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# **Characterization Test Procedures for Intersection Collision Avoidance Systems Based on Vehicle-to-Vehicle Communications**

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13. ABSTRACT Characterization test procedures have been developed to quantify the performance of intersection collision avoidance (ICA) systems based on vehicle-to-vehicle communications. These systems warn the driver of an imminent crossing-path collision at a road junction, and apply automatic braking if the driver does not respond in a timely manner to prevent the collision. This report describes test procedures for most common crossing-path pre-crash scenarios that involve light vehicles (passenger cars, vans, minivans, SUVs, or light pickup trucks with gross vehicle weight ratings less than 10,000 pounds). The test procedures include crash-imminent test scenarios to collect information on the ranges and time-to-collisions of crossing-path collision alerts and automatic braking onsets in prototype systems. In addition, the test procedures incorporate dynamic scenarios where countermeasure action is not needed so as to assess the capability of ICA systems to distinguish between crash-imminent and benign driving scenarios.				
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## LIST OF ACRONYMS

<b>BSM</b>	basic safety message
<b>CAMP</b>	Crash Avoidance Metrics Partnership
<b>CAN</b>	controller area network
<b>DAS</b>	data acquisition system
<b>DGPS</b>	differential global positioning system
<b>DSRC</b>	dedicated short-range communications
<b>GPS</b>	global positioning system
<b>HV</b>	host vehicle
<b>ICA</b>	intersection collision avoidance
<b>IMS</b>	independent measurement system
<b>LTAP/LD</b>	left turn across path/lateral direction
<b>LTAP/OD</b>	left turn across path/opposite direction
<b>LTIP</b>	left turn into path
<b>NHTSA</b>	National Highway Traffic Safety Administration
<b>OEM</b>	original equipment manufacturer
<b>RTIP</b>	right turn into path
<b>RTK</b>	real time kinematic
<b>RV</b>	remote vehicle
<b>SCP</b>	straight crossing paths
<b>TRC</b>	Transportation Research Center
<b>TTC</b>	time-to-collision
<b>UDP</b>	user datagram protocol
<b>UEI</b>	United Electronic Industries
<b>UTC</b>	coordinated universal time
<b>V2V</b>	vehicle-to-vehicle
<b>VRTC</b>	Vehicle Research and Test Center

## LIST OF VARIABLES

$A_{HV}$	HV acceleration
$A_{RV}$	RV acceleration
$R_{Control}$	range at ICA control action
$R_{HVInitial}$	initial range from HV to RV path
$R_{RVInitial}$	initial range from RV to HV path
$R_{Safety}$	range between HV and RVs at final conditions (if included)
$R_{Warning}$	range at ICA warning
$V_{HV}$	HV speed
$V_{RV}$	RV speed

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## PREFACE

The Volpe National Transportation Systems Center, in support of the National Highway Traffic Safety Administration, has devised and conducted characterization test procedures to quantify the performance of prototype crash avoidance systems for light vehicles based on vehicle-to-vehicle communications under a multi-year, multi-task intra-agency agreement. This agreement includes the tasks to develop, program, and document a safety impact methodology tool; identify performance measures and determine preliminary performance requirements; conduct an independent evaluation of crash warning applications from the Safety Pilot Model Deployment field operational test; and exercise the SIM tool using the results from the Safety Pilot Model Deployment, characterization tests, and additional data sources to estimate the potential safety benefits for V2V safety applications.

This report describes the test procedures to characterize the performance of prototype intersection crash warning and avoidance systems that address crossing-path crashes at junctions. In addition to this report, there are companion reports on V2V crash warning and avoidance applications for light vehicles that document characterization test procedures for forward/rear-end crash and lane-change crash avoidance prototypes, the description of the SIM tool, and the approach and results of performance measures, independent evaluation of the Safety Pilot Model Deployment, and potential safety benefits of V2V safety applications.

## EXECUTIVE SUMMARY

This report describes characterization test procedures for intersection collision avoidance systems that warn the driver of an imminent crossing-path collision at a road junction, and apply automatic braking if the driver does not respond in a timely manner to prevent the collision. These systems rely on vehicle-to-vehicle communications and relative positioning between the host and crossing-path vehicles, using the dedicated short-range communications as the base enabling technology. These tests are limited to light vehicles (passenger cars, vans and minivans, SUVs, and light pickup trucks with gross vehicle weight ratings less than 10,000 pounds) under closed test track and environmentally benign conditions. The test procedures have been developed as part of the V2V Safety research program by the National Highway Traffic Safety Administration and the Intelligent Transportation Systems Joint Program Office. The Volpe National Transportation Systems Center, in conjunction with NHTSA's Vehicle Research and Test Center, initially applied these test procedures to a number of prototype ICA systems built by different carmakers as part of Track 4 of the V2V Safety Research program. This report presents the refined test procedures based on the experience gained and lessons learned from these trials at the test track. The test procedures consist of the test scenarios, data variables, instrumentation, validity criteria, safety requirements, and driving instructions.

The test scenarios encompass a set of five crossing-path, crash-imminent scenarios (i.e., countermeasure-action scenarios) to assess the crash avoidance capability of the ICA systems under different initial conditions. The focus of the countermeasure-action tests is to characterize and document how different manufacturers implement the ranges and time-to-collisions when the collision alert is triggered followed by automatic controls in their prototype ICA systems under specified scenarios and test conditions. The countermeasure-action scenarios represent the most common crossing-path pre-crash scenarios reported in national crash databases, which involve a host vehicle that:

1. Crosses straight through an intersection across the path of an oncoming vehicle;
2. Turns right into the path of an oncoming vehicle approaching from the lateral direction;
3. Turns left into the path of an oncoming vehicle approaching from the lateral direction;
4. Turns left across the path of an oncoming vehicle approaching from the lateral direction;  
and
5. Turns left across the path of an oncoming vehicle approaching from the opposite direction.

The test procedures also incorporate a set of five test scenarios to judge the ability of the ICA systems to ignore benign driving scenarios (i.e., no-countermeasure-action scenarios), where one or both vehicles are stopping or intend to turn before crossing the path of the other vehicle.

The application of these test procedures will enable data collection to better understand the capability of prototype ICA systems and will help estimate their potential safety benefits. These characterization test procedures don't incorporate pass-fail criteria that judge how well the prototype ICA systems meet some pre-determined performance requirements. Moreover, these test procedures provide insight into ways by which V2V-based ICA applications may be evaluated on the test track. Finally, these procedures may be used by NHTSA as a basis for future system testing as part of any rulemaking activity regarding V2V-based ICA products.

## **1. INTRODUCTION**

This report describes test procedures and associated details to characterize the performance of prototype intersection collision avoidance systems that warn drivers of imminent crossing-path collisions at road junctions, and apply automatic controls to prevent such collisions when needed. These systems rely on vehicle-to-vehicle communications and relative positioning between vehicles using dedicated short-range communications as the base enabling technology. The test procedures have been developed as part of Track 4 of the V2V Safety Research plan for crash avoidance safety applications based mainly on V2V communications that address critical pre-crash scenarios [1]. The focus of the tests is to characterize and document how different manufacturers implement the ranges and time-to-collisions when the collision alert is triggered followed by automatic controls in their prototype ICA systems under specified scenarios and test conditions. Track 4 called for the functional safety analysis, build, and test of prototype systems that incorporate advanced crash avoidance applications (i.e., driver warning plus automatic vehicle controls) using only V2V technology. The purpose of Track 4 was to assess the capability of V2V technology to support these advanced applications. In August 2014, NHTSA published a research report that assessed the readiness of V2V-based safety applications in support of the Advanced Notice for Proposed Rulemaking on V2V technology [2]. This readiness report focused on V2V technology solutions for warning applications only. The test procedures described herein apply to crash warning applications only and to integrated crash warning and automatic crash avoidance applications.

