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Assessing the Feasibility of Adding Additional Actors to Intersection Safety Assist Draft Test Scenarios

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16. Abstract

This report summarizes how variants of two test scenarios and three sub-scenarios, proposed in NHTSA's intersection safety assist (ISA) draft research test procedure, were used to assess the feasibility of increasing the number of actors (e.g., other vehicles) in each driving situation. Better understanding the technical and logistic factors associated with such additions is of interest to NHTSA, as the expanded capability may improve the agency's ability to research the performance of vehicle technologies under new and/or more complex real-world driving situations on the test track.

For the straight crossing path scenario, a principal other vehicle (POV) approached the intersection from the right side of the subject vehicle (SV), while a secondary other vehicle (SOV) simultaneously approached from the left. In this case, the SV was driven behind both vehicles after they had just cleared its forward path. In the second scenario, the SOV also approached the intersection from the left, but after driving past the SOV from behind, the SV turned left in front of the POV, which was traveling in a lane opposite and adjacent to the SV's initial travel lane. Both scenarios were performed with near-miss timing, which allowed for the assessments described in this report to be performed with an SV not equipped with ISA.

Addition of another actor to the ISA scenarios increased the complexity of the tests, but not to the extent where it always and significantly affected overall effort. All test tolerances used to assess trial validity were satisfied for five of the six test conditions described in this report.

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Executive Summary

Intersection safety assist (ISA) is a type of an advanced driver assistance system (ADAS) designed to actively intervene to help the driver avoid an intersection-based collision with another vehicle that is approaching, or has entered into, the forward path of their vehicle. To document the test methods used by the agency to objectively research ISA operation on the test track, the National Highway Traffic Safety Administration assembled and publicly diseminated an ISA draft research test procedure (NHTSA, 2019). This draft research test procedure includes three core four-way intersection-based driving scenarios, subscenarios defining different subject vehicle to principal other vehicle interactions, and two event timing options — crash-imminent where the SV will impact the POV if an ISA intervention does not occur, and near-miss where the SV narrowly misses the POV to assess whether the ISA system responds to a driving situation where it is not required to do so.

The work described in this report used two of these scenarios, included three subscenarios per core scenario, and added an additional vehicle (a secondary other vehicle, or SOV) to increase the number of actors and overall test complexity. Better understanding the technical and logistic factors associated with such additions is of interest to NHTSA, as the expanded capability may improve the agency's ability to research the performance of vehicle technologies under new and/or more complex real-world driving situations on the test track. Steering, brake, and throttle robots were installed in the SV to control its position and speed, and to ensure accurate choreography with the SOV and POV, which were both surrogate vehicles secured to robotic platforms. Since the SV was not equipped with an ISA system, all testing was performed with near-miss timing (no crash-imminent tests were performed). Since this study was aimed specifically at evaluating the test feasibility associated with adding an SOV, and not the performance of an ISA system, the use of an SV without ISA was considered to be suitable. Additionally, the use of near-miss timing eliminated the potential equipment and SV wear and tear that can result from SV-to-POV and/or SV-to-SOV impacts.

The first core scenario was designed to evaluate the ISA system's ability to detect and respond to vehicles driven straight across the SV's forward path. Specifically, the SOV approached the intersection from the left side of the SV (i.e., perpendicular to the SV longitudinal centerline), while a POV simultaneously approached from the right in a lane opposite and adjacent to that of the SOV. In this case, the SV was driven behind each vehicle after it had just cleared the SV forward path. In the second core scenario, the SOV also approached the intersection from the left. However, after driving behind the SOV, the SV turned left in front of the POV, which was traveling in a lane opposite and adjacent to that of the SV's initial travel lane.

The three sub-scenarios were performed within the two core scenarios, each with unique vehicle speed combinations:

- Sub-scenario A: All actors travelled at speed for the duration of the test.
- Sub-scenario B: The SV and SOV travelled at speed for the duration of the test while the POV accelerated from rest at the intersection stop bar.

- Sub-scenario C: The POV and SOV travelled at speed for the duration of the test while the SV accelerated from rest at its respective intersection stop bar.

Generally speaking, adding another actor to the ISA scenarios described in this report increased the complexity of the tests, however not to the extent where it significantly affected overall effort. This was largely due to the iterative testing process required to achieve the proper scenario timing not being notably increased (i.e., it was similar with and without the additional SOV). The validity criteria were met for all tests with the exception of the sub-scenario C variant of the first core scenario, where the SV-to-SOV distance at the near-miss assessment point exceeded the desired distance by an average of 7.1 ft (2.16 m). This issue is believed to be resolvable by additional refinement of the test choreography, specifically by the adjustment of when the SOV initiates movement relative to the SV at the beginning of a trial. However, the final refinements could not be validated with the time and resources that were available for testing.

Although the SV used for the work described in this report was not equipped with an ISA system, it did have an automatic emergency braking (AEB) system. While it is unknown whether the vehicle's AEB system would have been activated if the driving situations used for the work described in this report had been performed with crash-imminent timing, it is noteworthy that no in-vehicle alerts or brake interventions were observed during any of the near-miss timing-based trials used in this study.

1 Introduction

ISA is an ADAS designed to actively and automatically help the driver avoid an intersection-based collision with another vehicle that is approaching, or has entered into, the forward path of their vehicle.

