the SV-to-POV choreography that results in TTC = 0 seconds occurring when the front center of the SV impacts the right front corner[5] of the POV (see Figure 5, left).
- "Near-miss" timing shall be defined as the SV-to-POV choreography that results in:
  - The front-most part of the SV reaching a vertical plane defined by the right side of the POV, parallel to the POV longitudinal centerline once the POV's turn has been completed, and
  - The front center of the SV being 6.6 ft (2 m) behind the rearmost part of the POV (see Figure 5, right).

5.3.7.1 ISA Scenario 2-A (S2-A): Constant SV Speed, POV Slows and Turns Left

In addition to the applicable general test requirements described in S5.3.1, the following requirements must also hold true throughout each ISA S2-A trial:

[5] Specifically, the right front corner of the POV shall be taken to be the intersection of two vertical planes: one defined by the right side of the POV parallel to the longitudinal centerline, and the other by the front-most part of the POV perpendicular to the longitudinal centerline.

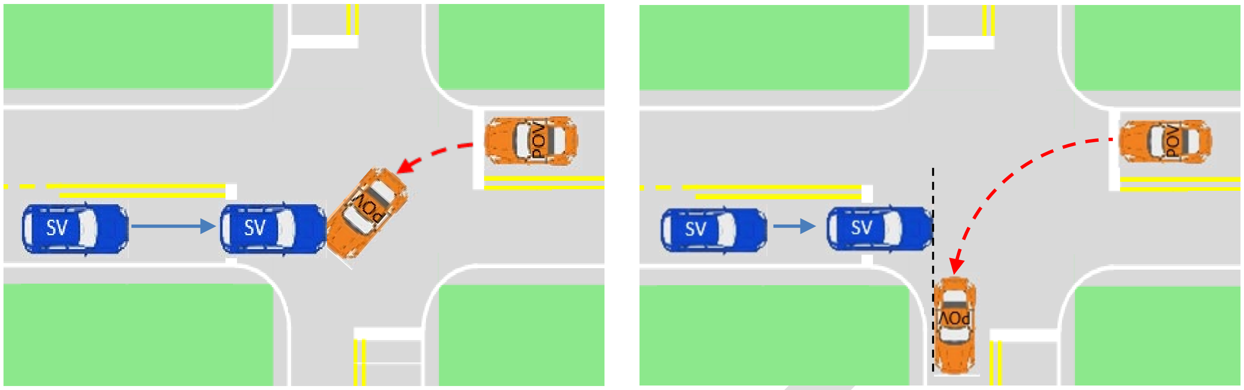


Figure 5. ISA Scenario 2 crash-imminent (left) and near-miss (right) timing.

A. Staging

i. The SV and POV shall be staged at rest.

ii. The SV and POV shall be located behind the intersection stop bar of their respective travel lanes at a distance where they can each be accelerated to the desired test speed by the onset of the validity period. Nominal recommendations for the staging distances, which assume average SV and POV accelerations of 0.127 g (1.25 m/s) from rest, are provided in Table 4.

B. Test Conduct

i. Using closed-loop control of the POV relative to the SV, both vehicles shall begin driving at the same time using the same acceleration profile until the desired speed is achieved.

ii. The POV forward velocity shall be maintained via:

a. Closed loop control relative to the SV from the beginning of the test to the time $t = t_{pov\_brake\_onset}$, which occurs when the distance from the front most part of the POV to the leading edge of the intersection stop bar located in the POV travel lane is 51.8 ft (15.8 m), and

b. Open loop control when $t > t_{pov\_brake\_onset}$.

iii. The POV shall slow to a speed of 15 mph (24.1 km/h) before initiating a left turn across the path of the SV.

a. POV braking shall be initiated at $t = t_{pov\_brake\_onset}$.

b. The average POV deceleration from the onset of POV braking to the leading edge of the POV stop bar shall be 0.26 g (2.53 m/s^2).

iv. The POV shall remain centered in its travel lane from onset of the validity period to the onset of the POV left turn.

  a. The POV left turn shall be initiated when the front-most part of the POV first reaches the leading edge of the intersection stop bar residing in the POV travel lane.

  b. The radius of the POV left turn, assessed at the front center of the POV, shall be 28.2 ft (8.59 m) and have an arc angle of 90 degrees.

v. Unless it is struck by the SV, the POV shall remain in the center of its new travel lane from completion of the left turn until the end of the validity period.

vi. The SV shall remain centered in its travel lane within the validity period, or up to the onset of an ISA intervention that occurs within the validity period, when operated in automation level 0 or 1.

vii. For S2-A tests performed with manual control of the SV speed,

  a. The driver shall maintain the SV speed within the validity period, or up to the onset of an ISA intervention that occurs within the validity period.

  b. If an ISA intervention occurs, the driver shall release the SV accelerator pedal within 500 ms of the ISA intervention onset.

viii. For S2-A tests that use cruise control to maintain SV speed,

  a. The SV driver shall enable the SV cruise control before onset of the validity period.

  b. The SV cruise control shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

ix. For S2-A tests performed with level 1 automation,

  a. The SV driver shall enable the SV ACC before onset of the validity period.

  b. The SV ACC shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

x. For S2-A tests performed with level 2 or 3 automation,

a. The SV driver shall enable the SV ACC and LCC before onset of the validity period.

b. The SV ACC shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

C. Scenario 2-A test synchronization check (see Appendix B Section 9.1 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. For tests performed with crash-imminent timing, the front center of the SV shall nominally be 33.46 ft (10.20 m) before the leading edge of the SV stop bar at the instant the front center of the POV crosses the leading edge of the POV stop bar.

ii. For tests performed with near-miss timing, the front center of the SV shall nominally be 71.32 ft (21.43 m) before the leading edge of the SV stop bar at the instant the front center of the POV crosses the leading edge of the POV stop bar.

5.3.7.2 ISA Scenario 2-B (S2-B): Constant SV Speed, POV Accelerates from Rest While Turning Left

In addition to the applicable general test requirements described in S5.3.1, the following requirements must also hold true throughout each ISA S2-B trial:

A. Staging

i. The SV and POV shall be staged at rest.

iii. The SV shall be located behind the intersection stop bar of its travel lane at a distance where it can be accelerated to the desired test speed by the onset of the validity period. A nominal staging distance recommendation, which assumes an average SV acceleration of 0.127 g (1.25 m/s) from rest, is provided in Table 4.

ii. The front-most part of the POV shall be located at the leading edge of the intersection stop bar of its travel lane by the onset of the validity period.

B. Test Conduct

i. The SV shall accelerate to the desired speed. SV acceleration is not restricted; however, the SV speed must be within the tolerance shown in Table 2 during the validity period.

ii. The SV shall remain centered in its travel lane within the validity period, or up to the onset of an ISA intervention that occurs within the validity period, when operated in automation level 0 or 1.

iii. For S2-B tests performed with manual control of the SV speed,

a. The driver shall maintain the SV speed within the validity period, or up to the onset of an ISA intervention that occurs within the validity period.

b. If an ISA intervention occurs, the driver shall release the SV accelerator pedal within 500 ms of the ISA intervention onset.

iv. For S2-B tests that use cruise control to maintain SV speed,

a. The SV driver shall enable the SV cruise control before onset of the validity period.

b. The SV cruise control shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

v. For S2-B tests performed with level 1 automation,

a. The SV driver shall enable the SV ACC before onset of the validity period.

b. The SV ACC shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

vi. For S2-B tests performed with level 2 or 3 automation,

a. The SV driver shall enable the SV ACC and LCC before onset of the validity period.

b. The SV ACC shall be used to maintain the SV speed within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

vii. The POV shall use an average acceleration of 0.127 g (1.25 m/s) from rest at its stop bar until it achieves the desired speed or is struck by the SV.

a. Open-loop control shall be used to achieve and maintain the desired POV speed.

b. The radius of the POV left turn, assessed at the front center of the POV, shall be 28.2 ft (8.59 m) and have an arc angle of 90 degrees.

viii. Unless it is struck by the SV, the POV shall remain in the center of its new travel lane from completion of the left turn until the end of the validity period.

C. Scenario 2-B test synchronization check (see Appendix B Section 9.2 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. For tests performed with crash-imminent timing, the onset of the POV acceleration shall occur when the front center of the SV is 124.76 ft (38.03 m) before the leading edge of the SV stop bar.

ii. For tests performed with near-miss timing, the onset of the POV acceleration shall occur when the front center of the SV is 168.29 ft (51.29 m) before the leading edge of the SV stop bar.

5.3.7.3 ISA Scenario 2-C (S2-C): SV Accelerates from Rest, POV Slows and Turns Left

Note: For the reasons described in S5.3.12, ISA S2-C tests shall only be performed with the SV operating in automation level 0 and manual control of SV speed.

In addition to the applicable general test requirements described in S5.3.1, the following requirements must also hold true throughout each ISA S2-C trial:

A. Staging

i. The SV and POV shall be staged at rest.

ii. The front-most part of the SV shall be located at the leading edge of the intersection stop bar of its travel lane by the onset of the validity period.

iii. The POV shall be located behind the intersection stop bar of its travel lane at a distance where it can be accelerated to the desired test speed by the onset of the validity period. A nominal staging distance recommendation, which assumes an average POV acceleration of 0.127 g (1.25 m/s) from rest, is provided in Table 4.

B. Test Conduct

i. The POV shall accelerate to the desired speed. POV acceleration is not restricted, however the POV speed must be within the tolerance shown in Table 2 during the validity period.

ii. The POV forward velocity shall be maintained via:

a. Closed loop control relative to the SV from the beginning of the test to the time $t = t_{pov\_brake\_onset}$, which occurs when the distance from the front most part of the POV to the leading edge of the intersection stop bar located in the POV travel lane is 51.8 ft (15.8 m), and

b. Open loop control when t > $t_{pov\_brake\_onset}$.

iii. The POV shall slow to a speed of 15 mph (24.1 km/h) before initiating a left turn across the path of the SV.

a. POV braking shall be initiated at $t = t_{pov\_brake\_onset}$.

b. The average POV deceleration from the onset of POV braking to the leading edge of the POV stop bar shall be 0.26 g (2.53 m/s^2).

iv. The POV shall remain centered in its travel lane from onset of the validity period to the onset of the POV left turn.

a. The POV left turn shall be initiated when the front-most part of the POV first reaches the leading edge of the intersection stop bar residing in the POV travel lane.

b. The radius of the POV left turn, assessed at the front center of the POV, shall be 28.2 ft (8.59 m) and have an arc angle of 90 degrees.

v. Unless it is struck by the SV, the POV shall remain in the center of its new travel lane from completion of the left turn until the end of the validity period.

vi. The SV shall use an average acceleration of 0.127 g (1.25 m/s^2) from rest at its stop bar until it achieves the desired speed, an ISA intervention occurs, or it strikes the POV. Manual control shall be used to achieve and maintain the desired SV speed.

vii. The SV shall remain centered in its travel lane within the validity period, or up to the onset of an ISA intervention that occurs within the validity period.

viii. If an SV ISA intervention occurs, the driver shall release the SV accelerator pedal within 500 ms of its onset.

C. Scenario 2-C test synchronization check (see Appendix B Section 9.3 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. For tests performed with crash-imminent timing, the onset of the SV acceleration shall occur when the front center of the POV is 46.79 ft (14.26 m) before the leading edge of the POV stop bar.

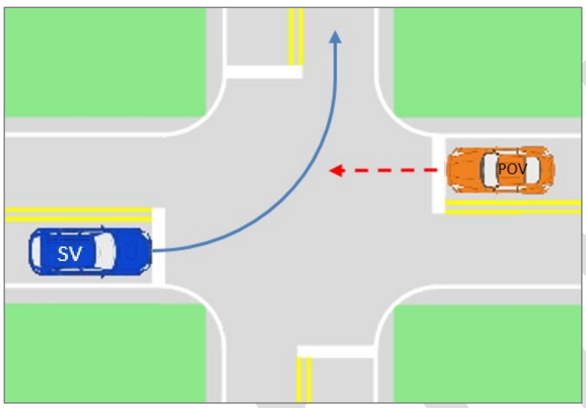
ii. For tests performed with near-miss timing, the onset of the SV acceleration shall occur when the front center of the POV is 10.83 ft (3.30 m) before the leading edge of the POV stop bar.

5.3.7.4 ISA Scenario 2 Test Tolerances and Specifications

An overview of the ISA Scenario 2 test tolerances and specifications are shown in Table 4.

5.3.8 ISA Scenario 3: SV Left Turn Across POV Path

The objective of the ISA Scenario 3 test, shown in Figure 6, is to evaluate the ISA system's ability to detect and respond to a POV while/after the SV is being steered left across the POV's forward path. Five SV and POV speed combinations are provided, as well as crash-imminent and near-miss timing. The specific details of how a given ISA Scenario 3 test is performed not only depends on the SV-to-POV speed combination and timing, but also what level of automation the SV is being operated in.



[1]Test scenario performed in automation level 0 only since the SV speed must be reduced just before the SV left turn is initiated.

[2]Test scenario performed in automation level 0 with conventional cruise control or automation level 1 using ACC since SV speed is constant before, during, and after the SV left turn.

ISA Scenario	Vehicle Speeds	
	SV	POV
S3-A0 [1]	25 ⇨15 mph (40.2 ⇨ 24.1 km/h)	25 mph (40.2 km/h)
S3-A1 [2]	15 mph (24.1 km/h)	25 mph (40.2 km/h)
S3-B0 [1]	25 ⇨15 mph (40.2 ⇨ 24.1 km/h)	0 ⇨25 mph (0 ⇨ 40.2 km/h)
S3-B1 [2]	15 mph (24.1 km/h)	0 ⇨25 mph (0 ⇨ 40.2 km/h)
S3-C0 [1]	0 ⇨25 mph (0 ⇨ 40.2 km/h)	25 mph (40.2 km/h)

Figure 6. ISA Scenario 3: SV Left Turn Across POV Path.

For ISA Scenario 3:

- "Crash-imminent" timing shall be defined as the SV-to-POV choreography that results in TTC = 0 seconds occurring when the front center of the SV impacts the front left corner of the POV (see Figure 7, left).

Table 4. ISA Scenario 2 Test Specifications.

Scenario	Initial Distance to Intersection Stop Bars[1]		Acceleration from Rest	Speed Within Validity Period	POV Turn Radius (when referenced from POV front center)	Lateral Path Tolerance Within Validity Period			Yaw Rate Within Validity Period[3]	Number of Trials Per Automation Level
	Crash-Imminent Timing	Near-Miss Timing				SV (Automation Level 0 and 1[2])	SV (Automation Level 2 and 3)	POV		
S2-A	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 308.3 ± 1 ft (94.0 ± 0.3 m)	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 323.6 ± 1 ft (98.6 ± 0.3 m)	Unrestricted from staging point	SV: 25 ± 1 mph (40.2 ± 1.6 km/h) POV: 25 ⇨ 15 ± 1 mph (40.2 ⇨ 24.1 ± 1.6 km/h)	28.2 ft (8.59 m)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3
S2-B	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 0 ft	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 0 ft	SV: Unrestricted from staging point POV: 0.127g (1.25 m/s²) from stop bar	SV: 25 ± 1 mph (40.2 ± 1.6 km/h) POV: 0 ⇨25 ± 1 mph (0 ⇨ 40.2 ± 1.6 km/h)	28.2 ft (8.59 m)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3
S2-C	SV: 0 ft POV: 273.9 ± 1 ft (83.5 ± 0.3 m)	SV: 0 ft POV: 273.9 ± 1 ft (83.5 ± 0.3 m)	SV: 0.127g (1.25 m/s²) from stop bar POV: Unrestricted from staging point	SV: 0 ⇨25 ± 1 mph (0 ⇨ 40.2 ± 1.6 km/h) POV: 25 ⇨ 15 ± 1 mph (40.2 ⇨ 24.1 ± 1.6 km/h)	28.2 ft (8.59 m)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3

[1] The non-zero distances are coarse approximations that assume the vehicle(s) achieve the desired steady state speed quickly after the acceleration from rest is complete.

[2] Where applicable.

[3] Yaw rate specifications are applicable only when the desired path of the SV is a straight line. Additionally, SV yaw rate specifications are only valid during tests performed in automation level 0 or 1.

[4] LCC actively controls the SV lateral path during tests performed in automation level 2 or 3.

- "Near-miss" timing shall be defined as the SV-to-POV choreography that results in:
    - The front-most part of the POV reaching a vertical plane defined by the right side of the SV, parallel to the SV longitudinal centerline once the SV's turn has been completed, and
    - The front center of the POV being 6.6 ft (2 m) behind the rearmost part of the SV (see Figure 7, right).

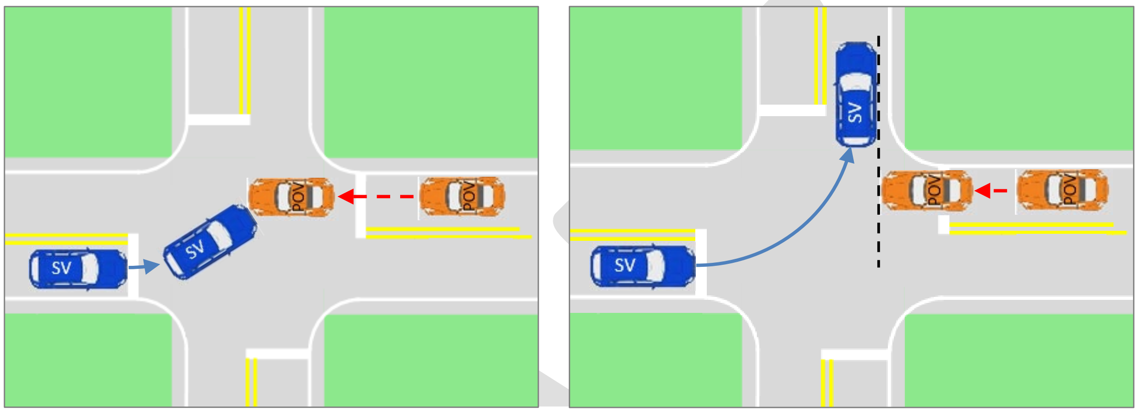


Figure 7. ISA Scenario 3 crash-imminent (left) and near-miss (right) timing.

5.3.8.1 ISA Scenario 3-A (S3-A): SV Turns Left at Speed, Constant POV Speed

Note: For the reasons described in S5.3.12, ISA S3-A0 tests shall only be performed with the SV operating in automation level 0 and manual control of SV speed. Similarly, the S3-A1 scenario shall only be performed when the SV speed is being controlled by conventional cruise control (automation level 0) or with ACC (automation level 1).

In addition to the applicable general test requirements described in S5.3.1, the following requirements must also hold true throughout each ISA S3-A trial:

A. Staging

i. The SV and POV shall be staged at rest.

ii. The SV and POV shall be located behind the intersection stop bar of their respective travel lanes at a distance where they can each be accelerated to the desired test speed by the onset of the validity period. Nominal recommendations for the staging distances, which assume an average SV and POV acceleration of 0.127 g (1.25 m/s) from rest, are provided in Table 5.

B. Test Conduct

i. Using closed-loop control of the POV relative to the SV, both vehicles shall begin driving at the same time using the same acceleration profile until the desired speed is achieved.

ii. The POV forward velocity shall be maintained via:

a. Closed loop control relative to the SV from the beginning of the test to a time $t = t_{pov\_stop\_bar} - 1$ second, where $t_{pov\_stop\_bar}$ is the time when the front most part of the POV first reaches the leading edge of the intersection stop bar located in the POV travel lane, and

b. Open loop control from a time $t > t_{pov\_stop\_bar} - 1$ second to the end of the validity period.

iii. The POV shall remain centered in its travel lane within the validity period.

iv. For S3-A0 tests performed with <u>manual control</u> of the SV speed,

a. The driver shall maintain an SV speed of 25 mph (40.2 km/h) from the onset of the validity period to the onset of the manually-applied SV braking used to reduce speed to 15 mph (24.1 km/h).

b. The SV deceleration and velocity profile shall be identical to that used by the POV during S2-A.

c. The onset of the SV deceleration shall occur when the longitudinal distance between the front center of the SV and the leading edge of the SV stop bar is 51.8 ft (15.8 m).

d. SV speed shall be 15 mph (24.1 km/h) by the time the front center of the SV crosses a vertical plane defined by the leading edge of the SV stop bar.

e. SV speed shall remain at 15 mph (24.1 km/h) for the remainder of the validity period, or up to the onset of an ISA intervention that occurs within the validity period.

f. If an ISA intervention occurs, the driver shall release the SV accelerator pedal within 500 ms of the ISA intervention onset.

v. For S3-A1 tests performed with <u>conventional cruise control</u> or <u>ACC</u> to maintain SV speed,

a. The SV driver shall enable the SV cruise control before onset of the validity period.

b. The SV cruise control shall be used to maintain an SV speed of 15 mph (24.1 km/h) within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

vi. The SV shall remain centered in its travel lane from onset of the validity period to the onset of the SV left turn, or up to the onset of an ISA intervention that occurs within the validity period before the SV left turn is initiated.

a. The SV left turn shall be initiated when the front-most part of the SV first reaches the leading edge of the intersection stop bar residing in the SV travel lane.

b. The radius of the SV left turn, assessed at the front center of the SV, shall be 28.2 ft (8.59 m) and have an arc angle of 90 degrees.

c. Unless an ISA intervention and/or the SV strikes the POV, the SV shall remain in the center of its new travel lane from completion of the left turn until the end of the validity period.