The characterization test procedures in this report include a set of scenarios designed to elicit a countermeasure action in imminent crossing-path pre-crash scenarios, and another set of scenarios devised to not elicit any countermeasure action from the prototype ICA systems in benign driving scenarios. These two sets of scenarios are referred to as “action” and “no-action” test scenarios, respectively. These characterization test procedures don’t incorporate pass-fail criteria that judge how well the prototype ICA systems meet some pre-determined performance requirements. These tests are limited to light vehicles (passenger cars, vans and minivans, SUVs, and light pickup trucks with gross vehicle weight ratings less than 10,000 pounds) under closed test track and environmentally benign conditions. It is noteworthy that the test procedures described in the report were developed for research purposes only, and that they are expected to evolve as V2V-based system capabilities are better understood and/or production-based systems become commercially available in the future.

This report adopts the terminology for vehicle reference used by the Crash Avoidance Metrics Partnership [3].

### **1.1. Test Scope**

This report covers characterization tests that are devised to independently collect information about the ranges and TTCs at the ICA application level as implemented by prototype systems

from different manufacturers. These tests characterize the ability of the prototype ICA systems to generate appropriate countermeasure actions or no-actions in the two sets of scenarios. The procedures presented have been optimized under the constraints of limited test track time and resources. Wherever possible and appropriate, existing procedures have been identified through a review of the relevant literature and collaboration with stakeholders including NHTSA's Vehicle Research and Test Center and CAMP participants from original equipment manufacturers. The characterization tests are designed to illicit responses from the ICA safety applications in an escalating format up to and including automatic braking.

The test procedures in this report don't evaluate the capability of the ICA subsystems. Moreover, these procedures don't address issues such as effects on naturalistic driving, driver acceptance, and effectiveness of the driver-vehicle interface. Interoperability, certification, and other test efforts being conducted as part of the Connected Vehicle Safety Program are not subjects to this report.

## **2. TEST APPROACH**

The test procedures were applied to prototype ICA systems built by different OEMs. The Volpe Center conducted these tests at the Transportation Research Center's test track in East Liberty, Ohio, in cooperation with NHTSA's VRTC. Appendix A shows the Vehicle Dynamics Area, Skid Pad, and Winding Road Course used for testing at TRC. The ICA-equipped test vehicles are referred to as the host vehicle in this report. On the other hand, the remote vehicle denotes the utility vehicles supplied by VRTC and used as target vehicles.

### **2.1. Host Vehicle Equipment**

The HV was equipped with an independent measurement system (IMS) provided and installed by NHTSA VRTC personnel. The IMS provides ground truth Differential Global Positioning System information and vehicle speed. The IMS also includes a data acquisition system, a PC to convert User Datagram Protocol packets to DAS format via Controller Area Network interface, and a PC-based driver/test-engineer aid. The IMS, including DGPS positioning data, is used only for the collection of performance characterization data. DGPS information is not passed to or used by the ICA safety application. Appendix B provides a high-level functional block diagram of the HV's in-vehicle test equipment.

### **2.2. Remote Vehicle Equipment**

One VRTC vehicle was instrumented to act as the RV and used for testing as needed. The RV was equipped with a ground truth DGPS positioning/vehicle-speed IMS and a Master DSRC radio. The RV's IMS communicates with the HV's IMS for ground truth performance data collection only. The Master DSRC radio broadcasts the basic safety message parts I and II [4]. NHTSA and OEM participants jointly agreed upon the final specifications for the RV Master radio specifications. Appendix B provides a high-level functional block diagram of the RV's in-

vehicle test equipment. Appendix C provides the DAS data requirements to be recorded from the HV.

### **2.3. Countermeasure Modality Requirements**

The IMS records up to four separate levels of advisory and/or warning signals as designated by the OEMs for their ICA application. The first three countermeasure actions could be visual, audible, haptic, or any combination of them. The fourth and highest level of countermeasure action was specifically reserved for automatic control if included in the ICA systems. The IMS also measures and records the automatic control action by the ICA application. All kinematic and positioning data recorded by the IMS focus on the RV speed, range, and range rate relative to the HV with calibration adjustments if a virtual/offset HV is used. The virtual/offset HV is created by using a false position that is displaced 10 meters ahead of the HV to allow for a safety margin during the tests. The position displacement is executed within the HV's ICA application

## **3. TEST RUN VALIDITY CRITERIA**

Each ICA's action or no-action test procedure is designed to apply to a specific range of initial conditions (e.g., a particular test speed). The limits of applicability are used to establish the "validity" of each test run. That is, if the run does not conform to pre-determined values of speed, geometry, and other requirements, it is presumed that it is not testing the system as the procedure intends. Thus, if the run is not performed within these limits, the run is declared invalid and not used in the characterization of the ICA application. General validity criteria have been established for all test procedures. These criteria delineate where the test procedures and function design intent overlap, thereby enabling the performance data of prototype ICA systems to be useful in the estimation of their potential safety benefits. Ten valid test runs are conducted for countermeasure-action tests. On the other hand, only five valid test runs are conducted for no-countermeasure-action tests.

## **4. INSTRUMENTATION, EQUIPMENT INSTALLATION, AND CALIBRATION**

The following information is applicable to all test procedures:

### **4.1. Host Vehicle**

- **IMS** – The IMS is the RT 3002 Inertial and GPS Measurement System from Oxford Technical Solutions. The system includes a base RT 3002 unit; Wi-Fi-based rover unit, and a track-wide broadcast-capable base station for real-time differential corrections. The base RT 3002 is rigidly mounted near the center of gravity of the vehicle. The IMS configuration being used is used extensively in VRTC testing and has a documented dynamic position accuracy of 1 sigma = 2 cm (absolute) [5].
- **DAS** – The DAS is produced by United Electronic Industries, and has been customized by VRTC for NHTSA's unique requirements. The system allows for data collection and

synchronization to the coordinated universal time provided by the RT 3002. The DAS is typically securely mounted in the trunk, rear seat, or cargo area of the vehicle. The DAS system has the capability to capture a full range of signals including analog, digital, CAN, Ethernet, and video.

- Driver's Aid/CAN interface – An RT 3002 high-speed CAN network is used to communicate to the DAS and a remote display. The remote display is securely mounted to the dash or windshield, and conveniently provides information (e.g., HV speed, HV-to-RV range or gap, etc.) to the driver while looking forward. Any RT 3002 and/or RT-Range-based variable can be displayed on the remote display.

#### **4.2. Remote Vehicle**

- IMS – Similar equipment is used for the RV's IMS as is used by the HV.
- DSRC master radio mode – The master radio is provided with GPS position from a U-Blox 6 chip that is used to populate the time and positioning information of the BSM being broadcast at 10 Hz. The BSM Parts I and II are consistent with the CAMP's Model Deployment BSM minimum performance requirements [4]. The master radio is securely mounted in the rear seat, trunk, or rear cargo area of the vehicle. The combined DSRC/GPS antenna is magnetically mounted to the top of the RV.