To document the methods used by NHTSA to research ISA system operation and performance on the test track, the agency developed a draft research test procedure comprising three test scenarios intended to represent real-world driving conditions within the system's operational design domain (NHTSA, 2019):

- **ISA Scenario 1: POV Straight Across SV Path.** The objective of the ISA Scenario 1 test is to evaluate the ISA system's ability to detect and respond to a POV driven straight across the SV's forward path. Three SV and POV speed combinations (referred to as sub-scenarios) are used, as well as crash-imminent and near-miss timing. The combination of crash-imminent timing and no ISA intervention results in the front center of the SV impacting the near-side longitudinal center of the POV, while the near-miss timing assessment point occurs when the front center of the SV first breaches a vertical plane defined by the near-side of the POV at a distance of 6.6 ft (2 m) behind a perpendicular plane defined by the rearmost part of the POV.

- **ISA Scenario 2: POV Left Turn Across SV Path.** The objective of the ISA Scenario 2 test 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. Crash-imminent timing and no ISA intervention results in the front center of the SV impacting the right front corner of the POV, while the near-miss timing assessment point occurs when the front center of the SV first breaches a vertical plane defined by the right side of the POV at a distance of 6.6 ft (2 m) behind the rearmost part of the POV.

- **ISA Scenario 3: SV Left Turn Across POV Path.** The objective of the ISA Scenario 3 test is to evaluate the ISA system's ability to detect and respond to a POV while/after the SV is 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. Crash-imminent timing and no ISA intervention results in the front center of the SV impacting the left front corner of the POV, while the near-miss timing assessment point occurs when the front center of the POV first breaches a vertical plane defined by the right side of the SV at a distance of 6.6 ft (2 m) behind the rearmost part of the SV.

The work described in this report details research performed to evaluate the feasibility of incorporating an additional actor (an SOV) into Scenarios 1 and 3 of the NHTSA ISA draft research test procedure. Each trial was performed with near-miss timing. Factors related to the increased test complexity (e.g., the ability to produce valid test trials) and testing effort are described and quantified.

2 Test Protocol

This section describes the SV, POV, and SOV used in this evaluation. Additionally, a brief description of test facility, the equipment used to perform the testing, and an outline of the ISA scenarios are presented.

2.1 Subject Vehicle

One SV, a 2017 BMW 540i sedan (subsequently referred to as either the SV), was used for the ISA testing detailed in this report. While the vehicle was equipped with a variety of ADAS systems including AEB, it was not equipped with an ISA system (Bayerische Motoren Werke, 2017). Since this study was aimed specifically at evaluating the test feasibility associated with adding an SOV, and not the performance of an ISA system, the use of an SV without an ISA was suitable. Additionally, the use of near-miss timing eliminated the potential equipment and SV wear and tear that can result from SV-to-POV and/or SV-to-SOV impacts.

2.2 Principal Other Vehicle and Secondary Other Vehicle

The POV used was a guided soft target (GST) system composed of a low-profile robotic vehicle (LPRV) that can be driven over by the SV, and a global vehicle target (GVT) revision G surrogate vehicle consisting of foam panels and skins that are designed to separate upon impact (Figure 2-1). Extensive collaborative research was performed from 2015 to 2018 to ensure the GVT appears realistic to the vehicle systems designed to respond to it (Euro NCAP, 2018). The LPRV provides accurate closed-loop control of the POV relative to the SV, and because the GST system is strikeable from any approach aspect it can be incorporated into nearly any pre-crash scenario. Multiple fail-safe measures are incorporated to ensure the safe operation of the GST.

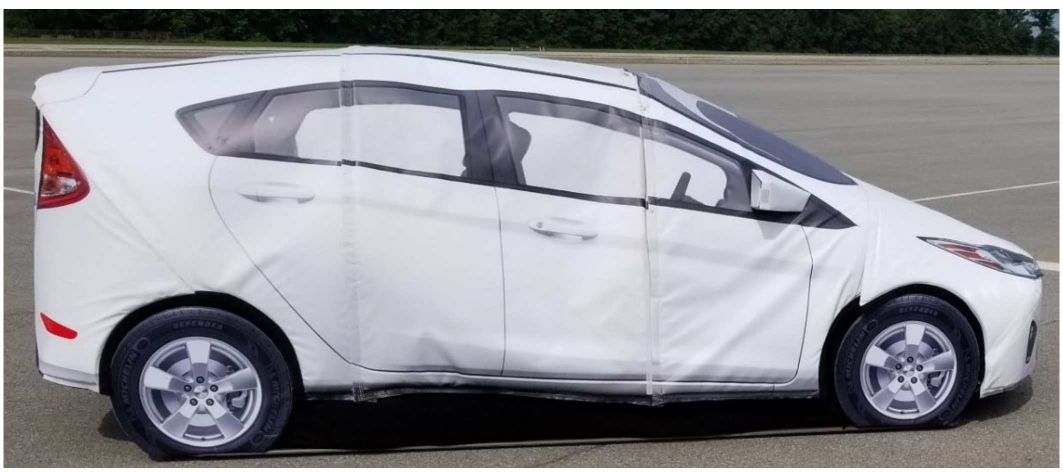

Figure 2-1. GVT surrogate vehicle secured to the top of the LPRV

2.3 Test Facility

Tests were performed at the Smart Mobility Advanced Research and Test (SMART) Center of the Transportation Research Center Inc. (TRC) in East Liberty, Ohio. A depiction of the intersection, defined in the NHTSA ISA draft research test procedure and used for the ISA tests described in this report, is presented in Figure 2-2.