C. Scenario S3-A0 and S3-A1 test synchronization check (see Appendix C Section 10.1 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. For tests performed with <u>crash-imminent</u> timing, the <u>front</u> center of the POV shall nominally be 13.12 ft (4.00 m) <u>before</u> the leading edge of the POV stop bar at the instant the front center of the SV crosses the leading edge of the SV stop bar.

ii. For tests performed with <u>near-miss</u> timing, the distance from the <u>front</u> center of the POV to the leading edge of the POV stop bar at the instant the front center of the SV crosses the leading edge of the SV stop bar depends on the length and width of the SV. Expressed in meters, this value is nominally taken to be:

$$D_{POV\_Offset\_To\_POV\_SB} = 1.667 * SV_{length} + 0.5 * SV_{width} + 12.91$$

5.3.8.2 ISA Scenario 3-B (S3-B): SV Turns Left at Speed, POV Accelerates from Rest

Note: For the reasons described in S5.3.12, ISA S3-B0 tests shall only be performed with the SV operating in automation level 0 and manual control of SV speed. Similarly, the S3-B1 scenario shall only be performed when the SV speed is being controlled by conventional cruise control (automation level 0) or with ACC (automation level 1).

In addition to the applicable general test requirements described in S5.3.1, the following requirements must also hold true throughout each ISA S3-B trial:

A. Staging

i. The SV and POV shall be staged at rest.

ii. The SV shall be located behind the intersection stop bar of its travel lane at a distance where it can be accelerated to the desired test speed by the onset of the validity period. A nominal staging distance recommendation, which assumes an average SV acceleration of 0.127 g (1.25 m/s) from rest, is provided in Table 5.

iii. The front-most part of the POV shall be located at the leading edge of the intersection stop bar of its travel lane by the onset of the validity period.

B. Test Conduct

i. The SV shall accelerate to the desired speed. SV acceleration is not restricted; however, the SV speed must be within the tolerance shown in Table 3 during the validity period.

ii. For S3-B0 tests performed with manual control of the SV speed,

a. The driver shall maintain an SV speed of 25 mph (40.2 km/h) from the onset of the validity period to the onset of the manually-applied SV braking used to reduce speed to 15 mph (24.1 km/h).

b. The SV deceleration and velocity profile shall be identical to that used by the POV during S2-A.

c. The onset of the SV deceleration shall occur when the longitudinal distance between the front center of the SV and the leading edge of the SV stop bar is 51.8 ft (15.8 m).

d. SV speed shall be 15 mph (24.1 km/h) by the time the front center of the SV crosses a vertical plane defined by the leading edge of the SV stop bar.

e. SV speed shall remain at 15 mph (24.1) km/h for the remainder of the validity period, or up to the onset of an ISA intervention that occurs within the validity period.

f. If an ISA intervention occurs, the driver shall release the SV accelerator pedal within 500 ms of the ISA intervention onset.

iii. For S3-B1 tests performed with conventional cruise control or ACC to maintain SV speed,

a. The SV driver shall enable the SV cruise control before onset of the validity period.

b. The SV cruise control shall be used to maintain an SV speed of 15 mph (24.1 km/h) within the validity period or up to the onset of an ISA intervention that occurs within the validity period.

iv. The SV shall remain centered in its travel lane from onset of the validity period to the onset of the SV left turn, or up to the onset of an ISA intervention that occurs within the validity period before the SV left turn is initiated.

a. The SV left turn shall be initiated when the front-most part of the SV first reaches the leading edge of the intersection stop bar residing in the SV travel lane.

b. The radius of the SV left turn, assessed at the front center of the SV, shall be 28.2 ft (8.59 m) and have an arc angle of 90 degrees.

c. Unless an ISA intervention and/or the SV strikes the POV, the SV shall remain in the center of its new travel lane from completion of the left turn until the end of the validity period.

v. The POV shall use an average acceleration of 0.127 g (1.25 m/s) from rest at its stop bar until it achieves the desired speed or is struck by the SV. Open-loop control shall be used to achieve and maintain the desired POV speed.

vi. Unless it is struck by the SV, the POV shall remain in the center of its new travel lane from completion of the left turn until the end of the validity period.

C. Scenario S3-B0 test synchronization check (see Appendix C Section 10.2 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. For tests performed with crash-imminent timing, the onset of the POV acceleration shall occur when the front center of the SV is 28.9 ft (8.82 m) before the leading edge of the SV stop bar.

ii. For tests performed with near-miss timing, the onset of the POV acceleration depends on the length and width of the SV. Expressed in meters, the distance from the front center of the SV to the leading edge of the SV stop bar at the onset of POV acceleration is nominally taken to be:

$$D_{SV\_Offset\_To\_SB} = 6.7056 * t_{SV_{decel}} - 1.2649 * t_{SV_{decel}}{}^2$$

Where,

$$t_{SV_{decel}} = \sqrt{\left(8.0512 - \frac{SV_{width}}{1.25}\right)} - \frac{SV_{length}}{6.7056} - 1.6050$$

D. Scenario S3-B1 test synchronization check (see Appendix C Section 10.3 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. For tests performed with <u>crash-imminent</u> timing, the onset of the POV acceleration shall occur when the <u>front</u> center of the SV is 53.3 ft (16.26 m) <u>before</u> the leading edge of the SV stop bar.

ii. For tests performed with <u>near-miss</u> timing, the onset of the POV acceleration depends on the length and width of the SV. Expressed in meters, the distance from the <u>front</u> center of the SV to the leading edge of the SV stop bar at the onset of POV acceleration is nominally taken to be:

$$D_{SV\_Offset\_To\_SB} = 6.7056 * \sqrt{\left(8.0512 - \frac{SV_{width}}{1.25}\right)} - 10.7628 - SV_{length}$$

5.3.8.3 ISA Scenario 3-C (S3-C): SV Accelerates from Rest While Turning Left, Constant POV Speed

Note: For the reasons described in S5.3.12 ISA S3-C tests shall only be performed with the SV operating in automation level 0 and manual control of SV speed.

In addition to the applicable general test requirements described in S5.3.1, the following requirements must also hold true throughout each ISA S3-C trial:

A. Staging

i. The SV and POV shall be staged at rest.

ii. The front-most part of the SV shall be located at the leading edge of the intersection stop bar of its travel lane by the onset of the validity period.

iii. The POV shall be located behind the intersection stop bar of its travel lane at a distance where it can be accelerated to the desired test speed by the onset of the validity period. A nominal staging distance recommendation, which assumes an average POV acceleration of 0.127 g (1.25 m/s) from rest, is provided in Table 5.

B. Test Conduct

i. The POV shall accelerate to the desired speed. POV acceleration is not restricted, however the POV speed must be within the tolerance shown in Table 3 during the validity period.

ii. The POV shall remain centered in its travel lane within the validity period.

iii. The SV shall use an average acceleration of 0.127 g (1.25 m/s²) from rest at its stop bar until it achieves the desired speed, an ISA intervention occurs, or it strikes the POV. Manual control shall be used to achieve and maintain the desired SV speed.

iv. If an SV ISA intervention occurs, the driver shall release the SV accelerator pedal within 500 ms of its onset.

v. The radius of the SV left turn, assessed at the front center of the SV, shall be 28.2 ft (8.59 m) and have an arc angle of 90 degrees.

vi. Unless it strikes the POV, the SV shall remain in the center of its new travel lane from completion of the left turn until the end of the validity period.

C. Scenario S3-C test synchronization check (see Appendix C Section 10.4 for additional details; nominal values assume a GVT revision F surrogate vehicle is used as the POV)

i. For tests performed with crash-imminent timing, the onset of the SV acceleration shall occur when the front center of the POV is 97.0 ft (29.57 m) before the leading edge of the POV stop bar.

ii. For tests performed with near-miss timing, the onset of the SV acceleration depends on the length and width of the SV. Expressed in meters, the distance from the front center of the POV to the leading edge of the POV stop bar at the onset of SV acceleration is nominally taken to be:

$$D_{POV\_Offset\_To\_POV\_SB} = 11.1760 * \sqrt{\left(19.4022 + \frac{SV_{length}}{1.25}\right)} - 5.0320 + 0.5 * SV_{width}$$

5.3.8.4 ISA Scenario 3 Test Tolerances and Specifications

An overview of the ISA Scenario 3 test tolerances and specifications are shown in Table 5.

5.3.9 Validity Period

1. Validity Onset

    A. For tests where the SV is initially stopped, the valid test interval shall begin three (3) seconds before the SV accelerates from rest.

    B. For tests where the SV is not initially stopped, the valid test interval shall begin three (3) seconds before the SV reaches the intersection stop bar located in the SV travel lane.

    Note: In the case of Scenarios S3-A0 and S3-B0, the 3 second interval described in S5.3.9.1.A includes the time needed to slow the SV from 25 to 15 mph (40.2 to 24.1 km/h). Since it nominally takes 1.767 seconds to perform this reduction with a deceleration of 0.26g (2.53 m/s^2), the SV is expected only expected to maintain constant speed for 1.233 seconds during these test trials (i.e., within the interval that occurs (1) after first reaching the desired target of 25 mph (40.2 km/h), and (2) initiation of the deceleration needed to reach the SV stop bar at 15 mph (24.1 km/h).

2. Validity Termination

    Regardless of whether a test trial is performed with crash-imminent or near-miss SV-to-POV timing, the valid test interval shall end:

    A. If the SV impacts the POV; or

    B. 3 seconds after the SV has avoided the SV-to-POV impact.

5.3.10 End-of-Test Instructions

1. After the respective ISA test trial 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 ISA test trial is complete.

Table 5. ISA Scenario 3 Test Specifications.

Scenario	Initial Distance to Intersection Stop Bar[1]		Acceleration from Rest	Speed Within Validity Period	SV Turn Radius (when referenced from POV front center)	Lateral Path Tolerance Within Validity Period			Yaw Rate Within Validity Period [4]	Number of Trials Per Automation Level
	Crash-Imminent Timing	Near-Miss Timing				SV (Automation Level 0 and 1[3])	SV (Automation Level 2 and 3)	POV		
S3-A0	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 277.3 ± 1 ft (84.5 ± 0.3 m)	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV[2]: 346.1 ± 1 ft (105.5 ± 0.3 m)	Unrestricted	SV: 25 ⇨ 15 ± 1 mph (40.2 ⇨ 24.1 ± 1.6 km/h) POV: 25 ± 1 mph (40.2 ± 1.6 km/h)	28.2 ft (8.59 m)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3
S3-A1	SV: 125.0 ± 1 ft (38.1 ± 0.3 m) POV: 277.3 ± 1 ft (84.5 ± 0.3 m	SV: 125.0 ± 1 ft (38.1 ± 0.3 m) POV[2]: 346.1 ± 1 ft (105.5 ± 0.3 m)	Unrestricted	SV: 15 ± 1 mph (24.1 ± 1.6 km/h) POV: 25 ± 1 mph (40.2 ± 1.6 km/h)	28.2 ft (8.59 m)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3
S3-B0	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 0 ft	SV: 273.9 ± 1 ft (83.5 ± 0.3 m) POV: 0 ft	SV: Unrestricted POV: 0.127g (1.25 m/s^2)	SV: 25 ⇨ 15 ± 1 mph (40.2 ⇨ 24.1 ± 1.6 km/h) POV: 0 ⇨25 ± 1 mph (0 ⇨ 40.2 ± 1.6 km/h)	28.2 ft (8.59 m)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3
S3-B1	SV: 125.0 ± 1 ft (38.1 ± 0.3 m) POV: 0 ft	SV: 125.0 ± 1 ft (38.1 ± 0.3 m) POV: 0 ft	SV: Unrestricted POV: 0.127g (1.25 m/s^2)	SV: 15 ± 1 mph (24.1 ± 1.6 km/h) POV: 0 ⇨25 ± 1 mph (0 ⇨ 40.2 ± 1.6 km/h)	28.2 ft (8.59 m)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3
S3-C	SV: 0 ft POV: 273.9 ± 1 ft (83.5 ± 0.3 m)	SV: 0 ft POV: 273.9 ± 1 ft (83.5 ± 0.3 m)	SV: 0.127g (1.25 m/s^2) POV: Unrestricted	SV: 0 ⇨25 ± 1 mph (0 ⇨ 40.2 ± 1.6 km/h) POV: 25 ± 1 mph (40.2 ± 1.6 km/h)	28.2 ft (8.59 m)	±0.8 ft (0.25 m)	n/a [4]	±0.8 ft (0.25 m)	SV: ± 1 deg/s POV: n/a	3

[1] The non-zero distances are coarse approximations that assume the vehicle(s) achieve the desired steady state speed quickly after the acceleration from rest is complete.

[2] Initial POV offset in the S3-A0 and S3-A1 scenarios depends on SV length and width. For the values shown in Table 5, SV dimensions were taken to be 193" L x 73" W (4.90 x 1.85 m)

[3] Where applicable.

[4] Yaw rate specifications are applicable only when the desired path of the SV is a straight line. Additionally, SV yaw rate specifications are only valid during tests performed in automation level 0 or 1.

[5] LCC actively controls the SV lateral path during tests performed in automation level 2 or 3.

5.3.11 Evaluation Criteria

1. The SV shall not impact the POV during any valid test, regardless of whether the test trial is performed with crash-imminent or near-miss SV-to-POV timing; and

2. The SV shall not be automatically braked with a deceleration of ≥0.5g during any trial performed with near-miss SV-to-POV timing.

5.3.12 Test Scenario Applicability

The tests described in this document have been designed to support ISA evaluations performed with the SV operating in automation levels 0, 1, 2, and 3. However, test conditions exist where it may not be possible to perform the movements specified for the SV.

For ISA scenarios S1-C, S2-C, and S3-C (where the SV is accelerated across the path of the POV from rest):

- It is not anticipated that all SVs will be able to accelerate from rest to the desired speed using conventional cruise control or ACC (e.g., by using the speed resume function).

- Even if it is possible for the SV to accelerate from rest using conventional cruise control or ACC, system responsiveness (e.g., time to engage, longitudinal acceleration, jerk, etc.) is expected to be SV-dependent. The chorography used for these maneuvers must be tightly controlled to ensure the desired crash-imminent and near-miss timing is realized.

Since accurately and consistently achieving the SV speed reduction from 25 to 15 mph (40 to 24 km/h) specified in scenarios S3-A0 and S3-B0 was not believed to be possible with conventional or adaptive cruise control, these tests shall only be performed with manual speed control. Conversely, since the SV speed specified in scenarios S3-A1 and S3-B1 is a constant 15 mph, controlling it with conventional or adaptive cruise control is expected to be possible.

At the time this document was written, it was not possible to perform ISA scenario S3 tests with the SV operating in automation level L2 or L3 since no production vehicle was equipped with the ability to automatically performing a left turn at an intersection (i.e., without any input from the driver).

Table 6 provides a summary of the SV automation conditions likely to be supported by each ISA scenario.

Table 6. ISA Test Applicability Matrix.

SV Automation Condition	ISA Scenario										
	S1-A[1]	S1-B[1]	S1-C[1]	S2-A	S2-B	S2-C	S3-A0	S3-A1	S3-B0	S3-A2	S3-C
Manual speed control, LCC off (Level 0)	✓	✓	✓	✓	✓	✓	✓	--	✓	--	✓
Cruise control, LCC off (Level 0)	✓	✓	--	✓	✓	--	--	✓	--	✓	--
ACC on, LCC off (Level 1)	✓	✓	--	✓	✓	--	--	✓	--	✓	--
ACC on, LCC on (Level 2 or 3)	✓	✓	--	✓	✓	--	--	--	--	--	--

[1] Includes of POV approaches from the left and right of the SV.

6.0 REFERENCES

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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?

Cruise Control (conventional)	
Operational Speed Range (mph or km/h)	Method to Engage (stalk, button, etc.)

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.)	Number of Headway Settings

SAE Automation Level 2 or 3 Driving
Process to engage automation level 2 or 3 driving, including how to proceed from being at rest (zero speed)

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)

GENERAL TEST FACILITY INFORMATION		
Facility Designation (e.g., "VDA west edge")	Test Surface (e.g., asphalt, concrete)	Surface Condition
Lane Line Description		
SV Orientation During **ISA S1, Left POV approach** tests (e.g., "North")	SV Orientation During **ISA S1, Right POV approach** tests (e.g., "North")	
SV Orientation During **ISA S2** tests (e.g., "North")	SV Orientation During **ISA S3** tests (e.g., "North")	

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")			
SV-to-POV Position During Static Calibration (e.g., SV front center to POV left side longitudinal center)			
SV-to-POV Distance During Static Cal, Measured (in. or mm)	SV-to-POV Distance During Static Cal, Displayed (in. or mm)		

POST-TEST CONDITIONS (complete after 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")			
SV-to-POV Position During Static Calibration (e.g., SV front center to POV left side longitudinal center)			
SV-to-POV Distance During Static Cal, Measured (in. or mm)	SV-to-POV Distance During Static Cal, Displayed (in. or mm)		

ISA Test Performance Summary (Crash-Imminent Timing)

POV Approach Direction	SV Automation Condition	Trial	ISA Scenario (indicate crash avoidance or SV speed at time of POV impact)					
			S1-A	**S1-B**	**S1-C**	**S2-A**	**S2-B**	**S2-C**
	Manual speed control, LCC off (Level 0)	1						
		2						
		3						
	Cruise control, LCC off (Level 0)	1						
		2						
Left[1]		3						
	ACC on, LCC off (Level 1)	1						
		2			n/a			n/a
		3						
	ACC on, LCC on (Level 2 or 3)	1						
		2						
		3						
	Manual speed control, LCC off (Level 0)	1						
		2						
		3						
	Cruise control, LCC off (Level 0)	1						
		2						
Right[1]		3					n/a	
	ACC on, LCC off (Level 1)	1						
		2			n/a			
		3						
	ACC on, LCC on (Level 2 or 3)	1						
		2						
		3						

[1] For ISA Scenario 1, the POV travel lane is perpendicular to that of the SV. For ISA Scenario 2, the POV travel lane is adjacent (on the left side of the SV) and parallel to that of the SV.

ISA Test Performance Summary (Near-Miss Timing)

POV Approach Direction	SV Automation Condition	Trial	ISA Scenario (indicate crash avoidance or SV speed at time of POV impact)					
			S1-A	S1-B	S1-C	S2-A	S2-B	S2-C
Left[1]	Manual speed control, LCC off (Level 0)	1						
		2						
		3						
	Cruise control, LCC off (Level 0)	1			n/a			n/a
		2						
		3						
	ACC on, LCC off (Level 1)	1						
		2						
		3						
	ACC on, LCC on (Level 2 or 3)	1						
		2						
		3						
Right[1]	Manual speed control, LCC off (Level 0)	1				n/a		
		2						
		3						
	Cruise control, LCC off (Level 0)	1			n/a			
		2						
		3						
	ACC on, LCC off (Level 1)	1						
		2						
		3						
	ACC on, LCC on (Level 2 or 3)	1						
		2						
		3						

[1] For ISA Scenario 1, the POV travel lane is perpendicular to that of the SV. For ISA Scenario 2, the POV travel lane is adjacent (on the left side of the SV) and parallel to that of the SV.