#### **4.3. Daily Calibration Requirements**

At the start of each testing day or optionally at the end of testing, the HV and RV IMS undergo the calibration checks described below, and sample data are recorded:

- All IMS equipment are powered on (minimum 15-minute warm-up), initialized, and driven for approximately 5 minutes on access or public roads to a paved location with a flat, straight section at least 40 meters in length under an open sky (as called for in the RT 3002 user manual to achieve real-time kinematic level corrections) [5].
- Verify that all RT 3002 units have achieved full (RTK) correction and are communicating via Wi-Fi to all rover units.
- Verify that, if used, the HV position displaced offset has been adjusted for as recorded in the DAS. (See Section 9.1.4 for more information regarding position displaced offsets)
- At two longitudinal and latitudinal distances of the RV and HV (rear bumper-to-front bumper, or centerline of the RT unit to front bumper or RT centerline to RT centerline) between 0 and 30.5 meters, measure and record the following:
  - Actual distance as measured by wheel or tape measure; and
  - Distance reported by the HV IMS and the RT 3002.

- The values as measured by the HV IMS and the RT 3002 must be within  $\pm 10$  cm of the actual distance.

## **5. DATA COLLECTION REQUIREMENTS**

The following data are recorded during testing:

1. Warning and advisory onset; audio at 100 Hz (10 milliseconds), visual at 30 frames per second (fps), haptic at 100 Hz (10 milliseconds).
2. CAN data converted from HV UDP data at 10 Hz (100 milliseconds)
3. Photographic documentation – Still photographs of the vehicle under test are taken. At least one video camera records an IMS-provided time stamp, and is used to support the documentation of all tests. Used primarily to provide visual context for the data collected, the frame rate and view may vary by the test being conducted. A video camera records the visual and audio advisory and/or warning countermeasure that includes the IMS timestamp for reference.

## **6. ENVIRONMENTAL, AMBIENT, AND STANDARD TEST CONDITIONS**

Unless otherwise specified, the following requirements shall apply to all test procedures:

1. Daytime illumination, defined as natural outdoor illumination.
2. Good atmospheric visibility, defined as an absence of fog and the ability to see clearly for more than 5,000 meters.
3. Dry conditions, defined as no light rain, ice or visible evidence of standing water on the track where test maneuvers are being conducted.
4. Non-extreme temperatures for summer and winter testing in East Liberty, defined as an ambient temperature between 20° F and 100° F (under hood and/or cabin temperatures are not specified).

## **7. SUSPENSION CRITERIA AND RESUMPTION REQUIREMENTS**

The safety implications of a potential malfunction or failure of the ICA system must be considered during the characterization tests especially in crash-imminent test scenarios. Thus, if the ICA application does not issue a countermeasure action for two consecutive valid runs, or for three valid runs in any group of ten valid runs, testing of the application is suspended until a satisfactory explanation is provided and the issue is resolved. A technical representative from the OEMs is present for all testing of the respective vehicles. In the event of test suspension, the OEM's technical representative is given a reasonable amount of time and assistance to troubleshoot their vehicle's safety application. Once changes are made to the safety application, a new series of test runs may be conducted.

## 8. SAFETY

The characterization tests require the ICA systems to issue warnings and to apply automatic controls to avoid a collision with the RV while running the test scenarios. It is important that professional drivers are in the test vehicles at all times and prepared to conduct avoidance maneuvers manually, if needed. The test vehicles do not require the driver to perform any manual action to take control of the vehicle (in addition to using normal driving) to avoid a real or perceived imminent collision. That is, the test driver is able to brake/steer/accelerate manually in a naturalistic manner without any need of pressing switches, buttons, etc. before taking control of the vehicle. This may play an important role in aborting the test scenario when the test driver assesses the situation as unsafe. It is assumed that the TTC and ranges between vehicles during these tests may become extremely small when automatic controls are applied; thus, all safety concerns are taken seriously before conducting the tests. It is important that the OEMs submit ICA performance descriptions to the test conductor, including expected ranges at which ICA warning and control will act, for safety review prior to testing. It may also help that the OEMs submit their safety measure procedures.

The expected behavior of the HV is to first establish the initial test conditions, issue a warning to the driver, and then apply automatic control to avoid a collision with the RV without the test driver's intervention. The mode of the system, especially when the brakes are pressed during automatic control, is decided by individual OEMs. The characterization tests of the prototype ICA systems at TRC were conducted in accordance with the following:

1. All testing was conducted at NHTSA's VRTC in East Liberty. VRTC is required to comply with TRC's *Facility Operating Guidelines* that govern the safety protocols for all testing conducted there.
2. All new test procedures require review and approval by the TRC Safety Committee. The safety committee reviews the procedures and assesses the ability of the test drivers to safely conduct the procedure including alternatives identified for conflict resolution. Procedures are provided to the safety committee approximately two weeks prior to track testing.
3. Each test procedure requires two people in the HV, a driver and observer/data aid knowledgeable of the test procedures and installed equipment.
4. The Safety Committee specifies the level of driver rating required for each driver used in each procedure. More complex or time-critical maneuvers may require a "Performance Driver" rating, a higher classification than an "Approved Driver."
5. All drivers were briefed by the Volpe Center and/or VRTC on the procedures and allowed to practice the maneuvers prior to the start of formal testing.
6. Technical assistance was provided by the OEMs as needed and/or requested in relation to each developer's application, test scenarios, and safety protocols.
7. A 10-meter position displaced HV was used for countermeasure-required straight crossing path scenarios when the HV countermeasures included automatic control/"Auto

Braking” for added safety. The RT 3002 ground truth data based on IMU components packaged within the RV and HV are used for among other things all speed, range, and positioning reported data. Any V2V radio virtual position displaced offset used is adjusted out during calibration.

## 9. PROCEDURES FOR CRASH-IMMINENT TEST SCENARIOS

The purpose of the crash-imminent test scenarios is to characterize the behavior of the HV to detect a collision threat from the RV, and produce a countermeasure action that warns the driver first and then automatically applies collision avoidance controls if the driver does not heed the warning. The intent is to characterize the control aspect of the ICA application; i.e., the ability to automatically avoid collisions without driver intervention. The test driver intentionally ignores the warning and allows the system to automatically apply controls to prevent the HV from colliding with the RV. The HV driver does not manually avoid the collision unless it poses a safety hazard to any driver or vehicle.

Table 1 lists a summary of all five crash-imminent test scenarios.

Table 2 shows the initial HV and RV states for these tests.

Table 1: Summary of Crash-Imminent ICA Test Scenarios

Test No.	Test Description
ICA-1	<u>Straight Crossing Paths (SCP)</u> ICA-1A: Both vehicles moving at constant speeds ICA-1B: RV moving at constant speed and HV first stopped and then accelerates to cross
ICA-2	<u>Right Turn into Path (RTIP)</u> ICA-2A: RV moving at constant speed and HV turns right at slower constant speed ICA-2B: RV moving at constant speed and HV turns right starting from a stop
ICA-3	<u>Left Turn into Path (LTIP)</u> ICA-3A: RV moving at constant speed and HV turns left at slower constant speed ICA-3B: RV moving at constant speed and HV turns left starting from a stop
ICA-4	<u>Left Turn across Path/Lateral Direction (LTAP/LD)</u> ICA-4A: RV moving at constant speed and HV turns left at slower constant speed ICA-4B: RV moving at constant speed and HV turns left starting from a stop
ICA-5	<u>Left Turn across Path/Opposite Direction (LTAP/OD)</u> ICA-5A: RV moving at constant speed and HV turns left at slower constant speed ICA-5B: RV moving at constant speed and HV turns left starting from a stop

Table 2: HV and RV Setup in Crash-Imminent ICA Test Scenarios

Test No.	ICA 1		ICA 2		ICA 3		ICA 4		ICA 5	
Scenario	A	B	A	B	A	B	A	B	A	B
RV Moving	x	x	x	x	x	x	x	x	x	x
HV Moving	x		x		x		x		x	
HV Stopped & Accelerate		x		x		x		x		x

Sensing in the tests is based on DSRC-enabled V2V technology and in-vehicle sensors only. ICA systems don't use other on-board object detection sensors (radar lidar, vision, etc.), lane detection systems, and map database to determine the road geometry, position, and attitude of the vehicle in the roadway and the lane. The tests may be repeated with above mentioned capabilities to assess the performance enhancement due to additional sensors.