The intersection comprised a four-way configuration designed to support two roads, each with two lanes of travel (one in each direction), intersecting perpendicularly. The intersection was defined by solid white edge lines, solid white stop bars, and yellow center lines. For the 98 ft (30 m) leading up to the intersection stop bar, the yellow centerline was a double yellow line. The yellow centerline was a single dashed line for the remainder of each lane. The width of the lane lines was 4 to 6 in (10 to 15 cm).

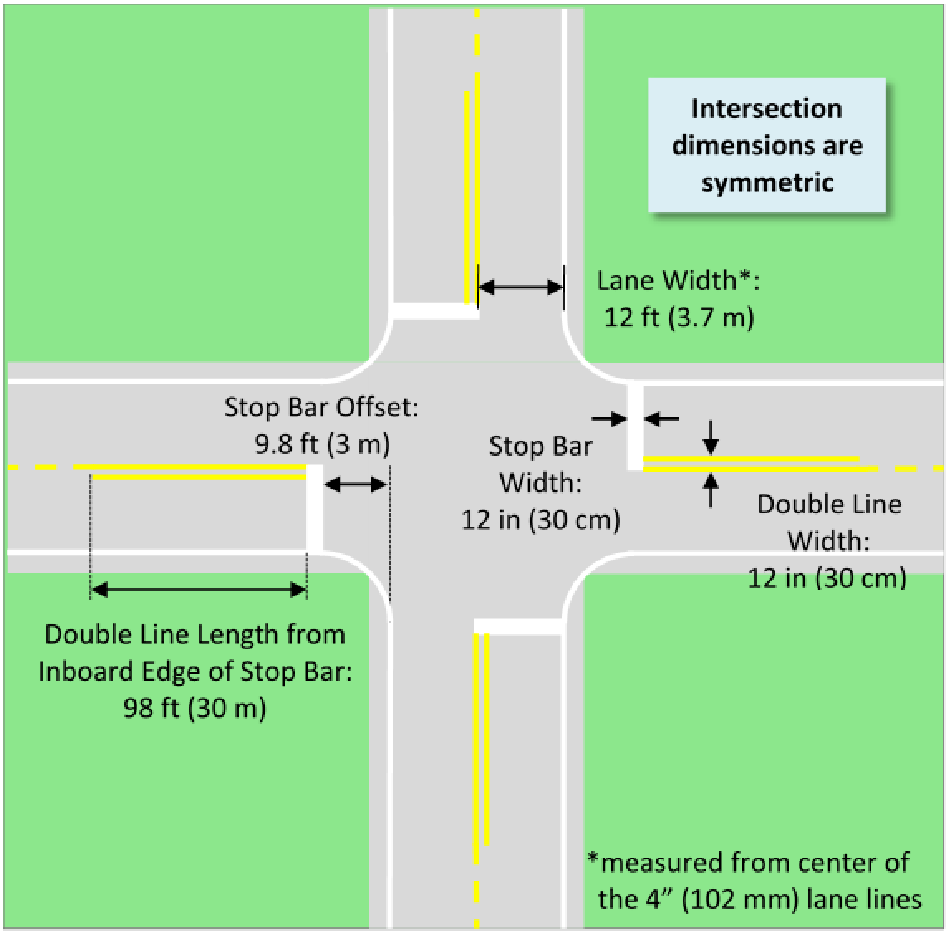

Figure 2-2. SMART Center intersection

2.4 Test Equipment

Test equipment included AB Dynamics (ABD) steering, brake, and throttle robots and an Oxford Technical Solutions (OxTS) RT and Range system. Each is briefly described in this section. An in-vehicle data acquisition system was installed in the SV to collect data from each actor during the test conduct.

2.4.1 Steering Robot

An ABD SR15 Orbit steering robot was installed in the SV for this study. The SR15 Orbit is a lightweight, low-torque robot that allowed the SV to be driven along a preprogrammed path (see Figure 2-3 for a typical installation example).

Figure 2-3. Example steering robot installation

2.4.2 Accelerator and Brake Robot

An ABD CBAR600 robot was installed in the SV to provide accurate longitudinal control of the vehicle. The robot used in this study was configured to provide accelerator inputs during each test via closed loop control with both GSTs, and to brake the vehicle after test completion. Figure 2-4 shows an example of a typical installation.

Figure 2-4. Example accelerator robot installation

2.4.3 Inertial and GPS Measurements

The SV, POV, and SOV were each instrumented with OxTS RT 3002 units to provide highly accurate inertial and differentially corrected GPS data. Paired with an OxTS Range S system, relative distances and velocities between each actor were also collected.

2.5 Test Scenarios

Section 2.5 provides descriptions of the two core test scenarios used for work described in this report, which are variants of those defined in the NHTSA ISA draft research test procedure but with the addition of an SOV. Also, while the ISA draft research test procedure defines two forms of event choreography of the SV relative to the POV (crash-imminent and near-miss timing), the work described in this report was only performed with near-miss timing. The reasons for this are twofold: (1) the SV used was not equipped with an ISA, so it would not be expected to respond to the POV in crash-imminent driving situations, and (2) near-miss choreography allowed for the objective of the study to be satisfied (i.e., to assess the feasibility of adding an additional actor to ISA draft test scenarios) without introducing excessive test equipment and/or SV wear and tear.