ISA Test Performance Summary (Crash-Imminent Timing)

<table>
<tr><th rowspan="2">POV Approach Direction</th><th rowspan="2">SV Automation Condition</th><th rowspan="2">Trial</th><th colspan="5">ISA Scenario (indicate crash avoidance or SV speed at time of POV impact)</th></tr>
<tr><th>S3-A0</th><th>S3-A1</th><th>S3-B0</th><th>S3-B1</th><th>S3-C</th></tr>
<tr><td rowspan="9">Right[1]</td><td rowspan="3">Manual speed control, LCC off (Level 0)</td><td>1</td><td></td><td rowspan="3">n/a</td><td></td><td rowspan="3">n/a</td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Cruise control, LCC off (Level 0)</td><td>1</td><td rowspan="6">n/a</td><td></td><td rowspan="6">n/a</td><td></td><td rowspan="6">n/a</td></tr>
<tr><td>2</td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td></tr>
<tr><td rowspan="3">ACC <u>on</u>, LCC off (Level 1)</td><td>1</td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td></tr>
</table>

[1] For ISA Scenario 3, the POV travel lane is adjacent (on the left side of the SV) and parallel to that of the SV.

ISA Test Performance Summary (Near-Miss Timing)

<table>
<tr><th rowspan="2">POV Approach Direction</th><th rowspan="2">SV Automation Condition</th><th rowspan="2">Trial</th><th colspan="5">ISA Scenario (indicate crash avoidance or SV speed at time of POV impact)</th></tr>
<tr><th>S3-A0</th><th>S3-A1</th><th>S3-B0</th><th>S3-B1</th><th>S3-C</th></tr>
<tr><td rowspan="9">Right[1]</td><td rowspan="3">Manual speed control, LCC off (Level 0)</td><td>1</td><td></td><td rowspan="3">n/a</td><td></td><td rowspan="3">n/a</td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Cruise control, LCC off (Level 0)</td><td>1</td><td rowspan="6">n/a</td><td></td><td rowspan="6">n/a</td><td></td><td rowspan="6">n/a</td></tr>
<tr><td>2</td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td></tr>
<tr><td rowspan="3">ACC <u>on</u>, LCC off (Level 1)</td><td>1</td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td></tr>
</table>

[1] For ISA Scenario 3, the POV travel lane is adjacent (on the left side of the SV) and parallel to that of the SV.

8.0 APPENDIX A – SCENARIO 1 TEST SYNCHRONIZATION

8.1 ISA Scenario 1-A (S1-A): Constant SV and POV Speed

8.1.1 S1-A Crash-Imminent Timing, Right-Side POV Approach

For tests performed with crash-imminent timing and a right-side POV approach, the relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Similarly, the relationship between the front of the POV and leading edge of the POV stop bar ($D_{POV\_SB\_R}$) at any moment in time ($t_{POV\_SB\_R}$) is defined as:

$$t_{POV\_SB\_R} = \frac{D_{POV\_SB\_R}}{V_{POV}}$$

Referenced from stop bars, and using the measurements provided in Figure A1, the time of impact becomes:

$$t_{SV\_impacts\_POV\_R} = \frac{D_{SV\_SB} + 8.8928\,m - \frac{1}{2}POV_{width}}{V_{SV}}$$

And,

$$t_{POV\_impacted\_by\_SV\_R} = \frac{D_{POV\_SB\_R} + 5.0320\,m + \frac{1}{2}POV_{length}}{V_{POV}}$$

When an SV-to-POV impact occurs,

$$t_{SV\_impacts\_POV\_R} = t_{POV\_impacted\_by\_SV\_R}$$

Therefore,

$$\frac{D_{SV\_SB} + 8.8928\,m - \frac{1}{2}POV_{width}}{V_{SV}} = \frac{D_{POV\_SB\_R} + 5.0320\,m + \frac{1}{2}POV_{length}}{V_{POV}}$$

Simplifying, $D_{POV\_SB\_R}$ presented as a function of D_{SV_SB}, V_{SV}, and V_{POV} becomes:

$$D_{POV\_SB\_R} = V_{POV}\left(\frac{D_{SV\_SB} + 8.8928\,m - \frac{1}{2}POV_{width}}{V_{SV}}\right) - 5.0320\,m - \frac{1}{2}POV_{length}$$

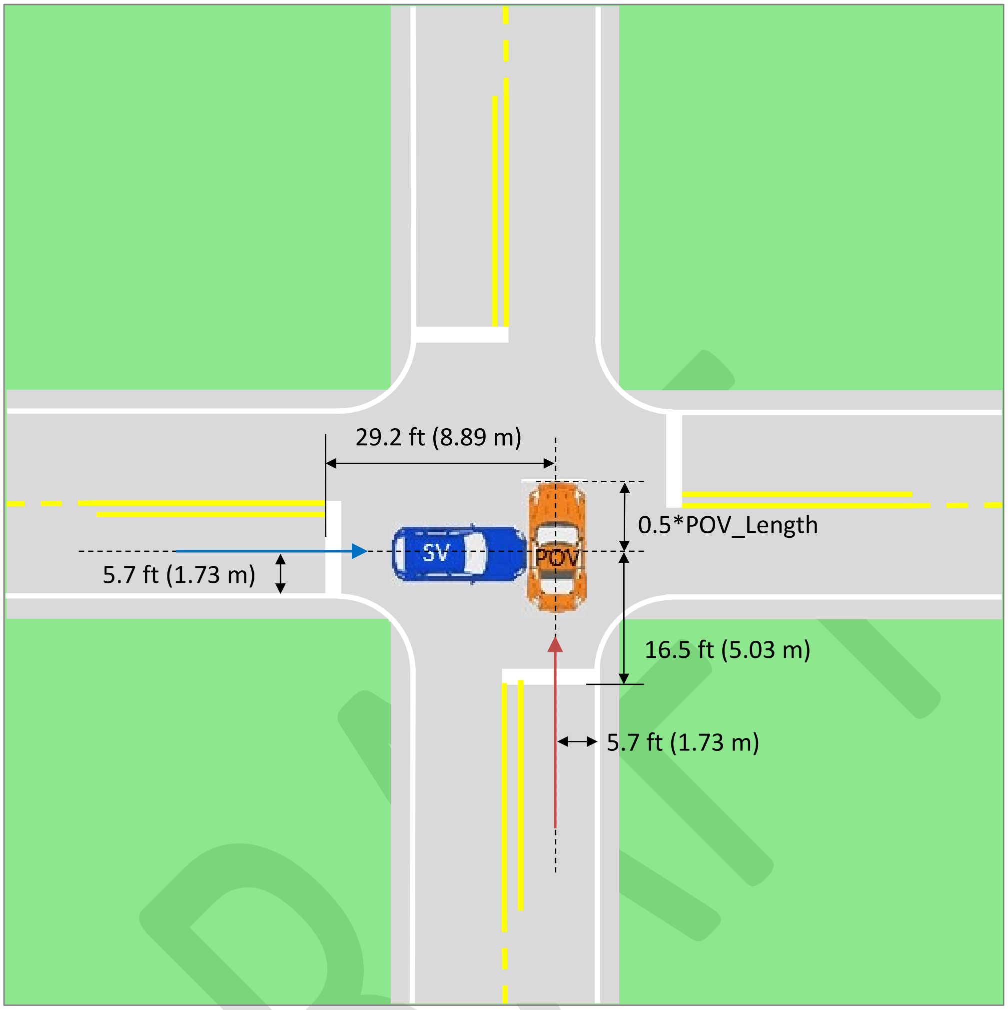

Figure A1. S1-A path details, crash-imminent timing, right-side POV approach.

8.1.2 S1-A Near-Miss Timing, Right-Side POV Approach

For tests performed with near-miss timing and a right-side POV approach, the relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Similarly, the relationship between the front of the POV and leading edge of the POV stop bar ($D_{POV\_SB\_R}$) at any moment in time ($t_{POV\_SB\_R}$) is defined as:

$$t_{POV\_SB\_R} = \frac{D_{POV\_SB\_R}}{V_{POV}}$$

Referenced from stop bars, and using the measurements provided in Figure A2, time at the near miss evaluation point becomes:

$$t_{SV\_near\_miss\_pt\_R} = \frac{D_{SV\_SB} + 8.8928\,m - \frac{1}{2}POV_{width}}{V_{SV}}$$

And,

$$t_{POV\_near\_miss\_pt\_R} = \frac{D_{POV\_SB\_R} + 5.0320\,m + POV_{length} + 2\,m}{V_{POV}}$$

At the near miss evaluation point,

$$t_{SV\_near\_miss\_pt\_R} = t_{POV\_near\_miss\_pt\_R}$$

Therefore,

$$\frac{D_{SV\_SB} + 8.8928\,m - \frac{1}{2}POV_{width}}{V_{SV}} = \frac{D_{POV\_SB\_R} + 5.0320\,m + POV_{length} + 2\,m}{V_{POV}}$$

Simplifying, $D_{POV\_SB\_R}$ presented as a function of D_{SV_SB}, V_{SV}, *and* V_{POV} becomes:

$$D_{POV\_SB\_R} = V_{POV}\left(\frac{D_{SV\_SB} + 8.8928\,m - \frac{1}{2}POV_{width}}{V_{SV}}\right) - 5.0320\,m - POV_{length} - 2\,m$$

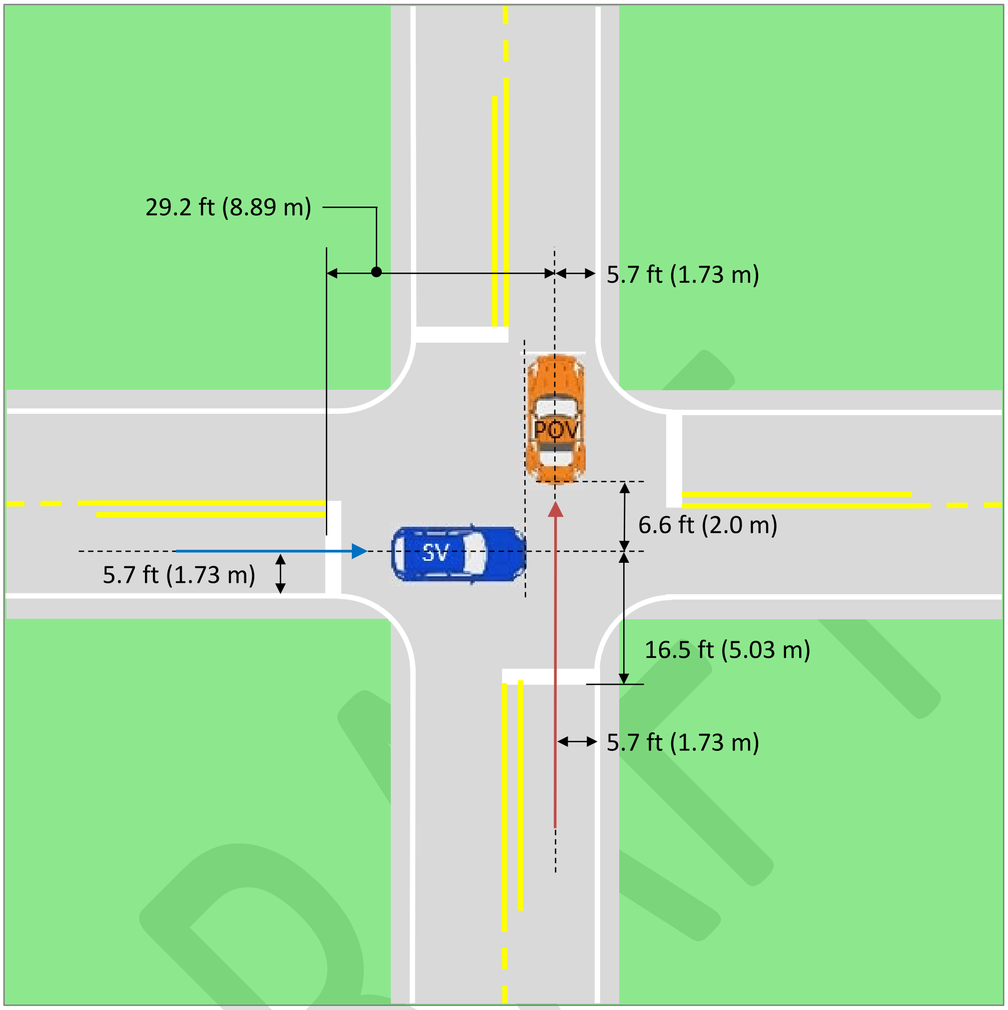

Figure A2. S1-A path details, near-miss timing, right-side POV approach.

8.1.3 S1-A Crash-Imminent Timing, Left-Side POV Approach

For tests performed with crash-imminent timing and a left-side POV approach, the relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Similarly, the relationship between the front of the POV and leading edge of the POV stop bar ($D_{POV\_SB\_R}$) at any moment in time ($t_{POV\_SB\_R}$) is defined as:

$$t_{POV\_SB\_L} = \frac{D_{POV\_SB\_L}}{V_{POV}}$$

Referenced from stop bars, and using the measurements provided in Figure A3, the time of impact becomes:

$$t_{SV\_impacts\_POV\_L} = \frac{D_{SV\_SB} + 5.0320\ m - \frac{1}{2} POV_{width}}{V_{SV}}$$

And,

$$t_{POV\_impacted\_by\_SV\_L} = \frac{D_{POV\_SB\_L} + 8.8928\ m + \frac{1}{2} POV_{length}}{V_{POV}}$$

When an SV-to-POV impact occurs,

$$t_{SV\_impacts\_POV\_L} = t_{POV\_impacted\_by\_SV\_L}$$

Therefore,

$$\frac{D_{SV\_SB} + 5.0320\ m - \frac{1}{2} POV_{width}}{V_{SV}} = \frac{D_{POV\_SB\_L} + 8.8928\ m + \frac{1}{2} POV_{length}}{V_{POV}}$$

Simplifying, $D_{POV\_SB\_L}$ presented as a function of D_{SV_SB}, V_{SV}, and V_{POV} becomes:

$$D_{POV\_SB\_L} = V_{POV}\left(\frac{D_{SV\_SB} + 5.0320\ m - \frac{1}{2} POV_{width}}{V_{SV}}\right) - 8.8928\ m - \frac{1}{2} POV_{length}$$

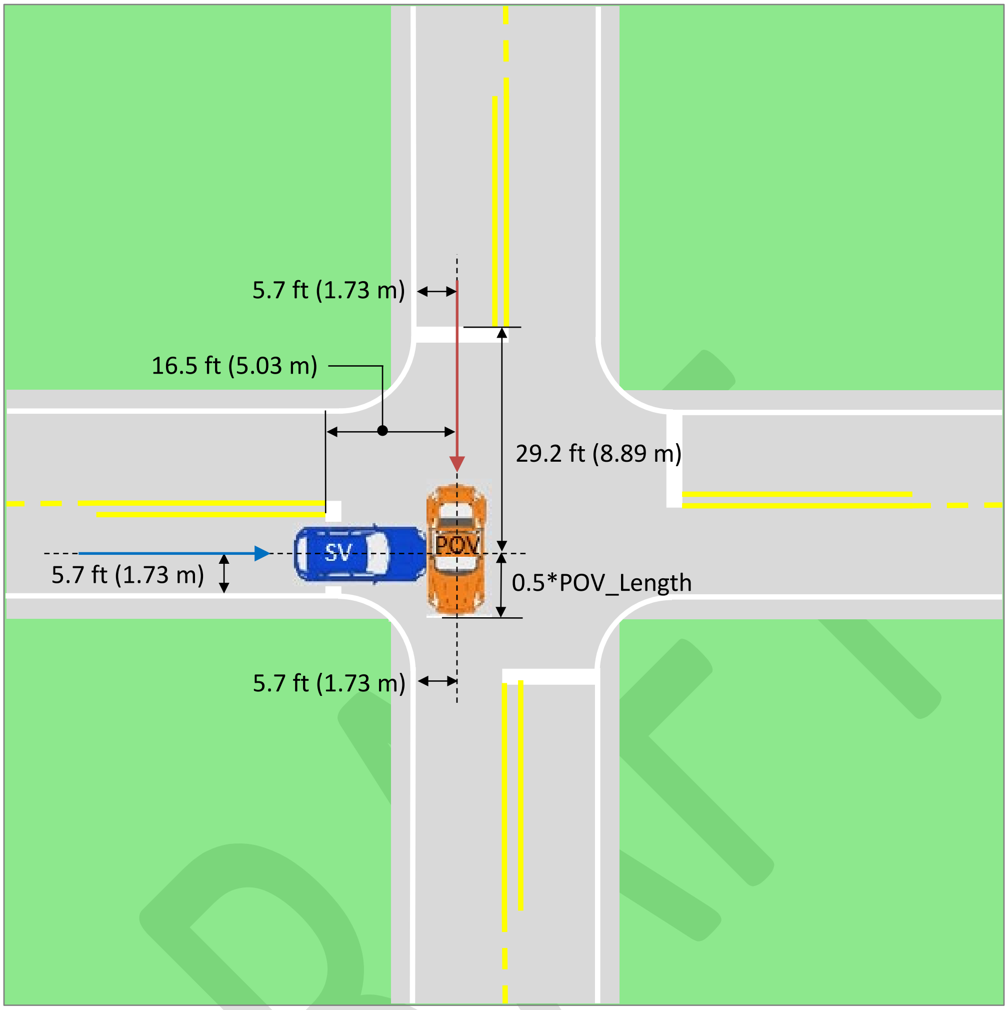

Figure A3. S1-A path details, crash-imminent timing, left-side POV approach.

8.1.4 S1-A Near-Miss Timing, Left-Side POV Approach

For tests performed with near-miss timing and a left-side POV approach, the relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Similarly, the relationship between the front of the POV and leading edge of the POV stop bar ($D_{POV\_SB\_R}$) at any moment in time ($t_{POV\_SB\_R}$) is defined as:

$$t_{POV\_SB\_L} = \frac{D_{POV\_SB\_R}}{V_{POV}}$$

Referenced from stop bars, and using the measurements provided in Figure A4, time at the near miss evaluation point becomes:

$$t_{SV\_near\_miss\_pt\_L} = \frac{D_{SV_{SB}} + 5.0320\ m - \frac{1}{2}POV_{width}}{V_{SV}}$$

And,

$$t_{POV\_near\_miss\_pt\_L} = \frac{D_{POV\_SB\ \_L} + 8.8928\ m + POV_{length} + 2\ m}{V_{POV}}$$

At the near miss evaluation point,

$$t_{SV\_near\_miss\_pt\_L} = t_{POV\_near\_miss\_pt\_L}$$

Therefore,

$$\frac{D_{SV\_SB} + 5.0320\ m - \frac{1}{2}POV_{width}}{V_{SV}} = \frac{D_{POV\_SB\_L} + 8.8928\ m + POV_{length} + 2\ m}{V_{POV}}$$

Simplifying, $D_{POV\_SB\_L}$ presented as a function of D_{SV_SB}, V_{SV}, and V_{POV} becomes:

$$D_{POV\_SB\_L} = V_{POV}\left(\frac{D_{SV\_SB} + 5.0320\ m - \frac{1}{2}POV_{width}}{V_{SV}}\right) - 8.8928\ m - POV_{length} - 2\ m$$

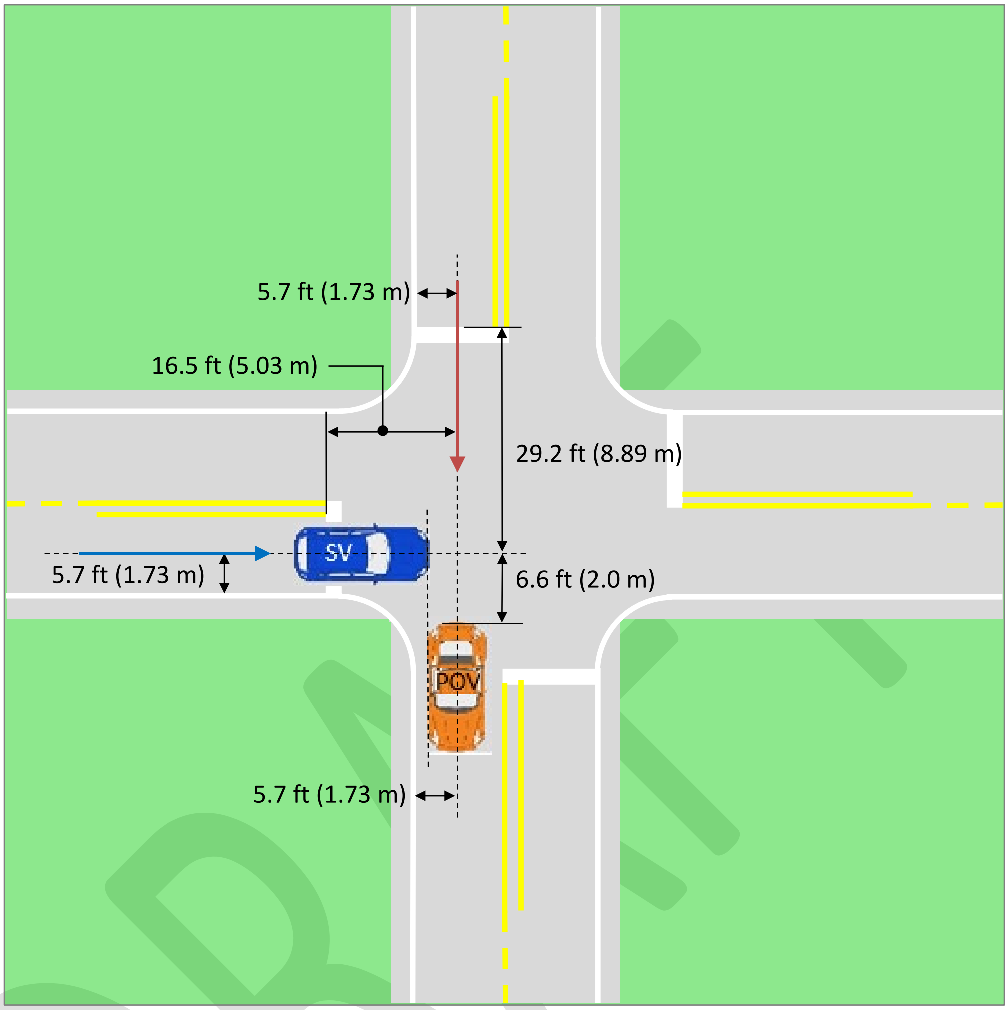

Figure A4. S1-A path details, near-miss timing, left-side POV approach.