### 9.1. ICA-1: Straight Crossing Paths (SCP)

This test determines the ranges and TTCs when the warning is triggered, followed by ICA automatic controls that occur when the HV encounters a crossing-path RV. This test especially characterizes the ability of the system to accurately identify lateral crossing-path targets at a perpendicular intersection and generate the appropriate countermeasure actions automatically. This test is run at two series of initial conditions in order to characterize ICA systems when the HV is initially moving (ICA-1A) and initially stopped (ICA-1B).

#### 9.1.1. Test Overview

The test begins with HV on a straight, flat road traveling at constant speed or stopped at an intersection about to proceed. In the crossing path ahead of the HV, the RV is traveling on a straight, flat road at constant speed, as shown in Figure 1 and Figure 2. In tests where the HV is moving initially, ICA-1A, the HV should attain the initial test speed,  $V_{HV}$ , at least 3 seconds from the intersection, measured by the corresponding range between HV and the intersection. The HV continues at constant speed towards the intersection, without cruise control, and without the test driver manually activating the brakes. During ICA-1B tests, the HV should be driven to the stop line and stopped for three seconds as the RV approaches. The RV should attain the initial test speed,  $V_{RV}$ , at least 3 seconds from the intersection and drive straight through the intersection at constant speed.

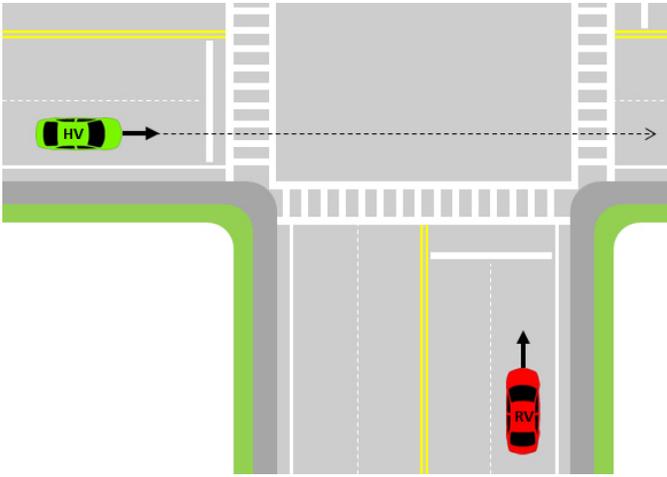


Figure 1: ICA-1A Test Initial Conditions

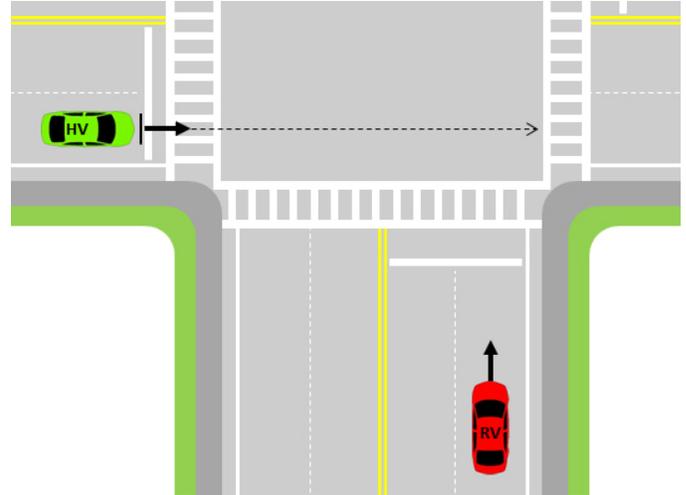


Figure 2: ICA-1B Test Initial Conditions

Figure 3 and Figure 4 illustrate the transitional and final conditions of the SCP tests. As the HV and the RV approach the intersection, the ICA system warns the HV driver at a range  $R_{Warning}$ . The OEMs may have included an earlier advisory alert in addition to the warning. The warning may be audible, visual, haptic, or any combination thereof. Subsequently, at a range  $R_{Control}$ , the ICA system applies an automatic control action after the warning is ignored. In case of automatic control, the action may consist of several sub-actions: transmission downshift, throttle cut-off, brake pre-charging, multiple levels of braking, etc., or any combination thereof. If applicable, ICA automatic control should bring the HV to a full stop before contacting the RV, preferably at a range  $R_{Safety}$ , as depicted below. Figure 3 illustrates the SCP ICA-1A test with the HV moving initially. Figure 4 illustrates the ICA-1B test with the HV stopped initially.

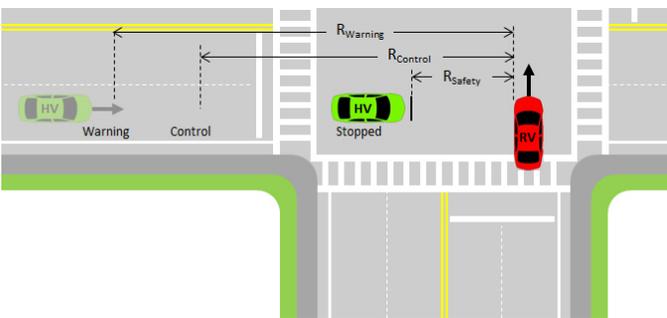


Figure 3: ICA-1A Transitional and Final Conditions

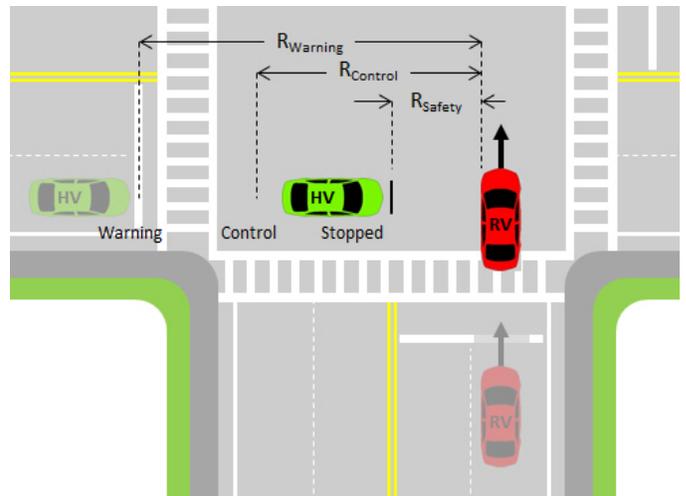


Figure 4: ICA-1B Transitional and Final Conditions

### 9.1.2. Run Validity Criteria

Table 3 shows the initial conditions for each ICA-1 test. The test runs are considered valid if the initial conditions are satisfied. The initial, transitional, and final conditions are recorded and used for system characterization.

Table 3: ICA-1 Tests Setup and Run Validity for SCP Scenarios

Parameter	ICA-1A Test 1		ICA-1A Test 2		ICA-1A Test 3		ICA-1B Test 1		ICA-1B Test 2	
	Value	Tolerance								
$V_{HV}$	25 mph	±1.3 mph	45 mph	±2.3 mph	25 mph	±1.3 mph	0 mph	N/A	0 mph	N/A
$V_{RV}$	25 mph	±1.3 mph	45 mph	±2.3 mph	45 mph	±2.3 mph	25 mph	±1.3 mph	45 mph	±2.2 mph
$R_{HVInitial}$	56 m	±5.6 m	101 m	±10.0 m	56 m	±5.6 m	N/A	N/A	N/A	N/A
$R_{RVInitial}$	56 m	±5.6 m	101 m	±10.0 m	101 m	±10.0 m	56 m	±5.6 m	101 m	±10.0 m

### 9.1.3. Test Setup and Driving Instructions – For ICA 1A and 1B Systems Without Automatic Controls

This test requires a straight-crossing intersection with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

#### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ , and maintain a constant speed.
3. Cross through the intersection.
4. Stop the RV after clearing the intersection.