Note: As mentioned in the introduction, the NHTSA ISA draft test procedure includes three test scenarios. Of these, a variant of Scenario 2 was excluded from testing described in this report since it was not possible to add an SOV in a meaningful way without also introducing a POV-to-SOV conflict when near-miss timing between the SV and the POV is used.

2.5.1 NHTSA ISA Test Scenario 1 Plus an SOV Driven Straight Across the SV Path (S1+SOV)

The Scenario S1+SOV driving situation used for the work, described in this report and shown in Figure 2-5, was designed to present an SV with two near-miss events that occurred closely in time. Specifically, the SOV approached the intersection from the left side of the SV, while a POV simultaneously approached from the right, albeit with slightly delayed timing. In this scenario, the SV was driven behind each vehicle after it had just cleared the SV forward path.

For this scenario, the SV-to-SOV and SV-to-POV near-miss assessment points were respectively defined as:

- When the front center of the SV was located 6.6 ft (2 m) behind the rearmost part of the SOV at the instant when the front center of the SV crossed a vertical plane defined by the right side of the SOV parallel to the its longitudinal centerline (Figure 2-5, left).
- When the front center of the SV was located 6.6 ft (2 m) behind the rearmost part of the POV at the instant when the front center of the SV crossed a vertical plane defined by the left side of the POV parallel to its longitudinal centerline (Figure 2-5, right).

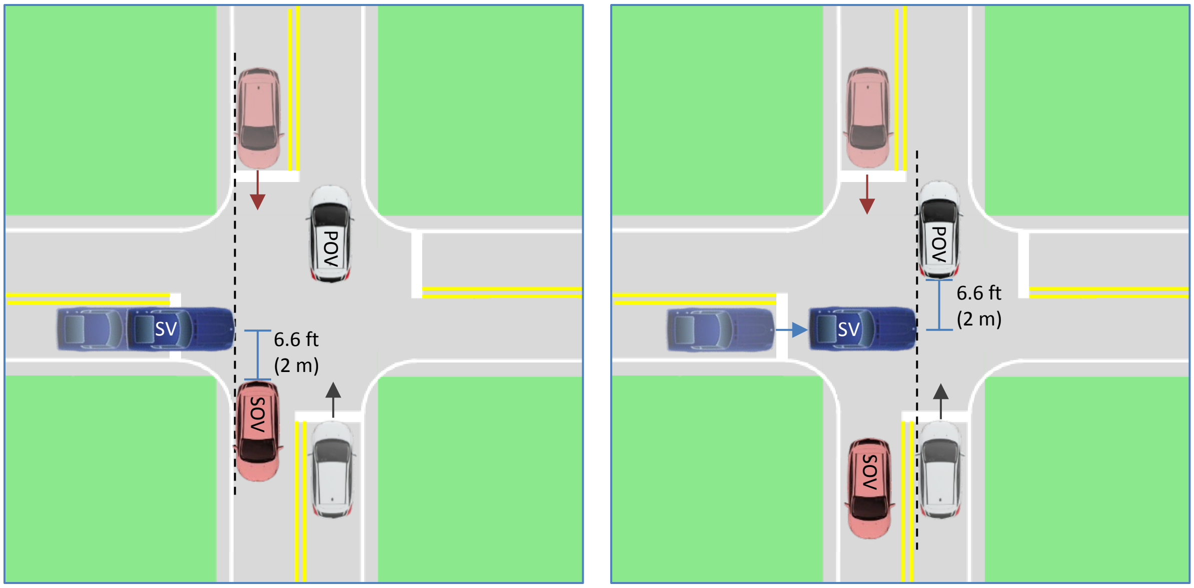

Figure 2-5. SV-to-SOV (left) and SV-to-POV (right) near-miss choreography used for S1+SOV test trials

2.5.2 NHTSA ISA Test Scenario 3 Plus an SOV Driven Straight Across the SV Path (S3+SOV)

The Scenario S3+SOV driving situation used for the work, described in this report and shown in Figure 2-6, was also designed to present an SV with two near-miss events that occurred closely in time. Like the S1+SOV scenario, the SOV also approached the intersection from the left side of the SV. However, after driving behind the SOV, the SV turned left in front of the POV, which was traveling in a lane adjacent to the SV's initial travel lane but in the opposite direction.