8.2 ISA Scenario 1-B (S1-B): POV Accelerates from Rest, Constant SV Speed

8.2.1 S1-B Crash-Imminent Timing, Right-Side POV Approach

For tests performed with <u>crash-imminent</u> timing and a <u>right-side</u> POV approach, achieving the desired crash-imminent position requires that the POV accelerate from rest, and be displaced such that the SV strikes its longitudinal center. This displacement, referenced from the POV stop bar is defined as:

$$D_{POV\_SB\_R} = \frac{1}{2}(a_{POV})(t_{POV\_impacted\_by\_SV\_R})^2$$

Where, a_{pov} is the POV acceleration, $D_{POV\_SB\_R}$ is the relationship between the front of the POV and leading edge of the POV stop bar, and $t_{POV\_impacted\_by\_SV\_R}$ is the time needed to accelerate the POV into position.

At the time of impact, using the measurements provided in Figure A1:

$$D_{POV\_SB\_R} = 5.0320\ m + \frac{1}{2}POV_{length}$$

Therefore,

$$t_{POV\_impacted\_by\_SV\_R} = \sqrt{\frac{2 * \left(5.0320\ m + \frac{1}{2}POV_{length}\right)}{a_{POV}}}$$

The relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Referenced from the SV stop bar, and using the measurements provided in Figure A1, the time of impact becomes:

$$t_{SV\_impacts\_POV\_R} = \frac{D_{SV\_SB} + 8.8928\ m - \frac{1}{2}POV_{width}}{V_{SV}}$$

Since the POV requires $t_{POV\_impacted\_by\_SV\_R}$ seconds to accelerate at a_{pov} to the desired crash-imminent position,

$$t_{SV\_impacts\_POV\_R} = t_{POV\_impacted\_by\_SV\_R}$$

Therefore, the distance from the front of the SV to the leading edge of the SV stop bar at the initiation of POV acceleration shall be defined as:

$$D_{SV\_SB} = V_{SV} * \sqrt{\frac{2 * \left(5.0320\ m + \frac{1}{2}POV_{length}\right)}{a_{POV}}} - 8.8928\ m + \frac{1}{2}POV_{width}$$

8.2.2 S1-B Near-Miss Timing, Right-Side POV Approach

For tests performed with near-miss timing and a right-side POV approach, achieving the desired near miss evaluation point position requires that the POV accelerate from rest, and be displaced such that the SV will pass behind it with the correct SV-to-POV orientation. This displacement, referenced from the POV stop bar is defined as:

$$D_{POV\_SB\_R} = \frac{1}{2}(a_{POV})(t_{POV\_near\_miss\_pt\_R})^2$$

Where, a_{pov} is the POV acceleration, $D_{POV\_SB\_R}$ is the relationship between the front of the POV and leading edge of the POV stop bar, and $t_{POV\_near\_miss\_pt\_R}$ is the time needed to accelerate the POV into position.

At the time of the near miss evaluation point, using the measurements provided in Figure A2:

$$D_{POV\_SB\_R} = 5.0320\ m + POV_{length} + 2\ m$$

Therefore,

$$t_{POV\_near\_miss\_pt\_R} = \sqrt{\frac{2 * (5.0320\ m + POV_{length} + 2\ m)}{a_{POV}}}$$

The relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Referenced from the SV stop bar, and using the measurements provided in Figure A2, time at the near miss evaluation point becomes:

$$t_{SV\_near\_miss\_pt\_R} = \frac{D_{SV\_SB} + 8.8928\ m - \frac{1}{2}POV_{width}}{V_{SV}}$$

Since the POV requires $t_{POV\_near\_miss\_pt\_R}$ seconds to accelerate at a_{pov} to the desired near miss evaluation point position,

$$t_{SV\_near\_miss\_pt\_R} = t_{POV\_near\_miss\_pt\_R}$$

Therefore, the distance from the front of the SV to the leading edge of the SV stop bar at the initiation of POV acceleration shall be defined as:

$$D_{SV\_SB} = V_{SV} * \sqrt{\frac{2 * (5.0320\ m + POV_{length} + 2\ m)}{a_{POV}}} - 8.8928\ m + \frac{1}{2}POV_{width}$$

8.2.3 S1-B Crash-Imminent Timing, Left-Side POV Approach

For tests performed with crash-imminent timing and a left-side POV approach, achieving the desired crash-imminent position requires that the POV accelerate from rest, and be displaced such that the SV strikes its longitudinal center. This displacement, referenced from the POV stop bar is defined as:

$$D_{POV\_SB\_L} = \frac{1}{2}(a_{POV})(t_{POV\_impacted\_by\_SV\_L})^2$$

Where, a_{pov} is the POV acceleration, $D_{POV\_SB\_L}$ is the relationship between the front of the POV and leading edge of the POV stop bar, and $t_{POV\_impacted\_by\_SV\_L}$ is the time needed to accelerate the POV into position.

At the time of impact, using the measurements provided in Figure A3:

$$D_{POV\_SB\_L} = 8.8928\ m + \frac{1}{2}POV_{length}$$

Therefore,

$$t_{POV\_impacted\_by\_SV\_L} = \sqrt{\frac{2 * \left(8.8928\ m + \frac{1}{2}POV_{length}\right)}{a_{POV}}}$$

The relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Referenced from the SV stop bar, and using the measurements provided in Figure A3, the time of impact becomes:

$$t_{SV\_impacts\_POV\_L} = \frac{D_{SV\_SB} + 5.0320\ m - \frac{1}{2}POV_{width}}{V_{SV}}$$

Since the POV requires $t_{POV\_impacted\_by\_SV\_L}$ seconds to accelerate at a_{pov} to the desired crash-imminent position,

$$t_{SV\_impacts\_POV\_L} = t_{POV\_impacted\_by\_SV\_L}$$

Therefore, the distance from the front of the SV to the leading edge of the SV stop bar at the initiation of POV acceleration shall be defined as:

$$D_{SV\_SB} = V_{SV} * \sqrt{\frac{2 * \left(8.8928\ m + \frac{1}{2}POV_{length}\right)}{a_{POV}}} - 5.0320\ m + \frac{1}{2}POV_{width}$$

8.2.4 S1-B Near-Miss Timing, Left-Side POV Approach

For tests performed with near-miss timing and a left-side POV approach, achieving the desired near miss evaluation point position requires that the POV accelerate from rest, and be displaced such that the SV will pass behind it with the correct SV-to-POV orientation. This displacement, referenced from the POV stop bar is defined as:

$$D_{POV\_SB\_L} = \frac{1}{2}(a_{POV})(t_{POV\_near\_miss\_pt\_L})^2$$

Where, a_{pov} is the POV acceleration, $D_{POV\_SB\_L}$ is the relationship between the front of the POV and leading edge of the POV stop bar, and $t_{POV\_near\_miss\_pt\_L}$ is the time needed to accelerate the POV into position.

At the time of the near miss evaluation point, using the measurements provided in Figure A4:

$$D_{POV\_SB\_L} = 8.8928\ m + POV_{length} + 2\ m$$

Therefore,

$$t_{POV\_near\_miss\_pt\_L} = \sqrt{\frac{2 * (8.8928\ m + POV_{length} + 2\ m)}{a_{POV}}}$$

The relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Referenced from the SV stop bar, and using the measurements provided in Figure A4, time at the near miss evaluation point becomes:

$$t_{SV\_near\_miss\_pt\_L} = \frac{D_{SV\_SB} + 5.0320\ m - \frac{1}{2}POV_{width}}{V_{SV}}$$

Since the POV requires $t_{POV\_near\_miss\_pt\_L}$ seconds to accelerate at a_{pov} to the desired near miss evaluation point position,

$$t_{SV\_near\_miss\_pt\_L} = t_{POV\_near\_miss\_pt\_L}$$

Therefore, the distance from the front of the SV to the leading edge of the SV stop bar at the initiation of POV acceleration shall be defined as:

$$D_{SV\_SB} = V_{SV} * \sqrt{\frac{2 * (8.8928\ m + POV_{length} + 2\ m)}{a_{POV}}} - 5.0320\ m + \frac{1}{2}POV_{width}$$

8.3 ISA Scenario 1-C (S1-C): SV Accelerates from Rest, Constant POV Speed

8.3.1 S1-C Crash-Imminent Timing, Right-Side POV Approach

For tests performed with crash-imminent timing and a right-side POV approach, achieving the desired crash-imminent position requires that the SV accelerate from rest, and be displaced such that it strikes the POV at its longitudinal center. This displacement, referenced from the SV stop bar is defined as:

$$D_{SV\_SB\_R} = \frac{1}{2}(a_{SV})\left(t_{SV\_impacts\_POV\_R}\right)^2$$

Where, a_{SV} is the SV acceleration, $D_{SV\_SB\_R}$ is the relationship between the front of the SV and leading edge of the SV stop bar, and $t_{SV\_impacts\_POV\_R}$ is the time needed to accelerate the SV into position.

At the time of impact, using the measurements provided in Figure A1:

$$D_{SV\_SB\_R} = 8.8928\ m - \frac{1}{2}POV_{width}$$

Therefore,

$$t_{SV\_impacts\_POV\_R} = \sqrt{\frac{2 * \left(8.8928\ m - \frac{1}{2}POV_{width}\right)}{a_{SV}}}$$

The relationship between the front of the POV and leading edge of the POV stop bar (D_{POV_SB}) at any moment in time (t_{POV_SB}) is defined as:

$$t_{POV\_SB} = \frac{D_{POV\_SB}}{V_{POV}}$$

Referenced from the POV stop bar, and using the measurements provided in Figure A1, the time of impact becomes:

$$t_{POV\_impacted\_by\_SV\_R} = \frac{D_{POV\_SB} + 5.0320\ m + \frac{1}{2}POV_{length}}{V_{POV}}$$

Since the SV requires $t_{SV\_impacts\_POV\_R}$ seconds to accelerate at a_{SV} to the desired crash-imminent position,

$$t_{POV\_impacted\_by\_SV\_R} = t_{SV\_impacts\_POV\_R}$$

Therefore, the distance from the front of the POV to the leading edge of the POV stop bar at the initiation of SV acceleration shall be defined as:

$$D_{POV\_SB} = V_{POV} * \sqrt{\frac{2 * \left(8.8928\ m - \frac{1}{2}POV_{width}\right)}{a_{SV}}} - 5.0320\ m - \frac{1}{2}POV_{length}$$

8.3.2 S1-C Near-Miss Timing, Right-Side POV Approach

For tests performed with near-miss timing and a right-side POV approach, achieving the desired near miss evaluation point position requires that the SV accelerate from rest, and be displaced such that it will pass behind the POV with the correct SV-to-POV orientation. This displacement, referenced from the SV stop bar is defined as:

$$D_{SV\_SB\_R} = \frac{1}{2}(a_{SV})(t_{SV\_near\_miss\_pt\_R})^2$$

Where, a_{SV} is the SV acceleration, $D_{SV\_SB\_R}$ is the relationship between the front of the SV and leading edge of the SV stop bar, and $t_{SV\_near\_miss\_pt\_R}$ is the time needed to accelerate the SV into position.

At the time of the near miss evaluation point, using the measurements provided in Figure A2:

$$D_{SV\_SB\_R} = 8.8928\ m - \frac{1}{2}POV_{width}$$

Therefore,

$$t_{SV\_near\_miss\_pt\_R} = \sqrt{\frac{2 * \left(8.8928\ m - \frac{1}{2}POV_{width}\right)}{a_{SV}}}$$

The relationship between the front of the POV and leading edge of the POV stop bar (D_{POV_SB}) at any moment in time (t_{POV_SB}) is defined as:

$$t_{POV\_SB} = \frac{D_{POV\_SB}}{V_{POV}}$$

Referenced from the POV stop bar, and using the measurements provided in Figure A2, time at the near miss evaluation point becomes:

$$t_{POV\_near\_miss\_pt\_R} = \frac{D_{POV\_SB} + 5.0320\ m + POV_{length} + 2\ m}{V_{POV}}$$

Since the SV requires $t_{SV\_near\_miss\_pt\_R}$ seconds to accelerate at a_{SV} to the desired near miss evaluation point position,

$$t_{POV\_near\_miss\_pt\_R} = t_{SV\_near\_miss\_pt\_R}$$

Therefore, the distance from the front of the POV to the leading edge of the POV stop bar at the initiation of SV acceleration shall be defined as:

$$D_{POV\_SB} = V_{POV} * \sqrt{\frac{2 * \left(8.8928\ m - \frac{1}{2}POV_{width}\right)}{a_{SV}}} - 5.0320\ m - POV_{length} - 2\ m$$

8.3.3 S1-C Crash-Imminent Timing, Left-Side POV Approach

For tests performed with crash-imminent timing and a left-side POV approach, achieving the desired crash-imminent position requires that the SV accelerate from rest, and be displaced such that it strikes the POV at its longitudinal center. This displacement, referenced from the SV stop bar is defined as:

$$D_{SV\_SB\_L} = \frac{1}{2}(a_{SV})\left(t_{SV\_impacts\_POV\_L}\right)^2$$

Where, a_{SV} is the SV acceleration, $D_{SV\_SB\_L}$ is the relationship between the front of the SV and leading edge of the SV stop bar, and $t_{SV\_impacts\_POV\_L}$ is the time needed to accelerate the SV into position.

At the time of impact, using the measurements provided in Figure A3:

$$D_{SV\_SB\_L} = 5.0320\ m - \frac{1}{2}POV_{width}$$

Therefore,

$$t_{SV\_impacts\_POV\_L} = \sqrt{\frac{2 * \left(5.0320\ m - \frac{1}{2}POV_{width}\right)}{a_{SV}}}$$

The relationship between the front of the POV and leading edge of the POV stop bar (D_{POV_SB}) at any moment in time (t_{POV_SB}) is defined as:

$$t_{POV\_SB} = \frac{D_{POV\_SB}}{V_{POV}}$$

Referenced from the POV stop bar, and using the measurements provided in Figure A3, the time of impact becomes:

$$t_{POV\_impacted\_by\_SV\_L} = \frac{D_{POV\_SB} + 8.8928\ m + \frac{1}{2}POV_{length}}{V_{POV}}$$

Since the SV requires $t_{SV\_impacts\_POV\_L}$ seconds to accelerate at a_{SV} to the desired crash-imminent position,

$$t_{POV\_impacted\_by\_SV\_L} = t_{SV\_impacts\_POV\_L}$$

Therefore, the distance from the front of the POV to the leading edge of the POV stop bar at the initiation of SV acceleration shall be defined as:

$$D_{POV\_SB} = V_{POV} * \sqrt{\frac{2 * \left(5.0320\ m - \frac{1}{2}POV_{width}\right)}{a_{SV}}} - 8.8928\ m - \frac{1}{2}POV_{length}$$

8.3.4 S1-C Near-Miss Timing, Left-Side POV Approach

For tests performed with near-miss timing and a left-side POV approach, achieving the desired near miss evaluation point position requires that the SV accelerate from rest, and be displaced such that it will pass behind the POV with the correct SV-to-POV orientation. This displacement, referenced from the SV stop bar is defined as:

$$D_{SV\_SB\_L} = \frac{1}{2}(a_{SV})\left(t_{SV\_near\_miss\_pt\_L}\right)^2$$

Where, a_{SV} is the SV acceleration, $D_{SV\_SB\_L}$ is the relationship between the front of the SV and leading edge of the SV stop bar, and $t_{SV\_near\_miss\_pt\_L}$ is the time needed to accelerate the SV into position.