#### HV Driving Instructions:

1. Position the HV in the right-hand lane on a road perpendicular to the RV.
2. ICA-1A: Accelerate to the test speed,  $V_{HV}$ , and maintain constant speed.  
ICA-1B: Drive the HV to the stop line and wait until the RV approaches.
3. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Start to cross the intersection into the path of the RV.
5. Maintain a constant accelerator pedal position and speed until an ICA warning, then apply the brakes to bring the HV to a stop.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually takes an evasive action to avoid a potential collision.

#### 9.1.4. Test Setup and Driving Instructions – For ICA 1A and 1B Systems With Automatic Controls

This test requires a straight-crossing intersection with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

##### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ , and maintain a constant speed.
3. Cross through the intersection.
4. Stop the RV after clearing the intersection.

##### HV Driving Instructions:

1. Position the HV in the right-hand lane on a road perpendicular to the RV.
2. ICA-1A: Accelerate to the test speed,  $V_{HV}$ , and maintain constant speed.  
ICA-1B: Drive the HV to the stop line and wait until the RV approaches.
3. The HV (adjusted for the 10-meter virtual forward position offset) and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Start to cross the intersection into the path of the RV.
5. Ignore the expected ICA warning and maintain a constant accelerator pedal position and speed. (Driver safety concerns at speeds up to 45/45 mph (20.1 m/s) at this step prompted the implementation of the 10-meter forward displaced virtual HV that was used only for ICA 1A and B with auto braking and is described in Figure 5 below.)
6. Maintain a constant accelerator pedal position when the ICA automatic braking activates.
7. When the HV comes to a full stop, apply the brakes.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision.

The effect of a 10-meter HV virtual position offset is illustrated in Figure 5 below:

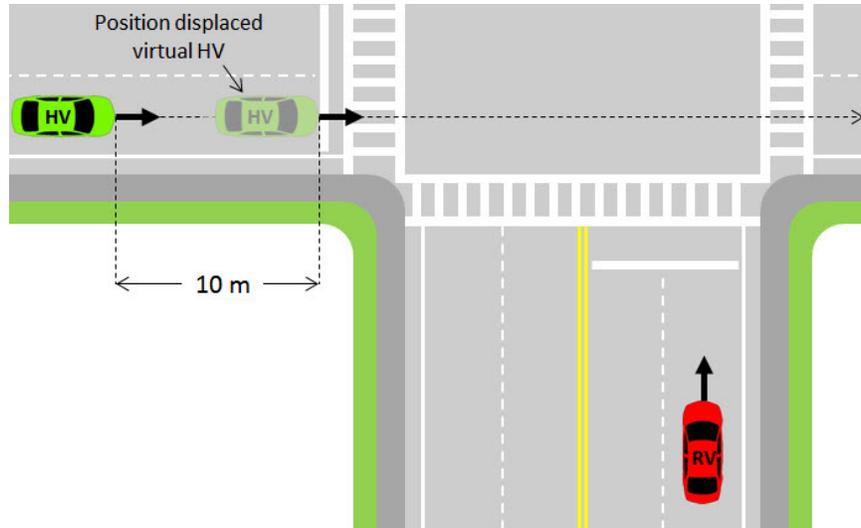


Figure 5: Straight Crossing Path Test With 10-Meter Position Displaced Virtual HV

## 9.2. ICA-2: Right Turn into Path (RTIP)

This test determines the ranges and TTCs when the warning is triggered, followed by ICA automatic controls that occur when the HV encounters an in-path RV. This test especially characterizes the ability of the system to accurately identify lateral crossing-path targets at a right turn intersection on straight roads and generate the appropriate countermeasure actions automatically. This test is run at two sets of initial conditions in order to characterize ICA systems when the HV is initially moving (ICA-2A) and initially stopped (ICA-2B).

### 9.2.1. Test Overview

The test begins with HV on a straight, flat road traveling at constant speed or stopped at an intersection about to proceed. In the crossing path ahead of the HV, the RV is traveling on a straight, flat road at constant speed as shown in Figure 6; the ICA-2B test is not depicted. The HV should attain the initial test speed of  $V_{HV}$  at least 3 seconds from the intersection, measured by the corresponding range between HV and the intersection. The HV continues at constant speed towards the intersection, without cruise control, and without the test driver manually activating the brakes. The HV intends to make a right turn at the intersection. The RV should attain the initial test speed of  $V_{RV}$  at least 3 seconds from the intersection and drive straight through the intersection at constant speed.

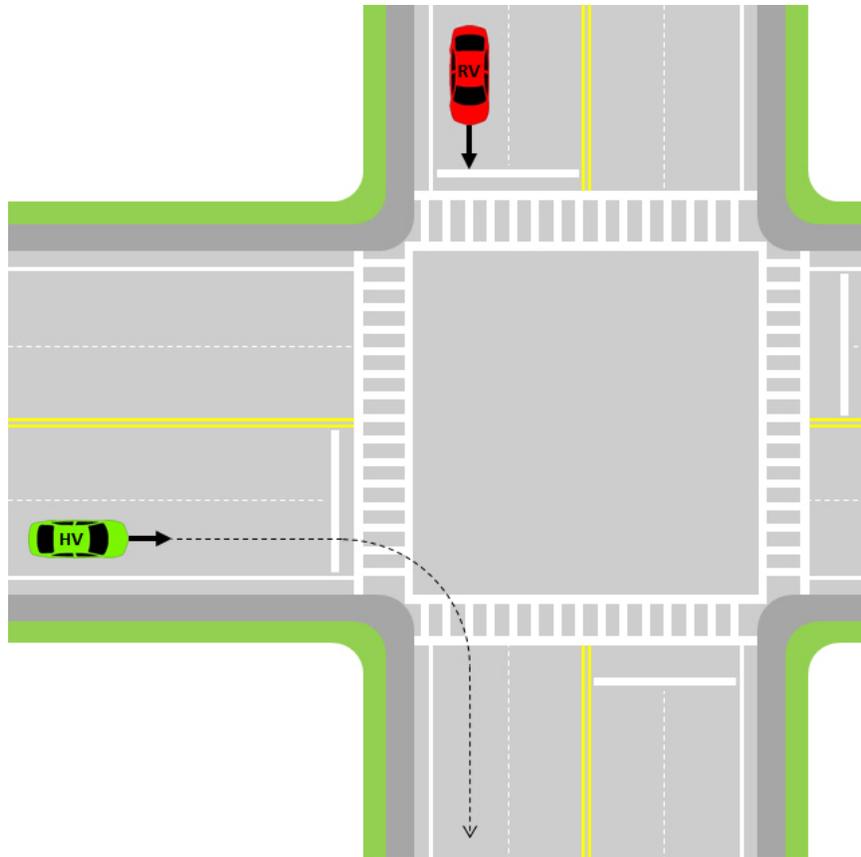


Figure 6: ICA-2A Test Initial Conditions

Figure 7 illustrates the transitional and final conditions of the RTIP test. As the HV approaches the intersection and intends to make a right turn, the ICA system warns the HV driver at a range  $R_{Warning}$ . The OEMs may have included an earlier advisory alert in addition to the warning. The warning may be audible, visual, haptic, or any combination thereof. Subsequently, at a range  $R_{Control}$ , the ICA system applies an automatic control action after the warning is ignored. In case of automatic control, the action may consist of several sub-actions: transmission downshift, throttle cut-off, brake pre-charging, multiple levels of braking, etc., or any combination thereof. If applicable, ICA automatic control should bring the HV to a full stop before contacting the RV, preferably at a range  $R_{Safety}$ , as depicted below.