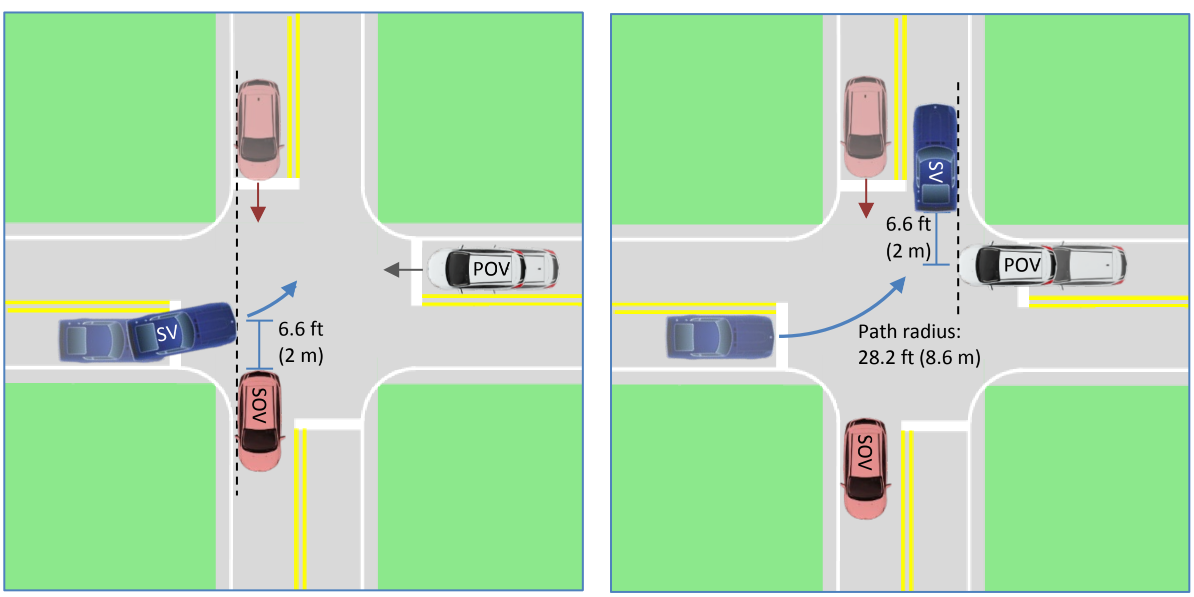

Figure 2-6. SV-to-SOV (left) and SV-to-POV (right) near-miss choreography used for S3+SOV test trial

For this scenario, SV-to-SOV and SV-to-POV near-miss choreography assessment points were respectively defined as:

- The instant when the front-most part of the SV reached a vertical plane defined by the right side of the SOV, parallel to the its longitudinal centerline, and the front center of the SV was 6.6 ± 0.8 ft (2 ± 0.25 m) behind the rearmost part of the SOV (Figure 2-6, left).

- When the front center of the POV was located 6.6 ft (2 m) behind the rearmost part of the SV at the instant when the front center of the POV crossed a vertical plane defined by the right side of the SV parallel to its longitudinal centerline (Figure 2-6, right).

2.6 Test Sub-Scenarios

Three sub-scenarios were performed within the S1+SOV and S3+SOV test series, each with their own unique vehicle speed combinations:

- Sub-scenario A: All actors travelled at speed for the duration of the test.

- Sub-scenario B: The SV and SOV travelled at speed for the duration of the test while the POV accelerated from rest at the intersection stop bar.

- Sub-scenario C: The POV and SOV travelled at speed for the duration of the test while the SV accelerated from rest at the intersection stop bar.

Tables 2-1 and 2-2 present the nominal test speeds for each actor, for each scenario and sub-scenario, respectively. All three vehicles were operated at 25 ± 1 mph (40.2 ±1.6 km/h) if they traveled straight through the intersection. For the S3+SOV trials where the SV approached the intersection, its initial travel speed was 25 ± 1 mph (40.2 ± 1.6 km/h), but was slowed to 15 ± 1 mph (24.1 ± 1.6 km/h) with a nominal average deceleration of 0.26 g (2.55 m/s^2) before reaching the intersection stop bar, at which point its left turn was initiated. For sub-scenarios where a vehicle was accelerated from its respective stop bar, it did so with a nominal average acceleration of 0.127g (1.25 m/s^2).

Table 2-1. Nominal Actor Test Speeds for Scenarios S1+SOV

Scenario 1+SOV			
Actor	**S1+SOV (A)**	**S1+SOV (B)**	**S1+SOV (C)**
SV	25 mph (40.2 km/h)	25 mph (40.2 km/h)	0 ⇨ 25 mph (0 ⇨ 40.2 km/h)
POV	25 mph (40.2 km/h)	0 ⇨ 25 mph (0 ⇨ 40.2 km/h)	25 mph (40.2 km/h)
SOV	25 mph (40.2 km/h)	25 mph (40.2 km/h)	25 mph (40.2 km/h)
POV	25 mph (40.2 km/h)	0 ⇨ 25 mph (0 ⇨ 40.2 km/h)	25 mph (40.2 km/h)

Table 2-2. Nominal Actor Test Speeds for Scenarios S3+SOV

Scenario 3+SOV			
Actor	**S3+SOV (A)**	**S3+SOV (B)**	**S3+SOV (C)**
SV	25 ⇨ 15 mph (40.2 ⇨ 24.1 km/h)	25 ⇨ 15 mph (40.2 ⇨ 24.1 km/h)	0 ⇨ 25 mph (0 ⇨ 40.2 km/h)
POV	25 mph (40.2 km/h)	0 ⇨ 25 mph (0 ⇨ 40.2 km/h)	25 mph (40.2 km/h)
SOV	25 mph (40.2 km/h)	25 mph (40.2 km/h)	25 mph (40.2 km/h)

2.7 Validity Criteria

The validity criteria described in the ISA draft research test procedure (NHTSA, 2019) were assessed for each trial performed in this study. These criteria are tolerance specifications for vehicle speed, lane positions, choreography, acceleration (when applicable), SV yaw rate (when the vehicle was being driven in a straight line), and checks to insure the driver did not provide unintended inputs to the SV.