At the time of the near miss evaluation point, using the measurements provided in Figure A4:

$$D_{SV\_SB\_L} = 5.0320\ m - \frac{1}{2}POV_{width}$$

Therefore,

$$t_{SV\_near\_miss\_pt\_L} = \sqrt{\frac{2*\left(5.0320\ m - \frac{1}{2}POV_{width}\right)}{a_{SV}}}$$

The relationship between the front of the POV and leading edge of the POV stop bar (D_{POV_SB}) at any moment in time (t_{POV_SB}) is defined as:

$$t_{POV\_SB} = \frac{D_{POV\_SB}}{V_{POV}}$$

Referenced from the POV stop bar, and using the measurements provided in Figure A4, time at the near miss evaluation point becomes:

$$t_{POV\_near\_miss\_pt\_L} = \frac{D_{POV\_SB} + 8.8928\ m + POV_{length} + 2\ m}{V_{POV}}$$

Since the SV requires $t_{SV\_near\_miss\_pt\_L}$ seconds to accelerate at a_{SV} to the desired near miss evaluation point position,

$$t_{POV\_near\_miss\_pt\_L} = t_{SV\_near\_miss\_pt\_L}$$

Therefore, the distance from the front of the POV to the leading edge of the POV stop bar at the initiation of SV acceleration shall be defined as:

$$D_{POV\_SB} = V_{SV} * \sqrt{\frac{2*\left(5.0320\ m - \frac{1}{2}POV_{width}\right)}{a_{POV}}} - 8.8928\ m - POV_{length} - 2\ m$$

9.0 APPENDIX B – SCENARIO 2 TEST SYNCHRONIZATION

9.1 ISA Scenario 2-A (S2-A): Constant SV Speed, POV Slows and Turns Left

9.1.1 S2-A Crash-Imminent Timing

For tests performed with crash-imminent timing, the relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Similarly, the relationship between the front of the POV and leading edge of the POV stop bar (D_{POV_SB}) at any moment in time (t_{POV_SB}) is defined as:

$$t_{POV\_SB} = \frac{D_{POV\_SB}}{V_{POV}}$$

As shown in Figure A5, the path of the POV right front corner is an arc that originates at the leading edge of the POV stop bar and ends at the point of impact. The longitudinal distance traveled by the POV along this path shall be the half chord length of an arc defined by the centerlines of two perpendicular lanes and half of the POV width (since the front center of the SV impacts the right front corner of the POV). This is represented by the following equation:

$$l_{POV\_RF\_path} = \sqrt{r_{POV\_RF\_path}{}^2 - (r_{POV\_RF\_path} - s_{POV\_SB})^2}$$

Where,

s_{POV_SB} = the arc sagitta (taken to be two 5.6667 ft (1.7272 m) half lane widths + the 0.6667 ft (0.2032 m) double line marking width (center line to center line) + $\frac{1}{2}POV_{width}$), and
$r_{POV\_RF\_path}$ = the 9.8425 ft (3 m) stop bar offset + one 12 ft (3.6576 m) lane + the 0.6667 ft (0.2032 m) double line marking width + one 5.6667 ft (1.7272 m) half lane width + $\frac{1}{2}POV_{width}$

Therefore,

$$l_{POV\_RF\_path} = \sqrt{\left(8.5880\,m + \frac{1}{2}POV_{width}\right)^2 - \left(8.5880\,m + \frac{1}{2}POV_{width} - (3.6576\,m + \frac{1}{2}POV_{width}\right)^2}$$

Simplifying:

$$l_{POV\_RF\_path} = \sqrt{\left(8.5880\,m + \frac{1}{2}POV_{width}\right)^2 - 24.3088\,m}$$

To determine the arc length of $D_{POV\_RF\_path}$, the angle α_{POV_RF}, defined in Figure A5, shall be calculated with the following:

$$\alpha_{POV\_RF} = arcsin \frac{l_{POV\_RF\_path}}{r_{POV\_RF\_path}}$$

Therefore,

$$\alpha_{POV\_impacted\_by\_SV} = arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Converting to degrees:

$$\theta_{POV\_impacted\_by\_SV} = \frac{180}{\pi} arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Calculating the ratio of $\theta_{POV\_impacted\_by\_SV}$ to 360 degrees and multiplying by the circumference of a circle defined by $r_{POV\_RF\_path}$,

$$D_{POV\_impacted\_by\_SV} = 2\pi r_{POV\_RF\_path} * \frac{\frac{180}{\pi} arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{360}$$

Simplifying,

$$D_{POV\_impacted\_by\_SV} = \left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

$D_{POV\_impacted\_by\_SV}$ is now used to determine the time needed by the POV to travel along the path from the POV stop bar to the point its right front is impacted by the SV:

$$t_{POV\_impacted\_by\_SV} = \frac{D_{POV\_impacted\_by\_SV}}{V_{POV}}$$

Therefore,

$$t_{POV\_impacted\_by\_SV} = \frac{\left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{V_{POV}}$$

For the SV, referenced from stop bars, the time of impact becomes:

$$t_{SV\_impacts\_POV} = \frac{D_{SV\_SB} + (13.9248\ m - l_{POV\_RF\_path})}{V_{SV}}$$

The times needed for each vehicle to arrive at the impact point are set to be equivalent to identify the distance the front of the SV must be offset from the leading edge of its stop bar at the instant the POV arrives at the leading edge of the POV stop bar:

$$t_{SV\_impacts\_POV} = t_{POV\_impacted\_by\_SV}$$

Therefore,

$$\frac{D_{SV\_SB} + (13.9248\ m - l_{POV\_RF\_path})}{V_{SV}} = \frac{\left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{V_{POV}}$$

Rearranging to isolate $D_{SV,SB}$,

$$D_{SV\_SB} = l_{POV\_RF\_path} - 13.9248\ m + V_{SV}\frac{\left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{V_{POV}}$$

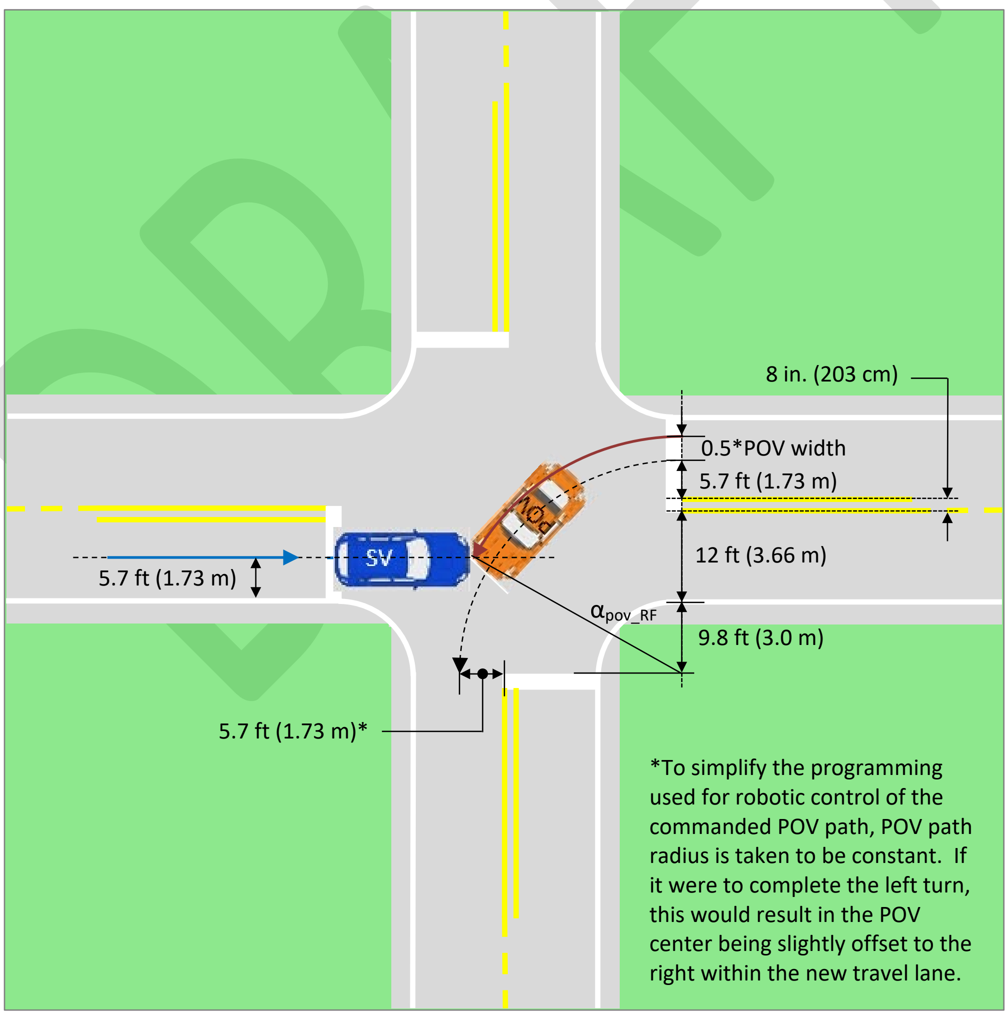

Figure A5. S2 path details, crash-imminent timing.

9.1.2 S2-A Near-Miss Timing

For tests performed with near-miss timing, the relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

For crash-imminent timing, the path of the POV shown in Figure A5 was the right front corner. For near-miss timing, the path shown in Figure A6 is taken to represent the POV right rear corner. Assessed from the instant the POV right rear corner reaches the leading edge of the POV stop bar to the point where the right rear of the POV is 6.5617 ft (2 m) beyond the path of the SV center, the half chord length of the POV path (arc) is represented by the following equation:

$$l_{POV\_RR\_path} = \sqrt{r_{POV\_RR\_path}{}^2 - (r_{POV\_RR\_path} - s_{POV\_SB})^2}$$

Where,

s_{POV_SB} = the arc sagitta (taken to be two 5.6667 ft (1.7272 m) half lane widths + the 0.6667 ft (0.2032 m) double line marking width (center line to center line) + $\frac{1}{2}POV_{width}$ + 6.5617 ft (2 m)), and
$r_{POV\_RR\_path}$ = the 9.8425 ft (3 m) stop bar offset + one 12 ft (3.6576 m) lane + the 0.6667 ft (0.2032 m) double line marking width + one 5.6667 ft (1.7272 m) half lane width + $\frac{1}{2}POV_{width}$

Therefore,

$$l_{POV\_RR\_path} = \sqrt{\left(8.5880\ m + \frac{1}{2}POV_{width}\right)^2 - \left(8.5880\ m + \frac{1}{2}POV_{width} - (3.6576\ m + \frac{1}{2}POV_{width} + 2\ m\right)^2}$$

Simplifying:

$$l_{POV\_RR\_path} = \sqrt{\left(8.5880\ m + \frac{1}{2}POV_{width}\right)^2 - 8.5872\ m}$$

To determine the arc length of $D_{POV\_RR\_path}$, the angle α_{POV_RR}, defined in Figure A6, shall be calculated with the following:

$$\alpha_{POV\_RR} = arcsin\frac{l_{POV\_RR\_path}}{r_{POV\_RR\_path}}$$

Therefore,

$$\alpha_{near\_miss\_pt} = arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Converting to degrees:

$$\theta_{near\_miss\_pt} = \frac{180}{\pi} arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2} POV_{width}}\right)$$

Calculating the ratio of $\theta_{near\_miss\_pt}$ to 360 degrees and multiplying by the circumference of a circle defined by $r_{POV\_RR\_path}$,

$$D_{POV\_RR\_to\_near\_miss\_pt} = 2\pi r_{POV\_RR\_path} * \frac{\frac{180}{\pi} arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2} POV_{width}}\right)}{360}$$

Simplifying,

$$D_{POV\_RR\_to\_near\_miss\_pt} = \left(8.5880\ m + \frac{1}{2} POV_{width}\right) arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2} POV_{width}}\right)$$

$D_{POV\_RR\_to\_near\_miss\_pt}$ is now used to determine the time needed by the right rear of the POV to travel along the path from the POV stop bar from the time when the front to a point 6.5617 ft (2 m) from the path of the SV center:

$$t_{POV\_RR\_SB\_to\_near\_miss\_pt} = \frac{D_{POV\_RR\_SB\_to\_near\_miss\_pt}}{V_{POV}}$$

Therefore,

$$t_{POV\_RR\_SB\_to\_near\_miss\_pt} = \frac{\left(8.5880\ m + \frac{1}{2} POV_{width}\right) arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2} POV_{width}}\right)}{V_{POV}}$$

For the SV, referenced from stop bars, the time to the near-miss evaluation point becomes:

$$t_{SV\_to\_near\_miss\_pt} = \frac{D_{SV\_SB} + (13.9248\ m - l_{POV\_RR\_path})}{V_{SV}}$$

The times needed for each vehicle to arrive at the near-miss evaluation point are set to be equivalent to identify the distance the front of the SV must be offset from the leading edge of its stop bar at the instant the POV arrives at the leading edge of the POV stop bar:

$$t_{SV\_to\_near\_miss\_pt} = t_{POV\_RR\_SB\_to\_near\_miss\_pt} + \frac{POV_{length}}{V_{POV}}$$

Therefore,

$$\frac{D_{SV\_SB} + (13.9248\,m - l_{POV\_RF\_path})}{V_{SV}} = \frac{\left(8.5880\,m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\,m + \frac{1}{2}POV_{width}}\right)}{V_{POV}} + \frac{POV_{length}}{V_{POV}}$$

Rearranging to isolate $D_{SV,SB}$,

$$D_{SV\_SB} = l_{POV\_RR\_path} - 13.9248\,m + V_{SV}\frac{\left(8.5880\,m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\,m + \frac{1}{2}POV_{width}}\right) + POV_{length}}{V_{POV}}$$

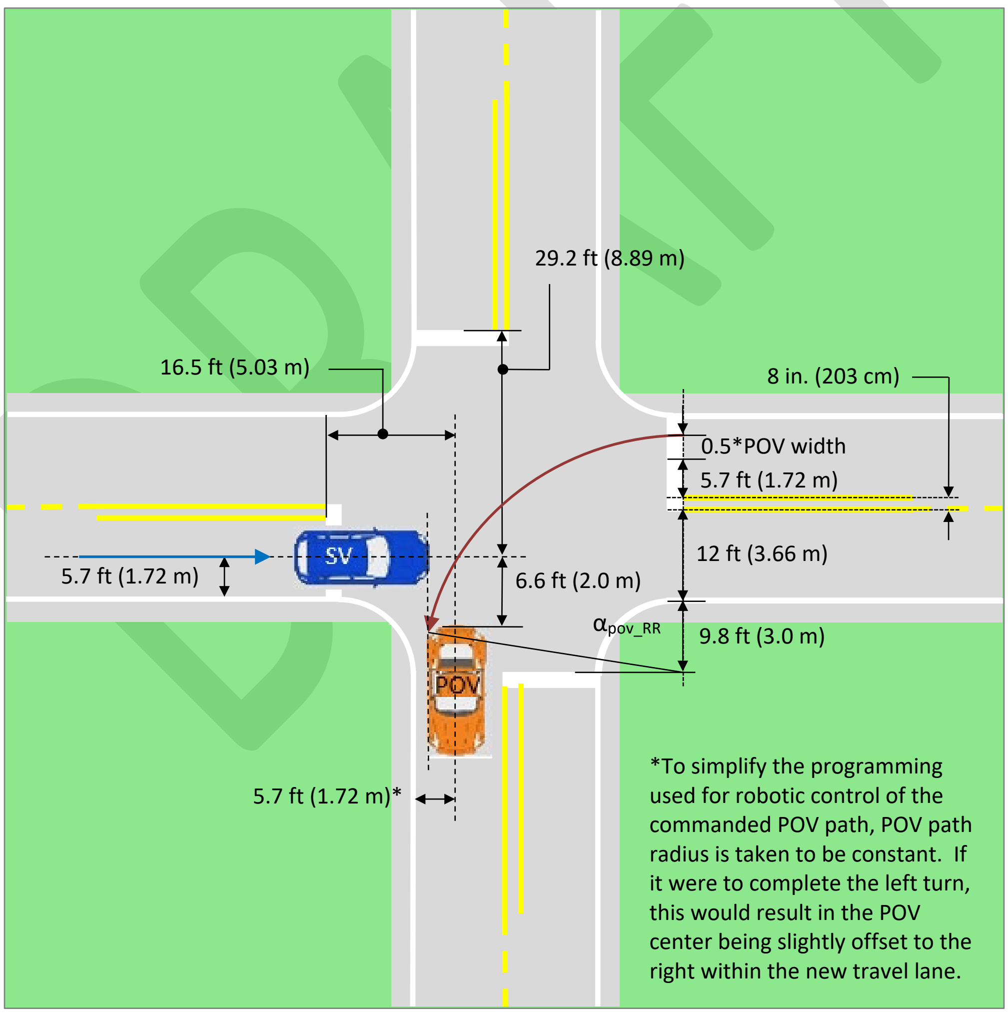

Figure A6. S2 path details, near-miss timing.

9.2 ISA Scenario 2-B (S2-B): Constant SV Speed, POV Accelerates from Rest While Turning Left

9.2.1 S2-B Crash-Imminent Timing

For tests performed with crash-imminent timing, achieving the desired test choreography requires that the POV accelerate from rest, and be displaced such that the SV strikes its right front corner.

The relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Referenced from stop bars, the time of impact becomes:

$$t_{SV\_impacts\_POV} = \frac{D_{SV\_SB} + (13.9248\ m - l_{POV\_RF\_path})}{V_{SV}}$$

The POV displacement, referenced from the leading edge of the POV stop bar to the point of impact is defined as:

$$D_{POV\_impacted\_by\_SV} = \frac{1}{2}(a_{POV})\left(t_{POV\_impacted\_by\_SV}\right)^2$$

Therefore,

$$t_{POV\_impacted\_by\_SV\_R} = \sqrt{\frac{2 * D_{POV\_impacted\_by\_SV}}{a_{POV}}}$$

Where a_{pov} is the POV acceleration, D_{POV_SB} is the path of the POV right front corner (an arc that originates at the leading edge of the POV stop bar and ends at the point of impact), and $t_{POV\_impacted\_by\_SV}$ is the time needed to accelerate the POV into position. To determine the arc length of the POV right front corner, the angle $\propto_{POV\_RF}$, defined in Figure A5, shall be calculated with the following:

$$\alpha_{POV\_RF} = arcsin \frac{l_{POV\_RF\_path}}{r_{POV\_RF\_path}}$$

Where, and as previously defined in Section 9.1,

$r_{POV\_RF\_path} = 8.5880\ m + \frac{1}{2}POV_{width}$, and

$$l_{POV\_RF\_path} = \sqrt{\left(8.5880\ m + \frac{1}{2}POV_{width}\right)^2 - 24.3088\ m}$$

Therefore,

$$\alpha_{POV\_impacted\_by\_SV} = arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Converting to degrees:

$$\theta_{POV\_impacted\_by\_SV} = \frac{180}{\pi} arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Calculating the ratio of $\theta_{POV\_impacted\_by\_SV}$ to 360 degrees and multiplying by the circumference of a circle defined by $r_{POV\_RF\_path}$,

$$D_{POV\_impacted\_by\_SV} = 2\pi r_{POV\_RF\_path} * \frac{\frac{180}{\pi} arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{360}$$

Simplifying,

$$D_{POV\_impacted\_by\_SV} = \left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Since the POV requires $t_{POV\_impacted\_by\_SV\_L}$ seconds to accelerate at a_{pov} to the desired crash-imminent position,

$$t_{SV\_impacts\_POV} = t_{POV\_impacted\_by\_SV}$$

Therefore,

$$\frac{D_{SV\_SB} + (13.9248\ m - l_{POV\_RF\_path})}{V_{SV}} = \sqrt{\frac{2 * \left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{a_{POV}}}$$

Rearranging and solving for D_{SV_SB} produces the distance from the front of the SV to the leading edge of the SV stop bar at the initiation of POV acceleration:

$$D_{SV\_SB} = l_{POV\_RF\_path} - 13.9248\ m + V_{SV}\sqrt{\frac{2 * \left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{a_{POV}}}$$

9.2.2 S2-B Near-Miss Timing

For tests performed with near-miss timing, the relationship between the front of the SV and leading edge of the SV stop bar (D_{SV_SB}) at any moment in time (t_{SV_SB}) is defined as:

$$t_{SV\_SB} = \frac{D_{SV\_SB}}{V_{SV}}$$

Referenced from stop bars, the time to the near-miss evaluation point becomes:

$$t_{SV\_to\_near\_miss\_pt} = \frac{D_{SV\_SB} + (13.9248\,m - l_{POV\_RR\_path})}{V_{SV}}$$

For near-miss timing, the path shown in Figure A6 is taken to represent the POV right rear corner. Assessed from the instant the POV right rear corner reaches the leading edge of the POV stop bar to the point where the right rear of the POV is 6.5617 ft (2 m) beyond the path of the SV center, the half chord length of the POV path (arc) is represented by the following equation:

$$l_{POV\_RR\_path} = \sqrt{{r_{POV\_RR\_path}}^2 - (r_{POV\_RR\_path} - s_{POV\_SB})^2}$$

Where,

s_{POV_SB} = the arc sagitta (taken to be two 5.6667 ft (1.7272 m) half lane widths + the 0.6667 ft (0.2032 m) double line marking width (center line to center line) + $\frac{1}{2}POV_{width}$ + 6.5617 ft (2 m)), and
$r_{POV\_RR\_path}$ = the 9.8425 ft (3 m) stop bar offset + one 12 ft (3.6576 m) lane + the 0.6667 ft (0.2032 m) double line marking width + one 5.6667 ft (1.7272 m) half lane width + $\frac{1}{2}POV_{width}$

The total distance traveled by the right rear corner of the POV is occurs over two segments: (1) a straight-line section from rest to the leading edge of the POV stop bar, and (2) along a curved path from the leading edge of the POV stop bar to the near-miss evaluation point. Therefore:

$$D_{POV\_RR\_to\_SB} + D_{POV\_RR\_SB\_to\_near\_miss\_pt} = \frac{1}{2}(a_{POV})\left(t_{POV\_RR\_to\_near\_miss\_pt}\right)^2$$

Rearranging,

$$t_{POV\_RR\_to\_near\_miss\_pt} = \sqrt{\frac{2 * (D_{POV\_RR\_to\_SB} + D_{POV\_RR\_SB\_to\_near\_miss\_pt})}{a_{POV}}}$$

Where a_{pov} is the POV acceleration and $t_{POV\_RR\_to\_near\_miss\_pt}$ is the total time needed to accelerate the right rear corner of the POV to the near-miss evaluation point. To determine the arc length of the curved path segment, the angle α_{POV_RR}, defined in Figure A6, shall be calculated with the following:

$$\alpha_{POV\_RR} = arcsin\frac{l_{POV\_RR\_curved\_path}}{r_{POV\_RR\_curved\_path}}$$

Where, and as previously defined in Section 9.1.2,

$$r_{POV\_RR\_curved\_path} = 8.5880\ m + \tfrac{1}{2}POV_{width}, \text{ and}$$

$$l_{POV\_RR\_curved\_path} = \sqrt{\left(8.5880\ m + \frac{1}{2}POV_{width}\right)^2 - 8.5872\ m}$$