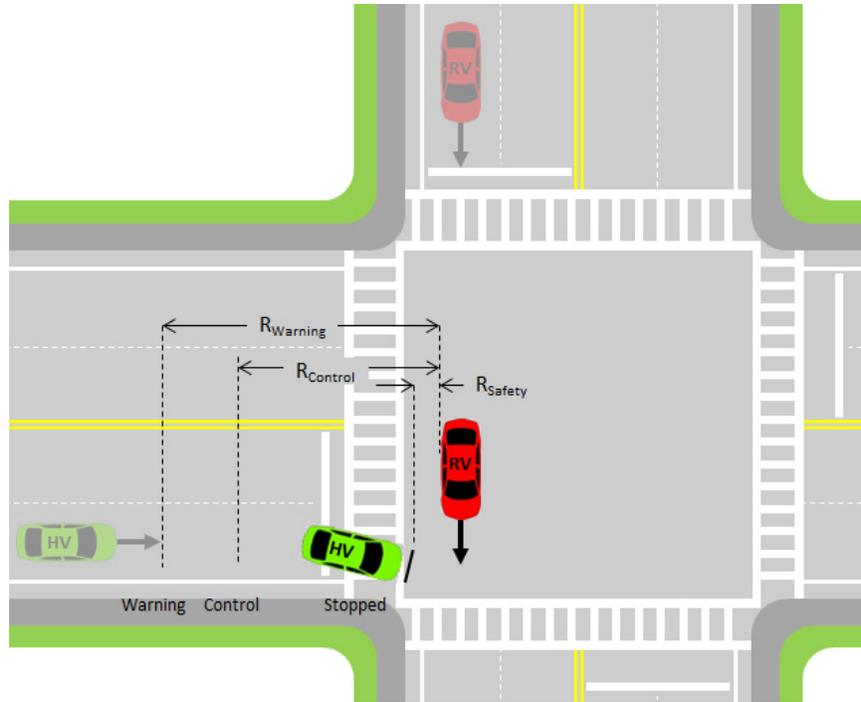


Figure 7: ICA-2A Transitional and Final Conditions

### 9.2.2. Run Validity Criteria

Table 4 shows the initial conditions for each test. The test runs are considered valid if the initial conditions are satisfied. The initial, transitional, and final conditions are recorded and used for system characterization.

Table 4: ICA-2 Tests Setup and Run Validity for RTIP Scenarios

Parameter	ICA-2A		ICA-2B	
	Value	Tolerance	Value	Tolerance
$V_{HV}$ (Approach)	22 mph	$\pm 1.1$ mph	0 mph	N/A
$V_{HV}$ (Turn)	12 mph	$\pm 1.1$ mph	0 mph	N/A
$A_{HV}$	-0.15 g	$\pm 0.5$ g	N/A	N/A
$V_{RV}$	35 mph	$\pm 1.8$ mph	35 mph	$\pm 1.8$ mph
$R_{HVInitial}$	49 m	4.9 m	0 m	0 m
$R_{RVInitial}$	78 m	7.8 m	78 m	7.8 m

### 9.2.3. Test Setup and Driving Instructions

This test requires a straight crossing intersection with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ , and maintain a constant speed.
3. Cross through the intersection.
4. Stop the RV after clearing the intersection.

### HV Driving Instructions:

1. Position the HV in the right-hand lane on a road perpendicular to the RV.
2. ICA-2A: Accelerate to the test speed,  $V_{HV}$ , and maintain constant speed.  
ICA-2B: Drive the HV to the stop line and wait until the RV approaches.
3. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Activate the right-turn signal, begin slowing to the target speed using the throttle and/or brakes, and start turning right into the path of the RV.
5. Maintain a constant accelerator pedal position and speed until an ICA warning, then apply the brakes to bring the HV to a stop.
6. If the vehicle has ICA system with automatic control, ignore the expected ICA warning and maintain a constant accelerator pedal position and speed.
7. Maintain a constant accelerator pedal position when the ICA automatic control activates.
8. When the HV comes to a full stop, apply the brakes.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision by braking and/or steering.

### **9.3. ICA-3: Left Turn into Path**

This test determines the ranges and TTCs when the warning is triggered, followed by ICA automatic controls that occur when the HV encounters an in-path RV. This test especially characterizes the ability of the system to accurately identify lateral crossing-path targets at a left turn intersection on straight roads and generate the appropriate countermeasure actions automatically. This test is run at two sets of initial conditions in order to characterize ICA systems when the HV is initially moving (ICA-3A) and initially stopped (ICA-3B).

#### **9.3.1. Test Overview**

The test begins with HV on a straight, flat road traveling at constant speed or stopped at an intersection about to proceed. In the crossing path ahead of the HV, the RV is traveling on a straight, flat road at constant speed as shown in Figure 8; the ICA-3B test is not depicted. The HV should attain the initial test speed of  $V_{HV}$  at least 3 seconds from the intersection, measured

by the corresponding range between HV and the intersection. The HV continues at constant speed towards the intersection, without cruise control, and without the test driver manually activating the brakes. The HV intends to make a left turn at the intersection. The RV should attain the initial test speed of  $V_{RV}$  at least 3 seconds from the intersection and drive straight through the intersection at constant speed.