To ensure a test trial was properly performed, the validity criteria were required to be satisfied during the validity period. For tests where the SV was initially moving, this began three seconds before the SV reached the intersection stop bar located in the SV travel lane. During conduct of sub-scenarios where the SV began the test from rest, the validity period began three seconds before the SV initiated its acceleration from the stop bar. For all trials, the validity period ended three seconds after the SV-to-POV near-miss event occurred.

For each ISA trial described in this report, the following validity criteria were used:

- Accelerator pedal position data confirmed that the driver did not press or override the accelerator robot's control of the SV accelerator pedal during the test.
- Brake pedal force data confirmed the driver did not apply force to the SV brake pedal during the test.
- For tests where the SV, POV, and/or SOV traveled straight through the intersection, the speeds were 25 ± 1 mph (40.2 ± 1.6 km/h).
- For tests where the SV turned left through the intersection, its speed was initially required to be 25 ± 1 mph (40.2 ± 1.6 km/h). The SV was then slowed with an average nominal deceleration of 0.26 g (2.55 m/s^2) using the timing needed to achieve 15 ± 1 mph (24.1 ± 1.6 km/h) at the instant it reached the stop bar in its travel lane before turning left. The SV then maintained 15 ± 1 mph (24.1 ± 1.6 km/h) until the end of the validity period.
- For tests where the SV or POV began the test from rest at the stop bar, the vehicle accelerated through the remainder of its path with an average nominal magnitude of 0.127 g (1.25 m/s^2) until the end of the validity period.
- The SV, POV, and SOV desired paths were defined as the center of its lane of travel and when applicable, the center of its turn radius. To assess path following accuracy, each

vehicle's position was measured from the center of its front bumper and compared to its desired path during data post-processing. The difference between the actual versus desired values was defined as the respective vehicle's path deviation, and was required to be ± 0.8 ft (± 0.25 m).

- The SV yaw rate was 0 ± 1 deg/s during the validity period for the S1+SOV scenario. For the S3+SOV scenario, the SV yaw rate was measured from the start of the validity period until the SV reached the stop bar.
- The desired SV-to POV and SV-to-SOV near-miss distances were 6.6 ± 0.8 ft (2 ± 0.25 m) at the assessment point.

3 Test Results

Results from the tests performed in this study are provided in this section, including an overall summary in Section 3.3. Three repeated trials of each test condition were conducted, and vehicle-to-vehicle measurements at the assessment point are provided. A summary of the validity criteria satisfied by each test trial is provided in Appendix A.

3.1 Scenario 1+SOV Results

A summary of the SV-to-POV and SV-to-SOV near-miss assessment point distances observed during the S1+SOV tests is provided in Tables 3-1 to 3-3. Discussions of each sub-scenario are provided in Sections 3.1.1 to 3.1.3.

3.1.1 S1+SOV (A) Test Results

For the S1+SOV trials performed with sub-scenario A choreography, assessment point distances between the SV and the POV ranged from 6.6 to 6.7 ft (2.01 to 2.03 m). During the same test trials, the assessment point distances between the SV and the SOV ranged from 6.5 to 6.6 ft (1.98 to 2.00 m). Both data sets are shown in Table 3-1.

Table 3-1. Scenario S1+SOV, Sub-Scenario A Results

Scenario Trial No.	Assessment	Assessment Point Distance	Difference from Desired
S1_SOV (A) - 1	SV-to-POV	6.6 ft (2.01 m)	0.0 ft (0.01 m)
	SV-to-SOV	6.5 ft (1.98 m)	-0.1 ft (-0.02 m)
S1_SOV (A) - 2	SV-to-POV	6.6 ft (2.02 m)	0.0 ft (0.02 m)
	SV-to-SOV	6.5 ft (1.99 m)	-0.1 ft (-0.01 m)
S1_SOV (A) - 3	SV-to-POV	6.7 ft (2.03 m)	0.1 ft (0.03 m)
	SV-to-SOV	6.6 ft (2.00 m)	0.0 ft (0.00 m)

3.1.2 S1+SOV (B) Test Results

For the Scenario 1+SOV trials performed with sub-scenario B choreography, assessment point distances between the SV and POV ranged from 6.4 to 6.6 ft (1.95 to 2.01 m). During the same test trials, the assessment point distances between the SV and the SOV ranged from 6.5 to 6.8 ft (1.95 to 2.08 m). Both data sets are shown in Table 3-2.

Table 3-2. Scenario S1+SOV, Sub-Scenario B Results

Scenario Trial No.	Assessment	Assessment Point Distance	Difference from Desired
S1_SOV (B) – 1	SV-to-POV	6.6 ft (2.01 m)	0.0 ft (0.01 m)
S1_SOV(B) - 1	SV-to-SOV	6.5 ft (1.98 m)	-0.1 ft (-0.02 m)
S1_SOV (B) - 2	SV-to-POV	6.4 ft (1.95 m)	-0.2 ft (-0.05 m)
	SV-to-SOV	6.8 ft (2.06 m)	0.2 ft (0.06 m)
S1_SOV (B) - 3	SV-to-POV	6.4 ft (1.96 m)	-0.2 ft (-0.04 m)
	SV-to-SOV	6.8 ft (2.08 m)	0.2 ft (0.08 m)

3.1.3 S1+SOV (C) Test Results

For the Scenario 1+SOV trials performed with sub-scenario C choreography, assessment point distances between the SV and POV ranged from 6.0 to 6.2 ft (1.84 to 1.89 m). During the same test trials, the assessment point distances between the SV and SOV ranged from 13.6 to 13.7 ft (4.13 to 4.18 m), which resulted in differences from the desired value of 7.0 to 7.1 ft (2.13 to 2.18 m). Both data sets are shown in Table 3-3. Although it is believed the test team may have been able to iteratively adjust the SV-to-SOV test choreography in a way that would have ultimately produced valid test trials for this test condition (like it was for all other scenario and sub-scenario combinations described in this report), the final refinements could not be validated with the time and resources that were available for testing.