Therefore,

$$\alpha_{near\_miss\_pt} = arcsin\left(\frac{l_{POV\_RR\_curved\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Converting to degrees:

$$\theta_{near\_miss\_pt} = \frac{180}{\pi}arcsin\left(\frac{l_{POV\_RR\_curved\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Calculating the ratio of $\theta_{near\_miss\_pt}$ to 360 degrees and multiplying by the circumference of a circle defined by $r_{POV\_RR\_path}$,

$$D_{POV\_RR\_SB\_to\_near\_miss\_pt} = 2\pi r_{POV\_RF\_path} * \frac{\frac{180}{\pi}arcsin\left(\frac{l_{POV\_RR\_curved\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{360}$$

Simplifying,

$$D_{POV\_RR\_SB\_to\_near\_miss\_pt} = \left(8.5880\ m + \frac{1}{2}POV_{width}\right)arcsin\left(\frac{l_{POV\_RR\_curved\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

At the near miss evaluation point,

$$t_{SV\_to\_near\_miss\_pt} = t_{POV\_RR\_to\_near\_miss\_pt}$$

Therefore,

$$\frac{D_{SV\_SB} + (13.9248\ m - l_{POV\_RR\_path})}{V_{SV}} = \sqrt{\frac{2 * (D_{POV\_RR\_to\_SB} + D_{POV\_RR\_SB\_to\_near\_miss\_pt})}{a_{POV}}}$$

Rearranging,

$$D_{SV\_SB} = l_{POV\_RR\_path} - 13.9248\ m + V_{SV}\sqrt{\frac{2 * (D_{POV\_RR\_to\_SB} + D_{POV\_RR\_SB\_to\_near\_miss\_pt})}{a_{POV}}}$$

Therefore,

$$D_{SV_{SB}} = l_{POV_{RR_{path}}} - 13.9248\ m + V_{SV}\sqrt{\frac{2 * \left(POV_{length} + \left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RR\_curved\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)\right)}{a_{POV}}}$$

9.3 ISA Scenario 2-C (S2-C): SV Accelerates from Rest While Turning Left, Constant POV Speed

9.3.1 S2-C Crash-Imminent Timing

For tests performed with crash-imminent timing, SV displacement, referenced from the leading edge of the SV stop bar to the point of impact is defined as:

$$D_{SV\_impacts\_POV} = \frac{1}{2}(a_{SV})(t_{SV\_impacts\_POV})^2$$

Therefore,

$$t_{SV\_impacts\_POV} = \sqrt{\frac{2 * D_{SV\_impacts\_POV}}{a_{SV}}}$$

As shown in Figure A5, the path of the POV right front corner is an arc that originates at the leading edge of the POV stop bar and ends at the point of impact. The longitudinal distance traveled by the POV along this path shall be the half chord length of an arc defined by the centerlines of two perpendicular lanes and half of the POV width (since the front center of the SV impacts the right front corner of the POV). This is represented by the following equation:

$$l_{POV\_RF\_path} = \sqrt{r_{POV\_RF\_path}{}^2 - (r_{POV\_RF\_path} - s_{POV\_SB})^2}$$

Where,

s_{POV_SB} = the arc sagitta (taken to be two 5.6667 ft (1.7272 m) half lane widths + the 0.6667 ft (0.2032 m) double line marking width (center line to center line) + $\frac{1}{2}POV_{width}$), and
$r_{POV\_RF\_path}$ = the 9.8425 ft (3 m) stop bar offset + one 12 ft (3.6576 m) lane + the 0.6667 ft (0.2032 m) double line marking width + one 5.6667 ft (1.7272 m) half lane width + $\frac{1}{2}POV_{width}$

Therefore,

$$l_{POV\_RF\_path} = \sqrt{\left(8.5880\,m + \frac{1}{2}POV_{width}\right)^2 - \left(8.5880\,m + \frac{1}{2}POV_{width} - (3.6576\,m + \frac{1}{2}POV_{width}\right)^2}$$

Simplifying:

$$l_{POV\_RF\_path} = \sqrt{\left(8.5880\,m + \frac{1}{2}POV_{width}\right)^2 - 24.3088\,m}$$

To determine the arc length of $D_{POV\_RF\_path}$, the angle α_{POV_RF}, defined in Figure A5, shall be calculated with the following:

$$\alpha_{POV\_RF} = arcsin\frac{l_{POV\_RF\_path}}{r_{POV\_RF\_path}}$$

Therefore,

$$\alpha_{POV\_impacted\_by\_SV} = arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Converting to degrees:

$$\theta_{POV\_impacted\_by\_SV} = \frac{180}{\pi}arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Calculating the ratio of $\theta_{POV\_impacted\_by\_SV}$ to 360 degrees and multiplying by the circumference of a circle defined by $r_{POV\_RF\_path}$,

$$D_{POV\_impacted\_by\_SV} = 2\pi r_{POV\_RF\_path} * \frac{\frac{180}{\pi}arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{360}$$

Simplifying,

$$D_{POV\_impacted\_by\_SV} = \left(8.5880\ m + \frac{1}{2}POV_{width}\right)arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

$D_{POV\_impacted\_by\_SV}$ is now used to determine the time needed to by the POV to travel along the path from the POV stop bar to the point its right front is impacted by the SV:

$$t_{POV\_impacted\_by\_SV} = \frac{D_{POV\_impacted\_by\_SV}}{V_{POV}}$$

Therefore,

$$t_{POV\_impacted\_by\_SV} = \frac{\left(8.5880\ m + \frac{1}{2}POV_{width}\right)arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{V_{POV}}$$

For the SV, referenced from stop bars, the time of impact becomes:

$$t_{SV\_impacts\_POV} = \sqrt{\frac{2 * (13.9248\ m - l_{POV\_RF\_path})}{a_{SV}}}$$

The times needed for each vehicle to arrive at the impact point are set to be equivalent to identify the distance the front of the POV must be offset from the leading edge of its stop bar at the onset of the SV acceleration from rest to ensure the SV and POV arrive at the impact point correctly:

$$t_{SV\_impacts\_POV} = t_{POV\_impacted\_by\_SV} + t_{POV\_timing\_offset}$$

Therefore,

$$\sqrt{\frac{2 * (13.9248\ m - l_{POV\_RF\_path})}{a_{SV}}} = \frac{\left(8.5880\ m + \frac{1}{2} POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2} POV_{width}}\right)}{V_{POV}} + t_{POV\_timing\_offset}$$

Rearranging to isolate $t_{POV\_timing\_offset}$:

$$t_{POV\_timing\_offset} = \sqrt{\frac{2 * (13.9248\ m - l_{POV\_RF\_path})}{a_{SV}}} - \frac{\left(8.5880\ m + \frac{1}{2} POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2} POV_{width}}\right)}{V_{POV}}$$

$t_{POV\_timing\_offset}$ is now used to determine the distance from POV to its stop bar at the instant the SV begins to accelerate from rest. If $t_{POV\_timing\_offset}$ occurs while the POV is decelerating from its initial velocity:

$$D_{POV\_to\_POV\_SB} = v_{POV_{SB}} * t_{POV\_timing\_offset} - \frac{1}{2}(a_{POV})\left(t_{POV\_timing\_offset}\right)^2$$

9.3.2 S2-C Near-Miss Timing

For tests performed with near-miss timing, SV displacement, referenced from the leading edge of the SV stop bar to the point of impact is defined as:

$$D_{SV\_to\_near\_miss\_pt} = \frac{1}{2}(a_{SV})\left(t_{SV\_impacts\_POV}\right)^2$$

Therefore,

$$t_{SV\_to\_near\_miss\_pt} = \sqrt{\frac{2 * D_{SV\_to\_near\_miss\_pt}}{a_{SV}}}$$

For near-miss timing, the path shown in Figure A6 is taken to represent the POV right rear corner. Assessed from the instant the POV right rear corner reaches the leading edge of the POV stop bar to the point where the right rear of the POV is 6.5617 ft (2 m) beyond the path of the SV center, the half chord length of the POV path (arc) is represented by the following equation:

$$l_{POV\_RR\_path} = \sqrt{{r_{POV\_RR\_path}}^2 - (r_{POV\_RR\_path} - s_{POV\_SB})^2}$$

Where,

s_{POV_SB} = the arc sagitta (taken to be two 5.6667 ft (1.7272 m) half lane widths + the 0.6667 ft (0.2032 m) double line marking width (center line to center line) + $\frac{1}{2}POV_{width}$ + 6.5617 ft (2 m)), and
$r_{POV\_RR\_path}$ = the 9.8425 ft (3 m) stop bar offset + one 12 ft (3.6576 m) lane + the 0.6667 ft (0.2032 m) double line marking width + one 5.6667 ft (1.7272 m) half lane width + $\frac{1}{2}POV_{width}$

Therefore,

$$l_{POV\_RR\_path} = \sqrt{\left(8.5880\,m + \frac{1}{2}POV_{width}\right)^2 - \left(8.5880\,m + \frac{1}{2}POV_{width} - (3.6576\,m + \frac{1}{2}POV_{width} + 2\,m\right)^2}$$

Simplifying:

$$l_{POV\_RR\_path} = \sqrt{\left(8.5880\,m + \frac{1}{2}POV_{width}\right)^2 - 8.5872\,m}$$

To determine the arc length of $D_{POV\_RR\_path}$, the angle α_{POV_RR}, defined in Figure A6, shall be calculated with the following:

$$\alpha_{POV}\_RR = arcsin\frac{l_{POV\_RR\_path}}{r_{POV\_RR\_path}}$$

Therefore,

$$\alpha_{near\_miss\_pt} = arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Converting to degrees:

$$\theta_{near\_miss\_pt} = \frac{180}{\pi} arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

Calculating the ratio of $\theta_{near\_miss\_pt}$ to 360 degrees and multiplying by the circumference of a circle defined by $r_{POV\_RR\_path}$,

$$D_{POV\_RR\_to\_near\_miss\_pt} = 2\pi r_{POV\_RF\_path} * \frac{\frac{180}{\pi} arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{360}$$

Simplifying,

$$D_{POV\_RR\_to\_near\_miss\_pt} = \left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RF\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)$$

$D_{POV\_RR\_to\_near\_miss\_pt}$ is now used to determine the time needed by the right rear of the POV to travel along the path from the POV stop bar from the time when the front to a point 6.56 ft (2 m) from the path of the SV center:

$$t_{POV\_RR\_SB\_to\_near\_miss\_pt} = \frac{D_{POV\_RR\_SB\_to\_near\_miss\_pt}}{V_{POV}}$$

Therefore,

$$t_{POV\_RR\_SB\_to\_near\_miss\_pt} = \frac{\left(8.5880\ m + \frac{1}{2}POV_{width}\right) arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2}POV_{width}}\right)}{V_{POV}}$$

For the SV, referenced from stop bars, the time to the near-miss evaluation point becomes:

$$t_{SV\_to\_near\_miss\_pt} = \sqrt{\frac{2 * \left(13.9248\ m - l_{POV\_RR\_path}\right)}{a_{SV}}}$$

The times needed for each vehicle to arrive at the near-miss evaluation point are set to be equivalent to identify the distance the <u>front</u> of the POV must be offset from the leading edge of its stop bar at the onset of the SV acceleration from rest to ensure the SV and POV arrive at the impact point correctly:

$$t_{SV\_to\_near\_miss\_pt} = t_{POV\_RR\_SB\_to\_near\_miss\_pt} + t_{POV\_RR\_to\_SB} + t_{POV\_timing\_offset}$$

Where, $t_{POV\_RR\_to\_SB}$ is the time required to displace the rear of the POV by the length of the POV after it's the front center crosses the leading edge of the POV stop bar.

Therefore,

$$\sqrt{\frac{2 * (13.9248\ m - l_{POV\_RR\_path})}{a_{SV}}} = \frac{\left(8.5880\ m + \frac{1}{2} POV_{width}\right) arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2} POV_{width}}\right)}{V_{POV}} + \frac{POV_{length}}{V_{POV}} + t_{POV\_timing\_offset}$$

Rearranging to isolate $t_{POV\_timing\_offset}$:

$$t_{POV\_timing\_offset} = \sqrt{\frac{2 * (13.9248\ m - l_{POV\_RR\_path})}{a_{SV}}} - \frac{\left(8.5880\ m + \frac{1}{2} POV_{width}\right) arcsin\left(\frac{l_{POV\_RR\_path}}{8.5880\ m + \frac{1}{2} POV_{width}}\right) + POV_{length}}{V_{POV}}$$

$t_{POV\_timing\_offset}$ is now used to determine the distance from POV to its stop bar at the instant the SV begins to accelerate from rest. If $t_{POV\_timing\_offset}$ occurs while the POV is decelerating from its initial velocity:

$$D_{POV\_to\_POV\_SB} = v_{POV_{SB}} * t_{POV\_timing\_offset} - \frac{1}{2}(a_{POV})(t_{POV\_timing\_offset})^2$$

10.0 APPENDIX C – SCENARIO 3 TEST SYNCHRONIZATION

10.1 ISA Scenario 3-A: SV Turns Left, Constant POV Speed (applicable to S3-A0 and S3-A1)

For Scenarios S3-A0 and S3-A1 the crash-imminent and near-miss timing is taken from the instant that the front of the SV is at the leading edge of the stop bar. The SV velocity will be the same at this instant for the S3-A0 and S3-A1 test since the SV decelerates to 15 mph (24.1 km/h) when the front of the SV is at the stop bar, therefore the synchronization timing from this instant on will be the same both scenarios. The value of interest for test synchronization is how far the POV needs to be offset from its corresponding stop bar when the SV is crossing its corresponding stop bar. These synchronization calculations assume no ISA intervention from the SV.

10.1.1 S3-A Crash-Imminent Timing

For tests performed with crash-imminent timing, the relationship between the front center point of the SV and the impact point where the front center point of the SV impacts the front left corner of the POV at any moment after the SV front center point crosses the stop bar is defined as:

$$t_{SV\_SBToImpact} = \frac{D_{SV\_SBToImpact}}{V_{SV}}$$

where $t_{SV\_SBToImpact}$ is the time after the front center point of the SV crosses the leading edge of the stop bar, $D_{SV\_SBToImpact}$ is the total distance traveled by the front center point of the SV from the leading edge of the stop bar to the point of impact, and V_{SV} is the subject vehicle velocity and is a constant.

Similarly, the relationship between the front left corner of the POV and the impact point where the front center of the SV impacts the front left corner of the POV at any moment after the front center point of the SV crosses the stop bar is defined as:

$$t_{POV\_OffsetToImpact} = \frac{D_{POV\_OffsetToImpact}}{V_{POV}}$$

where $t_{POV\_OffsetToImpact}$ is the time it takes for the POV to go from its initial position when the center front point of the SV is at the leading edge of the stop bar to the point of impact, $D_{POV\_OffsetToImpact}$ is the total distance traveled by the front left corner of the POV to the point of impact, and V_{POV} is the POV velocity and is a constant.

As shown in Figure A7, $D_{SV\_SBToImpact}$ is an arc that originates at the leading edge of the SV stop bar and ends at the point of impact. Therefore, $D_{SV\_SBToImpact}$ is equal to the arc length of this path which is defined as:

$$D_{SV\_SBToImpact} = R_{SV} * \theta$$

where R_{SV} is the radius of the circle that connects the centerline of the SV travel lane at the leading edge of the SV stop bar to the centerline of the desired lane of travel after completing the left turn at a point parallel to the leading edge of the stop bar in the adjacent lane, and θ is the angle in radians along R_{SV} from the centerline of the original lane of travel at the leading edge of the stop bar to the point of impact.

R_{SV} is calculated by adding one 5.6667 ft (1.7272 m) half lane width, the 0.6667 ft (0.2032 m) double line marking width, one 12 ft (3.6576 m) lane, and the 9.8425 ft (3 m) stop bar offset, which equals 28.18 ft (8.5880 m). θ is calculated by the following equation based on Figure A7:

$$\theta = \cos\left(\frac{4.7272\ m + \frac{1}{2} POV_{width}}{R_{SV}}\right)$$

where the numerator represents the lateral distance (i.e., perpendicular to the POV travel lane) from the center of the radius R_{SV} to the impact point. Since the impact point is the front left corner of the POV, this distance is calculated by adding the 9.8425 ft (3 m) stop bar offset, one 5.6667 ft (1.7272 m) half lane width, and one half of the POV width to get to the front left corner of the POV. With known values for R_{SV} and θ, $D_{SV\_SB\_to\_Impact}$ can be calculated.

Next, $D_{POV\_OffsetToImpact}$ is calculated with the following equation:

$$D_{POV\_OffsetToImpact} = D_{POV\_OffsetToSB} + D_{POV\_SBToImpact}$$

where $D_{POV\_OffsetToSB}$ is the distance the POV is offset from its stop bar the instant the SV is crossing the leading edge of the SV stop bar and $D_{POV\_SBToImpact}$ is the distance the POV must travel from its stop bar to the impact point. $D_{POV\_SBToImpact}$ is defined as:

$$D_{POV\_SBToImpact} = IW - X_{ImpactToSVSB}$$

where IW is the intersection width from the leading edge of the SV stop bar to the leading edge of the POV stop bar, and $X_{ImpactToSVSB}$ is the longitudinal distance from the impact point to the leading edge of the SV stop bar. IW is calculated by adding a 1 ft (0.3048 m) wide stop bar, one 9.8425 ft (3 m) stop bar offset, two 12 ft (3.6576 m) lane widths, another 9.8425 ft (3 m) stop bar offset, and another 1 ft (0.3048 m) stop bar width, which equals 45.6850 ft (13.9248 m). $X_{ImpactToSVSB}$ is calculated using the Pythagorean theorem:

$$X_{ImpactToSVSB} = \sqrt{\mathrm{R_{SV}}^2 - \left(4.7272\ m + \frac{1}{2} POV_{width}\right)^2}$$

The time needed for each vehicle to arrive at the impact point are set to be equivalent to identify the distance the front left corner of the POV must be offset from the leading edge of its stop bar at the instant the front center point of the SV arrives at the leading edge of the its stop bar:

$$t_{SV\_SBToImpact} = t_{POV\_OffsetToImpact}$$

Therefore,

$$\frac{D_{SV\_SBToImpact}}{V_{SV}} = \frac{D_{POV\_OffsetToImpact}}{V_{POV}}$$

Substituting,

$$\frac{D_{SV\_SBToImpact}}{V_{SV}} = \frac{D_{POV\_OffsetToSB} + D_{POV\_SBToImpact}}{V_{POV}}$$

$$\frac{R_{SV} * \theta}{V_{SV}} = \frac{IW - X_{ImpactToSVSB} + D_{POV\_OffsetToSB}}{V_{POV}}$$

Rearranging to isolate $D_{POV\_OffsetToSB}$,

$$D_{POV\_OffsetToSB} = V_{POV}\left(\frac{R_{SV} * \theta}{V_{SV}}\right) - IW + X_{ImpactToSVSB}$$

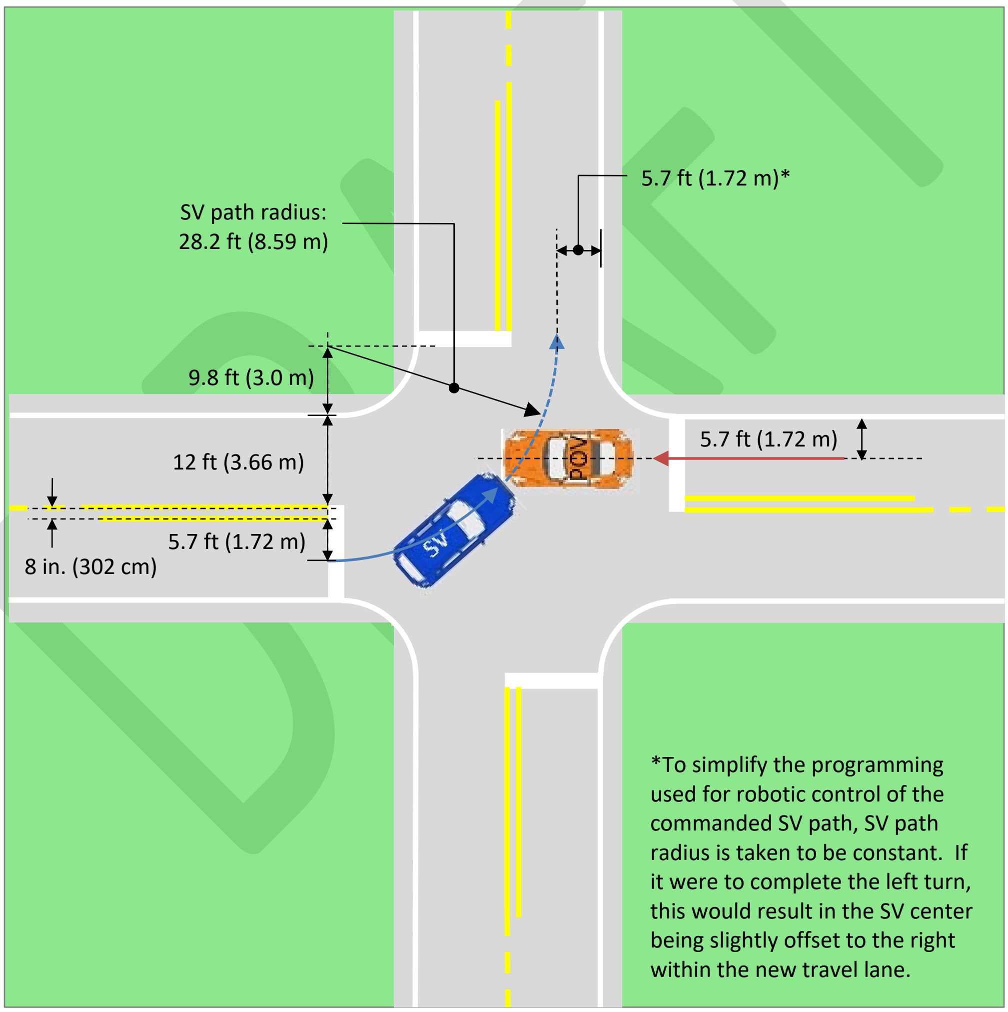

Figure A7. S3 path details, crash-imminent timing.