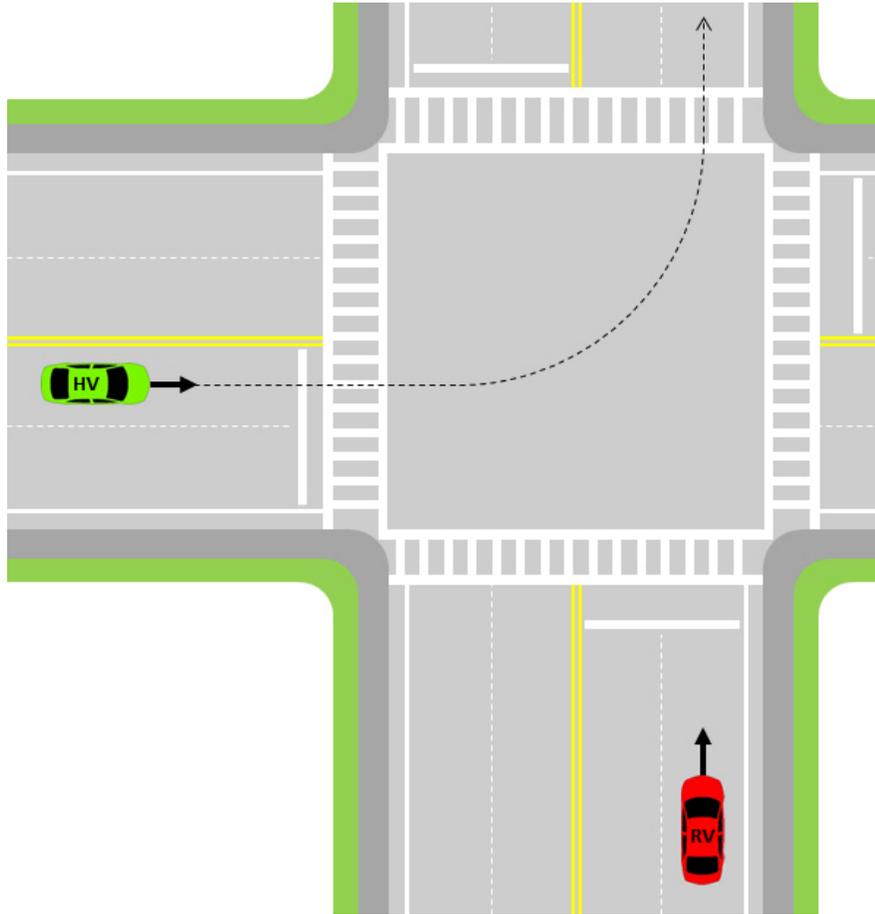


Figure 8: ICA-3A Test Initial Conditions

Figure 9 illustrates the transitional and final conditions of the LTIP test. As the HV approaches the intersection to make a left turn, the ICA system warns the HV driver at a range  $R_{Warning}$ . The warning may be audible, visual, haptic, or any combination thereof. Subsequently, at a range  $R_{Control}$ , the ICA system applies an automatic control action after the warning is ignored. In case of automatic control, the action may consist of several sub-actions: transmission downshift, throttle cut-off, brake pre-charging, multiple levels of braking, etc., or any combination thereof. If applicable, ICA automatic control should bring the HV to a full stop before contacting the RV, preferably at a range  $R_{Safety}$ , as depicted below.

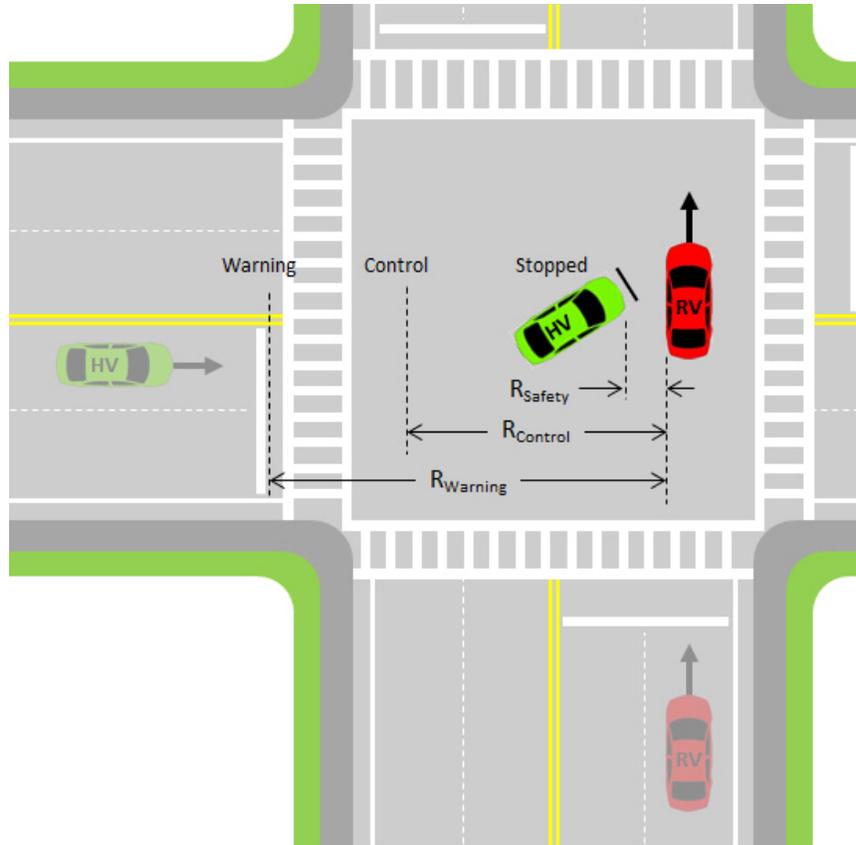


Figure 9: ICA-3A Transitional and Final Conditions

### 9.3.2. Run Validity Criteria

Table 5 shows the initial conditions for each test. The test runs are considered valid if the initial conditions are satisfied. The initial, transitional, and final conditions are recorded and used for system characterization.

Table 5: ICA-3 Tests Setup and Run Validity for LTIP Scenarios

Parameter	ICA-3A		ICA-3B	
	Value	Tolerance	Value	Tolerance
$V_{HV}$ (Approach)	22 mph	$\pm 1.1$ mph	0 mph	N/A
$V_{HV}$ (Turn)	12 mph	$\pm 1.1$ mph	0 mph	N/A
$A_{HV}$	-0.15 g	$\pm 0.5$ g	N/A	N/A
$V_{RV}$	35 mph	$\pm 1.8$ mph	35 mph	$\pm 1.8$ mph
$R_{HVInitial}$	49 m	4.9 m	0 m	0 m
$R_{RVInitial}$	78 m	7.8 m	78 m	7.8 m

### 9.3.3. Test Setup and Driving Instructions

This test requires a straight crossing path intersection with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

#### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ , and maintain a constant speed.
3. Cross through the intersection.
4. Stop the RV after clearing the intersection.

#### HV Driving Instructions:

1. Position the HV in the left-hand lane on a road perpendicular to the RV.
2. ICA-3A: Accelerate to the test speed,  $V_{HV}$ , and maintain constant speed.  
ICA-3B: Drive the HV to the stop line and wait until the RV approaches.
3. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Activate the left-turn signal, begin slowing to the target speed using the throttle and/or brakes, and start turning left into the path of the RV.
5. Maintain a constant accelerator pedal position and speed until an ICA warning, then apply the brakes to bring the HV to a stop.
6. If the vehicle has an ICA system with automatic control, ignore the expected ICA warning and maintain a constant accelerator pedal position and speed.
7. Maintain a constant accelerator pedal position when the ICA automatic control activates.
8. When the HV comes to a full stop, apply the brakes.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision.

### **9.4. ICA-4: Left Turn Across Path/Lateral Direction**

This test determines the ranges and TTCs when the warning is triggered, followed by ICA automatic controls that occur when the HV encounters a crossing-path RV. This test especially characterizes the ability of the system to accurately identify lateral crossing path targets at a left turn intersection on straight roads and generate the appropriate countermeasure actions automatically. This test is run at two sets of initial conditions in order to characterize ICA systems when the HV is initially moving (ICA-4A) and initially stopped (ICA-4B).

#### 9.4.1. Test Overview

The test begins with HV on a straight, flat road traveling at constant speed or stopped at an intersection about to proceed. In the crossing path ahead of the HV, the RV is traveling on a straight, flat road at constant speed as shown in Figure 10; the ICA-4B test is not depicted. The HV should attain the initial test speed of  $V_{HV}$  at least 3 seconds from the intersection, measured by the corresponding range between HV and the intersection. The HV continues at constant speed towards the intersection, without cruise control, and without the test driver manually activating the brakes. The HV intends to make a left turn at the intersection. The RV should attain the initial test speed of  $V_{RV}$  at least 3 seconds from the intersection and drive straight through the intersection at constant speed.