Table 3-3. Scenario S1+SOV, Sub-Scenario C Results

Scenario Trial No.	Assessment	Assessment Point Distance	Difference from Desired
S1_SOV (C) - 1	SV-to-POV	6.2 ft (1.89 m)	-0.4 ft (-0.11 m)
	SV-to-SOV	13.7 ft (4.18 m)	7.1 ft (2.18 m)
S1_SOV (C) - 2	SV-to-POV	6.0 ft (1.84 m)	-0.6 ft (-0.16 m)
	SV-to-SOV	13.6 ft (4.13 m)	7.0 ft (2.13 m)
S1_SOV (C) - 3	SV-to-POV	6.1 ft (1.85 m)	-0.5 ft (-0.15 m)
	SV-to-SOV	13.7 ft (4.16 m)	7.1 ft (2.16 m)

3.2 Scenario 3+SOV Results

A summary of the SV-to-POV and SV-to-SOV near-miss assessment point distances observed during the S3+SOV tests are provided in Tables 3-4 to 3-6. Discussions of the results for each sub-scenario are provided in Sections 3.2.1 to 3.2.3.

3.2.1 S3+SOV (A) Test Results

For the Scenario 3 trials performed with sub-scenario A speeds, assessment point distances between the SV and POV ranged from 6.0 to 6.1 ft (1.84 to 1.86 m). During the same test trials, the assessment point distances between the SV and SOV near-miss distance ranged from 5.8 to 5.9 ft (1.77 to 1.81 m). Both data sets are shown in Table 3-4.

Table 3-4. Scenario S3+SOV, Sub-Scenario A Results

Scenario Trial No.	Assessment	Assessment Point Distance	Difference from Desired
S3_SOV (A) - 1	SV-to-POV	6.0 ft (1.84 m)	-0.6 ft (-0.16 m)
	SV-to-SOV	5.8 ft (1.78 m)	-0.8 ft (-0.22 m)
S3_SOV (A) - 2	SV-to-POV	6.1 ft (1.86 m)	-0.5 ft (-0.14 m)
	SV-to-SOV	5.8 ft (1.77 m)	-0.8 ft (-0.23 m)
S3_SOV (A) - 3	SV-to-POV	6.1 ft (1.86 m)	-0.5 ft (-0.14 m)
	SV-to-SOV	5.9 ft (1.81 m)	-0.7 ft (-0.19 m)

3.2.2 S3 + SOV (B) Test Results

For the Scenario 3+SOV trials performed with sub-scenario B choreography, assessment point distances between the SV and POV ranged from 6.1 to 6.3 ft (1.85 to 1.91 m). During the same test trials, the assessment point distances between the SV and the SOV ranged from 6.1 to 7.2 ft (1.86 to 2.20 m). Both data sets are shown in Table 3-5.

3.2.3 S3 + SOV (C) Test Results

For the Scenario 3+SOV trials performed with sub-scenario C choreography, assessment point distances between the SV and POV ranged from 6.7 to 6.9 ft (2.05 to 2.10 m). During the same test trials, the assessment point distances between the SV and the SOV ranged from 6.2 to 6.8 ft (1.88 to 2.07 m). Both data sets are shown in Table 3-6.

Table 3-5. Scenario S3+SOV, Sub-Scenario B Results

Scenario Trial No.	Assessment	Assessment Point Distance	Difference from Desired
S3_SOV (B) - 1	SV-to-POV	6.1 ft (1.85 m)	-0.5 ft (-0.15 m)
	SV-to-SOV	7.2 ft (2.20 m)	0.6 ft (0.20 m)
S3_SOV (B) – 2	SV-to-POV	6.3 ft (1.91 m)	-0.3 ft (-0.09 m)
S3_SOV (B) - 2	SV-to-SOV	6.1 ft (1.86 m)	-0.5 ft (-0.14 m)
S3_SOV (B) - 3	SV-to-POV	6.2 ft (1.89 m)	-0.4 ft (-0.11 m)
	SV-to-SOV	6.7 ft (2.04 m)	0.1 ft (0.04 m)

Table 3-6. Scenario S3+SOV, Sub-Scenario C Results

Scenario Trial No.	Assessment	Assessment Point Distance	Difference from Desired
S3_SOV (B) - 1	SV-to-POV	6.9 ft (2.10 m)	0.3 ft (0.10 m)
	SV-to-SOV	6.2 ft (1.88 m)	-0.4 ft (-0.12 m)
S3_SOV (B) - 2	SV-to-POV	6.8 ft (2.06 m)	0.2 ft (0.06 m)
	SV-to-SOV	6.7 ft (2.05 m)	0.1 ft (0.05 m)
S3_SOV (B) - 3	SV-to-POV	6.7 ft (2.05 m)	0.1 ft (0.05 m)
	SV-to-SOV	6.8 ft (2.07 m)	0.2 ft (0.07 m)

3.3 Summary of Test Results

All validity requirements previously described in Section 2.7 were satisfied for five of six test scenario and sub-scenario combinations described in this report. In the case of the S1+SOV scenario, each of the three trials performed with sub-scenario 3 choreography were able to satisfy these criteria except for the SV-to-SOV near-miss distance at the assessment point, where it exceeded the desired value by an average of 7.1 ft (2.16 m).