10.1.2 S3-A Near-Miss Timing

For tests performed with near-miss timing, the relationship between the front center point of the SV and the leading edge of the SV stop bar at any moment after the SV front center point crosses the stop bar is defined as:

$$t_{SV\_SBToNearMiss} = \frac{D_{SV\_SBToNearMiss}}{V_{SV}}$$

where $t_{SV\_SBToNearMiss}$ is the time after the front center point of the SV crosses the leading edge of the stop bar, $D_{SV\_SBToNearMiss}$ is the total distance traveled by the front center point of the SV from the leading edge of the stop bar, and V_{SV} is the subject vehicle velocity and is a constant.

Similarly, the relationship between the front center point of the POV at any moment after the front center point of the SV crosses the stop bar is defined as:

$$t_{POV\_OffsetToNearMiss} = \frac{D_{POV\_OffsetToNearMiss}}{V_{POV}}$$

where $t_{POV\_OffsetToNearMiss}$ is the time it takes for the POV to go from its initial position when the center front point of the SV is at the leading edge of the stop bar to the near miss point, $D_{POV\_OffsetToNearMiss}$ is the total distance traveled by the front center of the POV from its initial position to the near miss point, and V_{POV} is the POV velocity and is a constant.

As shown in Figure A8, $D_{SV\_SBToNearMiss}$ is an arc that originates at the leading edge of the SV stop bar and ends when the SV is in the desired lane after the left turn and the rear most part of the SV is 6.6 ft (2 m) from the front center point of the POV. Therefore, $D_{SV\_SBToNearMiss}$ is equal to the arc length of this path, D_{SV_arc}, plus the distance after the turn where the SV is traveling straight in its post turn lane, $D_{SV\_straight}$:

$$D_{SV\_SBToNearMiss} = D_{SV\_arc} + D_{SV\_straight}$$

where D_{SV_arc} is

$$D_{SV\_arc} = R_{SV} * \theta$$

where R_{SV} was previously defined in Section 10.1.1 and equals 28.18 ft (8.5880 m). θ is $\pi/2$ radians (90 degrees). $D_{SV\_straight}$ is the longitudinal displacement of the front most point of the SV beyond the leading edge of the stop bar located in the lane adjacent to that of the SV's after completion of its left turn. To calculate this, the perpendicular distance from the SV's initial travel lane centerline to the POV front center point is calculated by adding a 5.7 ft (1.7272) half lane width, two 0.6667 ft (0.2032 m) double line marking widths, and another 5.7 ft (1.7272) half lane width, and equals 12.7 ft (3.8608 m). Adding this total to the desired 6.6 ft (2 m) near miss distance to the POV front center point provides the location of the SV rear relative to centerline of the SV's initial travel lane, and is 19.2 ft (5.8608 m). To determine how far the rear of the SV is from the leading edge of the adjacent lane stop bar after the SV completes its left turn, this total is subtracted from R_{SV}, and equals 8.9 ft (2.7272 m). This value is then added to the length of the SV to calculate $D_{SV\_straight}$. Therefore:

$$D_{SV\_SBToNearMiss} = (8.5880\ m * \frac{\pi}{2}) + SV_{length} - 2.7272\ m$$

Where the rear position of the SV is negative since it will not have passed the leading edge of the stop bar in the adjacent lane at the near miss point.

Next, $D_{POV\_OffsetToNearMiss}$ is calculated with the following equation:

$$D_{POV\_OffsetToNearMiss} = D_{POV\_OffsetToSB} + D_{POV\_SBToNearMiss}$$

where $D_{POV\_OffsetToSB}$ is the distance the POV is offset from its stop bar the instant the SV is crossing the leading edge of the SV stop bar and $D_{POV\_SBToNearMiss}$ is the distance the POV must travel from its stop bar to the near miss point. From Figure A8, $D_{POV\_SBToNearMiss}$ is equal to the sum of the 1 ft (0.3048 m) stop bar width, the 9.8425 ft (3 m) stop bar offset, and a 5.6667 ft (1.7272 m) half lane width minus half of the SV width to get the distance traveled by the front center of the POV from the leading edge of the stop bar to the near miss point defined as the location when the front center point of the SV reaches the plane defined by the right ride of the SV. Therefore,

$$D_{POV_{OffsetToNearMiss}} = D_{POV_{OffsetToSB}} + 5.0320\ m - \frac{1}{2}SV_{width}$$

The time needed for each vehicle to arrive at the near miss point are set to be equivalent to identify the distance the front center of the POV must be offset from the leading edge of its stop bar, $D_{POV\_OffsetToSB}$, at the instant the front center point of the SV arrives at the leading edge of the its stop bar:

$$t_{SV\_SBToNearMiss} = t_{POV\_OffsetToNearMiss}$$

Therefore,

$$\frac{D_{SV\_SBToNearMiss}}{V_{SV}} = \frac{D_{POV\_OffsetToNearMiss}}{V_{POV}}$$

Substituting,

$$\frac{\left(8.5880\ m * \frac{\pi}{2}\right) + SV_{length} - 2.7272\ m}{V_{SV}} = \frac{D_{POV\_OffsetToSB} + 5.0320\ m - \frac{1}{2}SV_{width}}{V_{POV}}$$

Rearranging to isolate $D_{POV\_OffsetToSB}$,

$$D_{POV\_OffsetToSB} = V_{POV}\left(\frac{(8.5880\ m * \frac{\pi}{2}) + SV_{length} - 2.7272\ m}{V_{SV}}\right) - 5.0320\ m + \frac{1}{2}SV_{width}$$

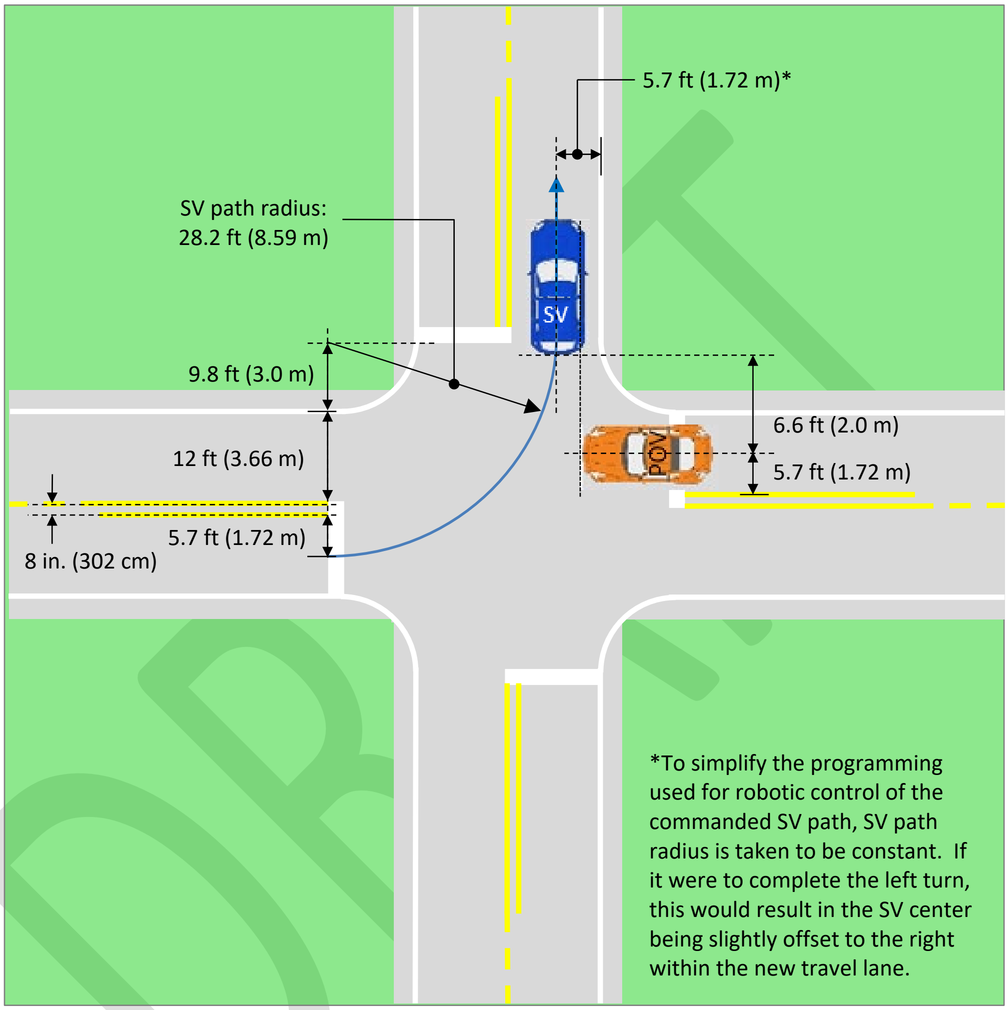

Figure A8. S3 path details, near-miss timing.

10.2 ISA Scenario 3-B0 (S3-B0): SV Decelerates and then Turns Left, POV Accelerates from Rest

For Scenarios S3-B0 the crash-imminent and near-miss timing is taken from the instant that the POV begins accelerating from rest and the front of the POV is at the leading edge of the stop bar. The value of interest for test synchronization is how far the SV needs to be offset from its corresponding stop bar when the POV begins accelerating from its corresponding stop bar. These synchronization calculations assume no ISA intervention from the SV.

10.2.1 S3-B0 Crash-Imminent Timing

For tests performed with crash-imminent timing, the relationship between the front center point of the SV and the front left corner of the POV at any moment after the POV beings to accelerate from rest at its stop bar is defined as:

$$t_{SV\_OffsetToImpact} = \frac{D_{SV\_OffsetToImpact}}{V_{SV}(t_{SV\_OffsetToImpact})}$$

where $t_{SV\_OffsetToImpact}$ is the time it takes for the SV to go from its initial offset position when the POV begins to accelerate from the POV stop bar to the point of impact, $D_{SV\_OffsetToImpact}$ is the total distance traveled by the front center point of the SV from the instant the POV begins accelerating to the point of impact, and $V_{SV}(t_{SV\_OffsetToImpact})$ is the SV velocity.

SV velocity is a piecewise function based on the subject vehicle location: initially constant (V_{SV_0}) decreasing for $t_{SV_{decel}}$ until the SV reaches the leading edge of the SV stop bar, and constant (V_{SV_f})from the leading edge of SV stop bar until the time of POV impact ($t_{SV\_SBToImpact}$). Assuming constant SV deceleration (a_{SV}), SV velocity is therefore defined by:

$$V_{SV}(t_{SV\_OffsetToImpact}) = \begin{cases} V_{SV\_0} & if \quad t_{SV\_OffsetToImpact} > t_{SV_{decel}} + t_{SV\_SBSBToImpact} \\ V_{SV\_0} - \frac{1}{2} a_{SV} * (t_{SV\_OffsetToImpact} - t_{SV\_SBToImpact}) & if \quad t_{SV_{decel}} + t_{SV\_SBToImpact} \geq t_{SV\_OffsetToImpact} \geq t_{SV\_SBToImpact} \\ V_{SV\_f} & if \quad t_{SV\_OffsetToImpact} < t_{SV\_SBToImpact} \end{cases}$$

For the given intersection geometry, vehicle coordination, and vehicle speeds, $t_{SV\_OffsetToImpact} \leq t_{SV_{decel}} + t_{SV\_SBToImpact}$. Therefore, the subject vehicle velocity only consists of a deceleration phase leading up to the stop bar and the constant velocity phase from the stop bar to the impact point. The time it takes for the SV to go from its initial position when the POV begins to accelerate from the POV stop bar to the point of impact is defined as:

$$t_{SV\_OffsetToImpact} = t_{SV_{decel}} + t_{SV\_SBToImpact}$$

where

$$t_{SV\_SBtoImpact} = \frac{D_{SV\_SBtoImpact}}{V_{SV\_f}}$$

where $D_{SV\_SBtoImpact}$ is the distance from the SV stop bar to the point of impact.

Similarly, the relationship between the front left corner of the POV and the impact point at any moment after the front center point of the SV crosses the stop bar is defined as:

$$t_{POV\_SBToImpact} = \sqrt{\frac{2 * D_{POV\_SBToImpact}}{a_{POV}}}$$

where $t_{POV\_SBToImpact}$ is the time it takes for the POV to go from its initial position when the center front point of the POV is at the leading edge of the stop bar to the point of impact, $D_{POV\_SBToImpact}$ is the total distance traveled by the front of the POV from the leading edge of the POV stop bar to the point of impact, and a_{POV} is the POV's constant acceleration.

As shown in Figure A7, $D_{SV\_SBToImpact}$ is an arc that originates at the leading edge of the SV stop bar and ends at the point of impact. Therefore, $D_{SV\_SBToImpact}$ is equal to the arc length of this path which is defined as:

$$D_{SV\_SBToImpact} = R_{SV} * \theta$$

where R_{SV} was previously defined in Section 10.1.1 and equals 28.18 ft (8.5880 m). θ is the angle along R_{SV} from the centerline of the original lane of travel at the leading edge of the stop bar to the point of impact, and is calculated by the following equation:

$$\theta = cos\left(\frac{4.7272\ m + \frac{1}{2}POV_{width}}{R_{SV}}\right)$$

where the numerator represents the lateral distance from the center of the radius R_{SV} to the impact point. Since the impact point is the front left corner of the SV, this distance is calculated by adding the 9.8425 ft (3 m) stop bar offset and a 5.6667 ft (1.7272 m) half lane width, and then adding half of the POV width to get to the front left corner of the POV.

Next, $D_{POV\_SBToImpact}$ is calculated with the following equation:

$$D_{POV\_SBToImpact} = IW - X_{ImpactToSVSB}$$

where IW was previously defined in Section 10.1.1 and equals 45.7 ft (13.92 m). $X_{ImpactToSVSB}$ is calculated using the Pythagorean theorem:

$$X_{ImpactToSVSB} = \sqrt{\mathrm{R_{SV}}^2 - \left(4.7272\ m + \frac{1}{2}POV_{width}\right)^2}$$

The time needed for each vehicle to arrive at the impact point are set to be equivalent to identify the distance the front of the SV must be offset from the leading edge of its stop bar at the instant the POV starts accelerating when the front of the POV is at the leading edge of the its stop bar:

$$t_{SV\_OFfsetToImpact} = t_{POV\_SBToImpact}$$

Therefore,

$$t_{SV_{decel}} + t_{SV\_SBtoImpact} = t_{POV\_SBToImpact}$$

Solving for $t_{SV_{decel}}$

$$t_{SV_{decel}} = t_{POV\_SBtoImpact} - t_{SV\_SBtoImpact}$$

Substituting

$$t_{SV_{decel}} = \sqrt{\frac{2 * D_{POV\_SBToImpact}}{a_{POV}}} - \frac{D_{SV\_SBtoImpact}}{V_{SV\_f}}$$

$t_{SV_{decel}}$ can now be used to calculate the $D_{SV\_OffsetToSB}$, the starting distance from the front of the SV to the leading edge of the stop bar at the instant POV begins accelerating with the front of the POV at the leading edge of the POV stop bar with the following equation:

$$D_{SV\_OffsetToSB} = V_{SV\_f} * t_{SV_{decel}} + \frac{1}{2} a_{SV} * t_{SV_{decel}}{}^{2}$$

10.2.2 S3-B0 Near-Miss Timing

For tests performed with near-miss timing, the relationship between the initial offset position of the front center point of the SV and the near miss point shown in Figure A8 at any moment after the POV beings to accelerate from rest is defined as:

$$t_{SV\_OffsetToNearMiss} = \frac{D_{SV\_OffsetToNearMiss}}{V_{SV}(t_{SV\_OffsetToNearMiss})}$$

where $t_{SV\_OffsetToNearMiss}$ is the time it takes for the SV to go from its initial position when the POV begins to accelerate from the POV stop bar to the point of near miss, $D_{SV\_OffsetToNearMiss}$ is the total distance traveled by the front center point of the SV from the instant the POV begins accelerating to the point of near miss, and $V_{SV}(t_{SV\_OffsetToNearMiss})$ is the subject vehicle velocity. The subject vehicle velocity is a piecewise function based on the subject vehicle location. The subject vehicle velocity is constant, V_{SV_0}, before the time when the subject vehicle begins deceleration before the stop bar $t_{SV_{decel}} + t_{SV\_SBToNearMiss}$, and constant, V_{SV_f}, after the time the subject vehicle crosses its stop bar, $t_{SV\_SBToNearMiss}$. During the deceleration period, the subject vehicle velocity is assumed to have a constant deceleration, a_{SV}. Therefore, the subject vehicle velocity is defined by:

$$V_{SV}(t_{SV\_OffsetToNearMiss}) = \begin{cases} V_{SV\_0} & if \quad t_{SV\_OffsetToNearMiss} > t_{SV_{decel}} + t_{SV\_SBToNearMiss} \\ V_{SV\_0} - \frac{1}{2}a_{SV} * (t_{SV\_OffsetToNearMiss} - t_{SV\_SBToNearMiss}) & if \quad t_{SV_{decel}} + t_{SV\_SBToNearMiss} \geq t_{SV\_OffsetToNearMiss} \geq t_{SV\_SBToNearMiss} \\ V_{SV\_f} & if \quad t_{SV\_OffsetToNearMiss} < t_{SV\_SBToNearMiss} \end{cases}$$

For the given intersection geometry, vehicle coordination, and vehicle speeds, $t_{SV\_OffsetToNearMiss} \leq t_{SV_{decel}} + t_{SV\_SBToNearMiss}$. Therefore, the subject vehicle velocity only consists of a deceleration phase leading up to the stop bar and the constant velocity phase from the stop bar to the near miss point. Then the time it takes for the SV to go from its initial position when the POV begins to accelerate from the POV stop bar to the point of near miss is defined as:

$$t_{SV\_OffsetToNearMiss} = t_{SV_{decel}} + t_{SV\_SBtoNearMiss}$$

Where $t_{SV_{decel}}$ is the time it takes for the SV to decelerate from its initial position from the stop bar to the desired velocity at the stop bar and $t_{SV\_SBtoNearMiss}$ is the time it takes for the SV to travel from the stop bar to the near miss point. $t_{SV\_SBtoNearMiss}$ is defined as

$$t_{SV\_SBtoNearMiss} = \frac{D_{SV\_SBtoNearMiss}}{V_{SV\_f}}$$

where $D_{SV\_SBtoImpact}$ is the distance from the SV stop bar to the point of near-miss.

Similarly, the relationship between the front of the POV and the near-miss point where the rear of the SV is 6.6 ft (2 m) away from the front of the POV at a plane parallel to the SV right side at the instant the POV begins to accelerate when the front of the POV is that the stop bar is defined as:

$$t_{POV\_SBtoNearMiss} = \sqrt{\frac{2 * D_{POV\_SBtoNearMiss}}{a_{POV}}}$$

where $t_{POV\_SBtoNearMiss}$ is the time it takes for the POV to accelerate from its initial position when the front of the POV is at the leading edge of the stop bar to the point of near-miss, $D_{POV\_SBtoNearMiss}$ is the total distance traveled by the front of the POV from the leading edge of the POV stop bar to the point of near-miss, and a_{POV} is the POV's constant acceleration.

As shown in Figure A8, $D_{SV\_SBToNearMiss}$ is an arc that originates at the leading edge of the SV stop bar and ends when the SV is in the desired lane after the left turn and the rear most part of the SV is 6.6 ft (2 m) from the front center point of the POV. Therefore, $D_{SV\_SBToNearMiss}$ is equal to the arc length of this path, D_{SV_arc}, plus the distance after the turn where the SV is traveling straight in its post turn lane, $D_{SV\_straight}$:

$$D_{SV\_SBToNearMiss} = D_{SV\_arc} + D_{SV\_straight}$$

where D_{SV_arc} is

$$D_{SV\_arc} = R_{SV} * \theta$$

where R_{SV} was previously defined in Section 10.1.1 and equals 28.18 ft (8.5880 m). θ is $\pi/2$ radians (90 degrees). $D_{SV\_straight}$ was previously defined in Section 10.1.2 and equals the length of the SV less 8.9 ft (2.7272 m). Therefore,

$$D_{SV\_SBtoNearMiss} = (8.5880\ m * \frac{\pi}{2}) + SV_{length} - 2.7272\ m$$

Next, $D_{POV\_SBToNearMiss}$ is calculated based on Figure A8 by adding the 1 ft (0.3048 m)stop bar width, the 9.8425 ft (3 m) stop bar offset, and a 5.6667 ft (1.7272 m) half lane width, and then subtracting half of the SV width to get the distance traveled by the front center of the POV from the leading edge of the stop bar to the near-miss:

$$D_{POV\_SBtoNearMiss} = 5.0320\ m - \frac{1}{2} SV_{width}$$

The time needed for each vehicle to arrive at the near miss point are set to be equivalent to identify the distance the front of the SV must be offset from the leading edge of its stop bar at the instant the POV starts accelerating when the front of the POV is at the leading edge of the its stop bar:

$$t_{SV\_OffsetToNearMiss} = t_{POV\_SBtoNearMiss}$$

Therefore,

$$t_{SV_{decel}} + t_{SV\_SBtoNearMiss} = t_{POV\_SBtoNearMiss}$$

Solving for $t_{SV_{decel}}$

$$t_{SV_{decel}} = t_{POV\_SBtoNearMiss} - t_{SV\_SBtoNearMiss}$$

Substituting

$$t_{SV_{decel}} = \sqrt{\frac{2 * D_{POV\_SBtoNearMiss}}{a_{POV}}} - \frac{D_{SV\_SBtoNearMiss}}{V_{SV\_f}}$$

$t_{SV_{decel}}$ can now be used to calculate the $D_{SV\_OffsetToSB}$, the starting distance from the front of the SV to the leading edge of the stop bar at the instant POV begins accelerating with the front of the POV at the leading edge of the POV stop bar with the following equation:

$$D_{SV\_OffsetToSB} = V_{SV\_f} * t_{SV_{decel}} + \frac{1}{2} a_{SV} * {t_{SV_{decel}}}^2$$

10.3 ISA Scenario 3-B1 (S3-B1): SV Turns Left at Constant Speed, POV Accelerates from Rest

For Scenarios S3-B1 the crash-imminent and near-miss timing is taken from the instant that the POV begins accelerating from rest and the front of the POV is at the leading edge of the stop bar. The value of interest for test synchronization is how far the SV needs to be offset from its corresponding stop bar when the POV begins accelerating from its corresponding stop bar. These synchronization calculations assume no intervention from the SV.

10.3.1 S3-B1 Crash-Imminent Timing

For tests performed with crash-imminent timing, the relationship between the front center point of the SV and front left corner of the POV at any moment after the POV beings to accelerate from rest at its stop bar is defined as:

$$t_{SV\_OffsetToImpact} = \frac{D_{SV\_OffsetToImpact}}{V_{SV}}$$

where $t_{SV\_OffsetToImpact}$ is the time it takes for the SV to go from its initial position when the POV begins to accelerate from the POV stop bar to the point of impact, $D_{SV\_OffsetToImpact}$ is the total distance traveled by the front center point of the SV from the instant the POV begins accelerating to the point of impact, and V_{SV} is the subject vehicle velocity and is constant.

Similarly, the relationship between the front left corner of the POV and the impact point where the front center of the SV impacts the front left corner of the POV at any moment after the front center point of the SV crosses the stop bar is defined as:

$$t_{POV\_SBToImpact} = \sqrt{\frac{2 * D_{POV\_SBToImpact}}{a_{POV}}}$$

where $t_{POV\_SBToImpact}$ is the time it takes for the POV to accelerate from rest from its stop bar to the point of impact, $D_{POV\_SBToImpact}$ is the total distance traveled by the front of the POV from the leading edge of the POV stop bar to the point of impact, and a_{POV} is the POV's constant acceleration.

As shown in Figure A7, $D_{SV\_SBToImpact}$ is an arc that originates at the leading edge of the SV stop bar and ends at the point of impact. Therefore, $D_{SV\_SBToImpact}$ is equal to the arc length of this path which is defined as:

$$D_{SV\_SBToImpact} = R_{SV} * \theta$$

where R_{SV} was previously defined in Section 10.1.1 and equals 28.18 ft (8.5880 m). θ is the angle along R_{SV} from the centerline of the original lane of travel at the leading edge of the stop bar to the point of impact, and is calculated by the following equation:

$$\theta = cos\left(\frac{4.7272\ m + \frac{1}{2}POV_{width}}{R_{SV}}\right)$$

where the numerator represents the vertical distance from the center of the radius R_{SV} to the impact point. Since the impact point is the front left corner of the SV, this distance is calculated by adding the 9.8425 ft (3 m) stop bar offset, and a 5.6667 ft (1.7272 m) half lane width to half of the lane width, and then adding half of the POV width to get to the front left corner of the POV.

Next, $D_{POV\_SBToImpact}$ is calculated with the following equation:

$$D_{POV\_SBToImpact} = IW - X_{ImpactToSVSB}$$

where IW was previously defined in Section 10.1.1 and equals 45.7 ft (13.92 m). $X_{ImpactToSVSB}$, the horizontal distance from the impact point to the leading edge of the SV stop bar, is calculated using the Pythagorean theorem:

$$X_{ImpactToSVSB} = \sqrt{R_{SV}^2 - \left(4.7272\ m + \frac{1}{2}POV_{width}\right)^2}$$

The time needed for each vehicle to arrive at the impact point are set to be equivalent to identify the distance the front of the SV must be offset from the leading edge of its stop bar at the instant the POV starts accelerating when the front of the POV is at the leading edge of the its stop bar:

$$t_{SV\_OffsetToImpact} = t_{POV\_SBToImpact}$$

Substituting

$$\frac{D_{SV\_OffsetToSB} + D_{SV\_SBToImpact}}{V_{SV}} = \sqrt{\frac{2 * D_{POV\_SBToImpact}}{a_{POV}}}$$

Solving for the distance the SV needs to be offset from its stop bar, $D_{SV\_OffsetToSB}$, the moment the POV begins accelerating from rest at its stop bar:

$$D_{SV\_OffsetToSB} = V_{SV}\sqrt{\frac{2 * D_{POV\_SBToImpact}}{a_{POV}}} - D_{SV\_SBToImpact}$$

10.3.2 S3-B1 Near-Miss Timing

For tests performed with near-miss timing, the relationship between the front center point of the SV and the near miss-point shown in Figure A8 at any moment after the POV beings to accelerate from rest at its stop bar is defined as:

$$t_{SV\_OffsetToNearMiss} = \frac{D_{SV\_OffsetToNearMiss}}{V_{SV}}$$

where $t_{SV\_OffsetToNearMiss}$ is the time it takes for the SV to go from its initial offset position when the POV begins to accelerate from the POV stop bar to the point of near miss, $D_{SV\_OffsetToNearMiss}$ is the total distance traveled by the front center point of the SV from the instant the POV begins accelerating to the point of near miss, and V_{SV} is the subject vehicle velocity and is constant.

Similarly, the relationship between the front of the POV and the near miss point at the instant the POV begins to accelerate when the front of the POV is that the stop bar is defined as:

$$t_{POV\_SBtoNearMiss} = \sqrt{\frac{2 * D_{POV\_SBtoNearMiss}}{a_{POV}}}$$

where $t_{POV\_SBtoNearMiss}$ is the time it takes for the POV to accelerate from its initial position when the front of the POV is at the leading edge of the stop bar to the point of near-miss, $D_{POV\_SBtoNearMiss}$ is the total distance traveled by the front of the POV from the leading edge of the POV stop bar to the point of near-miss, and a_{POV} is the POV's constant acceleration.

As shown in Figure A8, $D_{SV\_SBToNearMiss}$ is an arc that originates at the leading edge of the SV stop bar and ends when the SV is in the desired lane after the left turn and the rear most part of the SV is 6.6 ft (2 m) from the front center point of the POV. Therefore, $D_{SV\_SBToNearMiss}$ is equal to the arc length of this path, D_{SV_arc}, plus the distance after the turn where the SV is traveling straight in its post turn lane, $D_{SV\_straight}$:

$$D_{SV\_SB\_to\_NearMiss} = D_{SV\_arc} + D_{SV\_straight}$$

where D_{SV_arc} is

$$D_{SV\_arc} = R_{SV} * \theta$$

where R_{SV} was previously defined in Section 10.1.1 and equals 28.18 ft (8.5880 m). θ is $\pi/2$ radians (90 degrees). $D_{SV\_straight}$ was previously defined in Section 10.1.2 and equals the length of the SV less 8.9 ft (2.7272 m). Therefore,

$$D_{SV\_SBToNearMiss} = \left(8.5880\ m * \frac{\pi}{2}\right) + SV_{length} - 2.7272\ m$$

Next, $D_{POV\_SBToNearMiss}$ is calculated based on Figure A8 by adding the 1 ft (0.3048 m) stop bar width, the 9.8425 ft (3 m) stop bar offset, and a 5.667 ft (1.7272 m) half lane width, and subtracting half of the

SV width to get the distance traveled by the front center of the POV from the leading edge of the stop bar to the near miss point (defined as the location when the front center point of the SV reaches the plane defined by the right ride of the SV):

$$D_{POV\_SBToNearMiss} = 5.0320\ m - \frac{1}{2} SV_{width}$$

The time needed for each vehicle to arrive at the impact point are set to be equivalent to identify the distance the front of the SV must be offset from the leading edge of its stop bar at the instant the POV starts accelerating when the front of the POV is at the leading edge of the its stop bar:

$$t_{SV\_OffsetToNearMiss} = t_{POV\_SBToNearMiss}$$

Therefore,

$$\frac{D_{SV\_OffsetToNearMiss}}{V_{SV}} = \sqrt{\frac{2 * D_{POV_{SBtoNearMiss}}}{a_{POV}}}$$

$$\frac{D_{SV\_OffsetToSB} + D_{SV\_SBtoNearMiss}}{V_{SV}} = \sqrt{\frac{2 * D_{POV\_SBtoNearMiss}}{a_{POV}}}$$

Solving for $D_{SV\_OffsetToSB}$

$$D_{SV\_OffsetToSB} = V_{SV} \sqrt{\frac{2 * D_{POV\_SBToNearMiss}}{a_{POV}}} - D_{SV\_SBToNearMiss}$$

10.4 ISA Scenario 3-C (S3-C): SV Accelerates from Rest While Turning Left, Constant POV Speed

For Scenario S3-C, the crash-imminent and near-miss timing is taken from the instant that the SV begins accelerating from rest from the leading edge of the stop bar. The value of interest for test synchronization is how far the POV needs to be offset from its corresponding stop bar when the SV begins accelerating from its corresponding stop bar. These synchronization calculations assume no ISA intervention from the SV.

10.4.1 S3-C Crash-Imminent Timing

For tests performed with <u>crash-imminent</u> timing, the relationship between the front center point of the SV and the impact point where the front center point of the SV impacts the front left corner of the POV at any moment after the SV begins accelerating from its stop bar is defined as:

$$t_{SV\_SBToImpact} = \sqrt{\frac{2 * D_{SV\_SBToImpact}}{a_{SV}}}$$

where $t_{SV\_SBToImpact}$ is the time from when the SV begins to accelerate when the front center point of the SV is at the leading edge of the stop bar to the point of impact, $D_{SV\_SBToImpact}$ is the total distance traveled by the front center point of the SV from the leading edge of the stop bar to the point of impact, and a_{SV} is the subject vehicle acceleration and is constant.

Similarly, the relationship between the front left corner of the POV and the impact point where the front center of the SV impacts the front left corner of the POV at any moment after the SV begins accelerating from its stop bar is defined as:

$$t_{POV\_OffsetToImpact} = \frac{D_{POV\_OffsetToImpact}}{V_{POV}}$$

where $t_{POV\_OffsetToImpact}$ is the time it takes for the POV to go from its initial offset position when the SV begins accelerating to the point of impact, $D_{POV\_OffsetToImpact}$ is the total distance traveled by the front left corner of the POV to the point of impact, and V_{POV} is the POV velocity and is a constant.

As shown in Figure A7, $D_{SV\_SBToImpact}$ is an arc that originates at the leading edge of the SV stop bar and ends at the point of impact. Therefore, $D_{SV\_SBToImpact}$ is equal to the arc length of this path which is defined as:

$$D_{SV\_SBToImpact} = R_{SV} * \theta$$

where R_{SV} was previously defined in Section 10.1.1 and equals 28.18 ft (8.5880 m). θ is the angle in radians along R_{SV} from the centerline of the original lane of travel at the leading edge of the stop bar to the point of impact. θ is calculated by the following equation:

$$\theta = \cos\left(\frac{4.7272\ m + \frac{1}{2} POV_{width}}{R_{SV}}\right)$$

where the numerator represents the lateral distance from the center of the radius R_{SV} to the impact point. Since the impact point is the front left corner of the SV, this distance is calculated by adding the 9.8425 ft (3 m) stop bar offset to the 5.6667 ft (1.7272 m) half of the lane width, and then adding half of the POV width to get to the front left corner of the POV. With values for R_{SV} and θ, $D_{SV\_SBToImpact}$ can be calculated.

Next, $D_{POV\_OffsetToImpact}$ is calculated with the following equation:

$$D_{POV\_OffsetToImpact} = IW - X_{ImpactToSVSB} + D_{POV\_OffsetToSB}$$

where IW is the width of the intersection from the leading edge of the SV stop bar to the leading edge of the POV stop bar, $X_{ImpactToSVSB}$ is the horizontal distance traveled by the SV from the impact point to the leading edge of the SV stop bar, and $D_{POV\_OffsetToSB}$ is the starting distance from the POV to the leading edge of the stop bar at the instant the SV begins to accelerate from rest with the front center of the SV at the leading edge of the SV stop bar. IW was previously defined in Section 10.1.1 and equals 45.6850 ft (13.9248 m). $X_{ImpactToSVSB}$ is calculated using the Pythagorean theorem:

$$X_{ImpactToSVSB} = \sqrt{R_{SV}{}^2 - \left(4.7272\ m + \frac{1}{2} POV_{width}\right)^2}$$

The time needed for each vehicle to arrive at the impact point are set to be equivalent to identify the distance the front left corner of the POV must be offset from the leading edge of its stop bar at the instant the SV begins accelerating from its stop bar:

$$t_{SV\_SBToImpact} = t_{POV\_OffsetToImpact}$$

Therefore,

$$\sqrt{\frac{2 * D_{SV\_SBToImpact}}{a_{SV}}} = \frac{D_{POV\_OffsetToImpact}}{V_{POV}}$$

Substituting,

$$\sqrt{\frac{2 * R_{SV} * \theta}{a_{SV}}} = \frac{IW - X_{ImpactToSVSB} + D_{POV\_OffsetToSB}}{V_{POV}}$$

Rearranging to isolate $D_{POV\_OffesetToSB}$,

$$D_{POV\_OffsetToSB} = V_{POV} * \sqrt{\frac{2 * R_{SV} * \theta}{a_{SV}}} - IW + X_{ImpactToSVSB}$$

10.4.2 S3-C Near-Miss Timing

For tests performed with near-miss timing, the relationship between the front center point of the SV and the leading edge of the SV stop bar at any moment after the SV begins accelerating from its stop bar is defined as:

$$t_{SV\_SBToNearMiss} = \sqrt{\frac{2 * D_{SV\_SBToNearMiss}}{a_{SV}}}$$

where $t_{SV\_SBToNearMiss}$ is the time after the SV begins accelerating from the leading edge of the stop bar, $D_{SV\_SBToNearMiss}$ is the total distance traveled by the front center point of the SV from the leading edge of the stop bar, and a_{SV} is the subject vehicle acceleration and is a constant.

Similarly, the relationship between the front center point of the POV at any moment after the SV begins accelerating from its stop bar is defined as:

$$t_{POV\_OffsetToNearMiss} = \frac{D_{POV\_OffsetToNearMiss}}{V_{POV}}$$

where $t_{POV\_OffsetToNearMiss}$ is the time it takes for the POV to go from its initial position offset from the stop bar to the near miss point, $D_{POV\_OffsetToNearMiss}$ is the total distance traveled by the front center of the POV to the near miss point, and V_{POV} is the POV velocity and is a constant.

As shown in Figure A8, $D_{SV\_SBToNearMiss}$ is an arc that originates at the leading edge of the SV stop bar and ends when the SV is in the desired lane after the left turn and the rear most part of the SV is 6.6 ft (2 m) from the front center point of the POV. Therefore, $D_{SV\_SBToNearMiss}$ is equal to the arc length of this path, D_{SV_arc}, plus the distance after the turn where the SV is traveling straight in its post turn lane, $D_{SV\_straight}$:

$$D_{SV\_SBToNearMiss} = D_{SV\_arc} + D_{SV\_straight}$$

where D_{SV_arc} is

$$D_{SV\_arc} = R_{SV} * \theta$$

where R_{SV} was previously defined in Section 10.1.1 and equals 28.18 ft (8.5880 m). θ is $\pi/2$ radians (90 degrees). $D_{SV\_straight}$ was previously defined in Section 10.1.2 and equals the length of the SV less 8.9 ft (2.7272 m). Therefore,

$$D_{SV\_SBToNearMiss} = \left(8.5880\ m * \frac{\pi}{2}\right) + SV_{length} - 2.7272\ m$$

Next, $D_{POV\_OFfsetToNearMiss}$ is calculated based on Figure A8 by adding the $D_{POV\_OffsetToSB}$ (the distance the POV is offset from the stop bar), the 1 ft (0.3048 m) stop bar width, the 9.8425 ft (3 m) stop bar offset, and a 5.667 ft (1.7272 m) half lane width, and subtracting half of the SV width to get the distance traveled by the front center of the POV from its original position to the leading edge of the stop bar to the near miss point (defined as the location when the front center point of the SV reaches the plane defined by the right ride of the SV):

$$D_{POV\_OffsetToNearMiss} = D_{POV\_OffsetToSB} + 5.0320\ m - \frac{1}{2} SV_{width}$$

The time needed for each vehicle to arrive at the near miss point are set to be equivalent to identify the distance the front center of the POV must be offset from the leading edge of its stop bar, $D_{POV\_to\_SB}$, at the instant the SV begins accelerating from its stop bar:

$$t_{SV\_SBToNearMiss} = t_{POV\_OffsetToNearMiss}$$

Therefore,

$$\sqrt{\frac{2 * D_{SV\_SBToNearMiss}}{a_{SV}}} = \frac{D_{POV\_OffsetToNearMiss}}{V_{POV}}$$

Substituting,

$$\sqrt{\frac{2 * \left(8.5880\ m * \frac{\pi}{2}\right) + SV_{length} - 2.7272\ m}{a_{SV}}} = \frac{D_{POV\_OffsetToSB} + 5.0320\ m - \frac{1}{2} SV_{width}}{V_{POV}}$$

Rearranging to isolate $D_{POV\_OffsetToSB}$,

$$D_{POV\_OffsetToSB} = V_{POV}\sqrt{\frac{2 * \left(8.5880\ m * \frac{\pi}{2}\right) + SV_{length} - 2.7272\ m}{a_{SV}}} - 5.0320\ m + \frac{1}{2} SV_{width}$$