Although the SV used for the work described in this report was not equipped with an ISA, it did have an AEB system. While it is unknown whether the vehicle's AEB system would have been activated if the driving situations used for the work described in this report had been performed with crash-imminent timing, it is noteworthy that no in-vehicle alerts or brake interventions were observed during any of the near-miss timing based trials used in this study.

4 Conclusions

Overall, the work described in this report indicates it is feasible to add an additional actor to the Scenario 1 and 3 tests defined in the agency's ISA draft research test procedure with near-miss event choreography. This also implies it should be possible to perform these tests with crash-imminent timing, as the only adjustment would be to the POV initial conditions.

Of all the criteria used to assess test trial validity in this study, the SV-to-POV and SV-to-SOV distances at the respective assessment points were found to be the most challenging. Since the software used to coordinate the actors did not offer a precise way to define vehicle-to-vehicle relations at the assessment point, iterative adjustments were required to achieve the desired values. After completion of a given test condition, this process involved:

- Downloading test data from the SV, post-processing, then an analysis to assess whether the correct distances (and overall test validity) had been realized.

- If the measured values exceeded allowable tolerances, the known distance error of the SV to the POV or SOV was used to offset the initial position of the POV or SOV such that, theoretically, the proper value(s) would be produced during the next test session.

- Repeat the process until three valid trials for the test condition were collected.

This process was ultimately successful for all but the S1+SOV tests performed with sub-scenario 3 choreography, as the final refinements could not be validated with the time and resources that were available for testing.

With regards to test effort, inclusion of an SOV to the tests described in this report increased the overall test complexity since additional scenario programming, set-up, and test-execution was required. However, performing tests inclusive of an SOV was generally found to not require significantly more time than for those performed with just the SV and POV. This is because the most time-consuming aspect of the work was the physical test conduct and the iterative tuning associated with it. While test iterations were required for trials inclusive of the SV, POV, and SOV, they were also required for trials only performed with the SV and POV. Since the tuning used to refine both interactions (i.e., that of the SV-to-POV and for the SV-to-SOV) could be evaluated concurrently during conduct and analysis of the same test trial, increasing the number of actors did not typically require additional iterative tuning trials be performed solely to achieve SOV-related validity.

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Appendix A

Tables 6-1 and 6-2 list whether a given S1+SOV or S3+SOV test trial was able to satisfy applicable validity criteria, respectively. For tests where the SV and/or POV was accelerated from rest from their respective stop bar, the speed check is listed as "ACCEL" – meaning that it was not applicable to check the speed validity. For tests where each actor was traveling at speed at the beginning of the test, there was no vehicle accelerating, thus the average acceleration check is listed as "N/A." For tests where the SV to POV or SOV distance at the assessment point did not meet the required distance, values are displayed in red font.

Table 6-1. Scenario S1+SOV Test Validity Assessment

Test File	Scenario	Sub-Scenario	SV Speed Check	POV Speed Check	SOV Speed Check	Accel Avg Check	SV Yaw Check	SV Path Following Check	POV Path Following Check	SOV Path Following Check	POV Near-Miss Distance (m)	SOV Near-Miss Distance (m)
122	S1	A	PASS	PASS	PASS	N/A	PASS	PASS	PASS	PASS	2.01	1.98
124	S1	A	PASS	PASS	PASS	N/A	PASS	PASS	PASS	PASS	2.02	1.99
126	S1	A	PASS	PASS	PASS	N/A	PASS	PASS	PASS	PASS	2.03	2.00
149	S1	B	PASS	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	2.01	1.98
150	S1	B	PASS	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	1.95	2.06
151	S1	B	PASS	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	1.96	2.08
262	S1	C	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	1.89	4.18
264	S1	C	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	1.84	4.13
266	S1	C	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	1.85	4.16

Table 6-2. Scenario S3+SOV Test Validity Assessment

Test File	Scenario	Sub-Scenario	SV Speed Check	POV Speed Check	SOV Speed Check	Accel Avg Check	SV Yaw Check	SV Path Following Check	POV Path Following Check	SOV Path Following Check	POV Near-Miss Distance (m)	SOV Near-Miss Distance (m)
199	S3	A	PASS	PASS	PASS	N/A	PASS	PASS	PASS	PASS	1.84	1.78
200	S3	A	PASS	PASS	PASS	N/A	PASS	PASS	PASS	PASS	1.86	1.77
201	S3	A	PASS	PASS	PASS	N/A	PASS	PASS	PASS	PASS	1.86	1.81
231	S3	B	PASS	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	1.85	2.20
232	S3	B	PASS	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	1.91	1.86
233	S3	B	PASS	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	1.89	2.04
253	S3	C	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	2.10	1.88
254	S3	C	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	2.06	2.05
256	S3	C	ACCEL	PASS	PASS	PASS	PASS	PASS	PASS	PASS	2.05	2.07

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