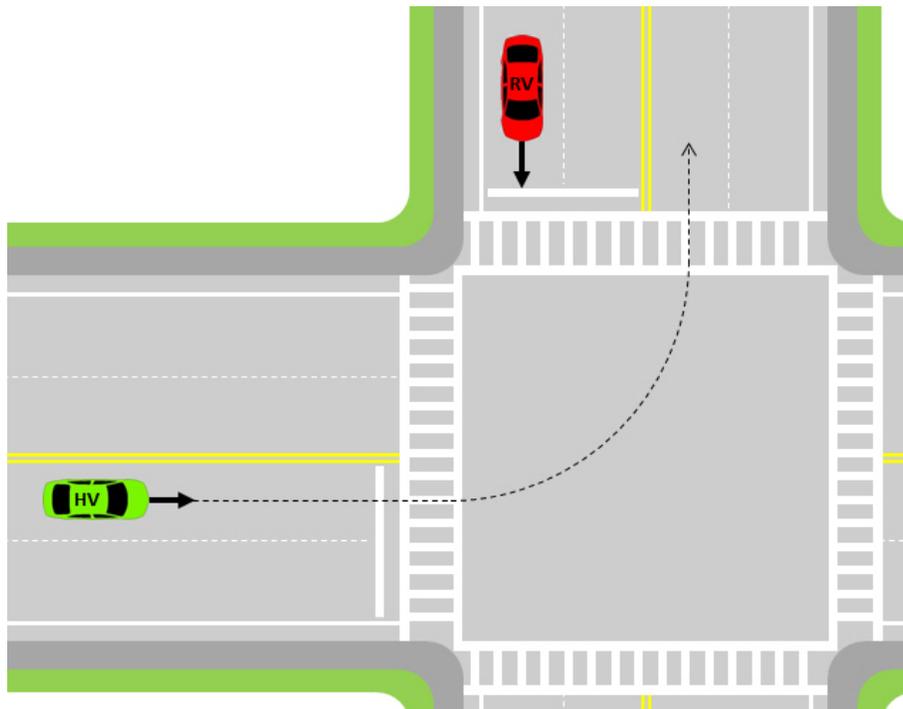


Figure 10: ICA-4A Test Initial Conditions

Figure 11 illustrates the transitional and final conditions of the LTAP/LD test. As the HV approaches the intersection to make a left turn, the ICA system warns the HV driver at a range  $R_{Warning}$ . The OEMs may have included an earlier advisory alert in addition to the warning. The warning may be audible, visual, haptic, or any combination thereof. Subsequently, at a range  $R_{Control}$ , the ICA system applies an automatic control action after the warning is ignored. In case of automatic control, the action may consist of several sub-actions: transmission downshift, throttle cut-off, brake pre-charging, multiple levels of braking, etc., or any combination thereof. If applicable, ICA automatic control should bring the HV to a full stop before contacting the RV, preferably at a range  $R_{Safety}$ , as depicted below.

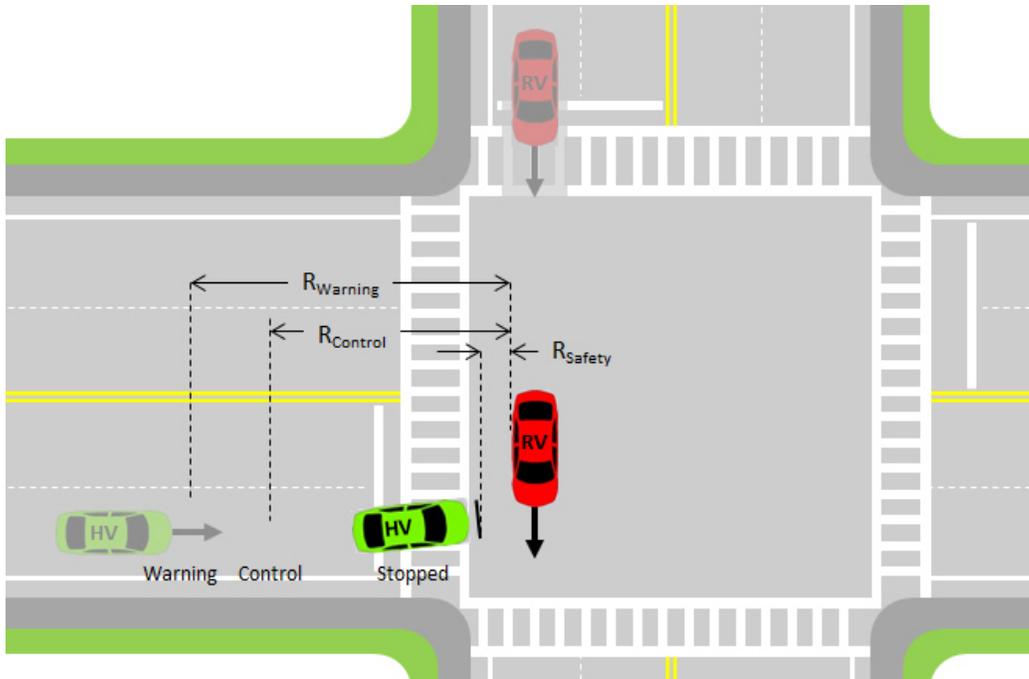


Figure 11: ICA-4A Transitional and Final Conditions

#### 9.4.2. Run Validity Criteria

Table 6 shows the initial conditions for each test. The test runs are considered valid if the initial conditions are satisfied. The initial, transitional, and final conditions are recorded and used for system characterization.

Table 6: ICA-4 Tests Setup and Run Validity for LTAP/LD Scenarios

Parameter	ICA-4A		ICA-4B	
	Value	Tolerance	Value	Tolerance
$V_{HV}$ (Approach)	22 mph	$\pm 1.1$ mph	0 mph	N/A
$V_{HV}$ (Turn)	12 mph	$\pm 1.1$ mph	0 mph	N/A
$A_{HV}$	-0.15 g	$\pm 0.5$ g	N/A	N/A
$V_{RV}$	35 mph	$\pm 1.8$ mph	35 mph	$\pm 1.8$ mph
$R_{HVInitial}$	49 m	4.9 m	0 m	0 m
$R_{RVInitial}$	78 m	7.8 m	78 m	7.8 m

#### 9.4.3. Test Setup and Driving Instructions

This test requires a straight crossing path road with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ , and maintain a constant speed.
3. Cross through the intersection.
4. Stop the RV after clearing the intersection.

### HV Driving Instructions:

1. Position the HV in the left-hand lane on a road perpendicular to the RV.
2. ICA-4A: Accelerate to the test speed,  $V_{HV}$ , and maintain constant speed.  
ICA-4B: Drive the HV to the stop line and wait until the RV approaches.
3. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Activate the left-turn signal, begin slowing to the target speed using the throttle and/or brakes, and start turning left into the path of the RV.
5. Maintain a constant accelerator pedal position and speed until an ICA warning, then apply the brakes to bring the HV to a stop.
6. If the vehicle has an ICA system with automatic control, ignore the expected ICA warning and maintain a constant accelerator pedal position and speed.
7. Maintain a constant accelerator pedal position when the ICA automatic control activates.
8. When the HV comes to a full stop, apply the brakes.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision.

## **9.5. ICA-5: Left Turn \Across Path/Opposite Direction**

This test determines the ranges and TTCs when the warning is triggered, followed by ICA automatic controls that occur when the HV encounters a crossing-path RV from the opposite direction. This test especially characterizes the ability of the system to accurately identify opposite-direction targets at a left-turn intersection on straight roads and generate the appropriate countermeasure actions automatically. This test is run at two sets of initial conditions in order to characterize ICA systems when the HV is initially moving (ICA-5A) and initially stopped (ICA-5B).

### 9.5.1. Test Overview

The test begins with HV on a straight, flat road traveling at constant speed or stopped at an intersection about to proceed. In the opposite lane ahead of the HV, the RV is traveling toward the HV on a straight, flat road at constant speed as shown in Figure 12; the ICA-5B test is not

depicted. The HV should attain the initial test speed of  $V_{HV}$  at least 3 seconds from the intersection, measured by the corresponding range between HV and the intersection. The HV continues at constant speed towards the intersection, without cruise control, and without the test driver manually activating the brakes. The HV intends to make a left turn at the intersection. The RV should attain the initial test speed of  $V_{RV}$  at least 3 seconds from the intersection and drive straight through the intersection at constant speed.

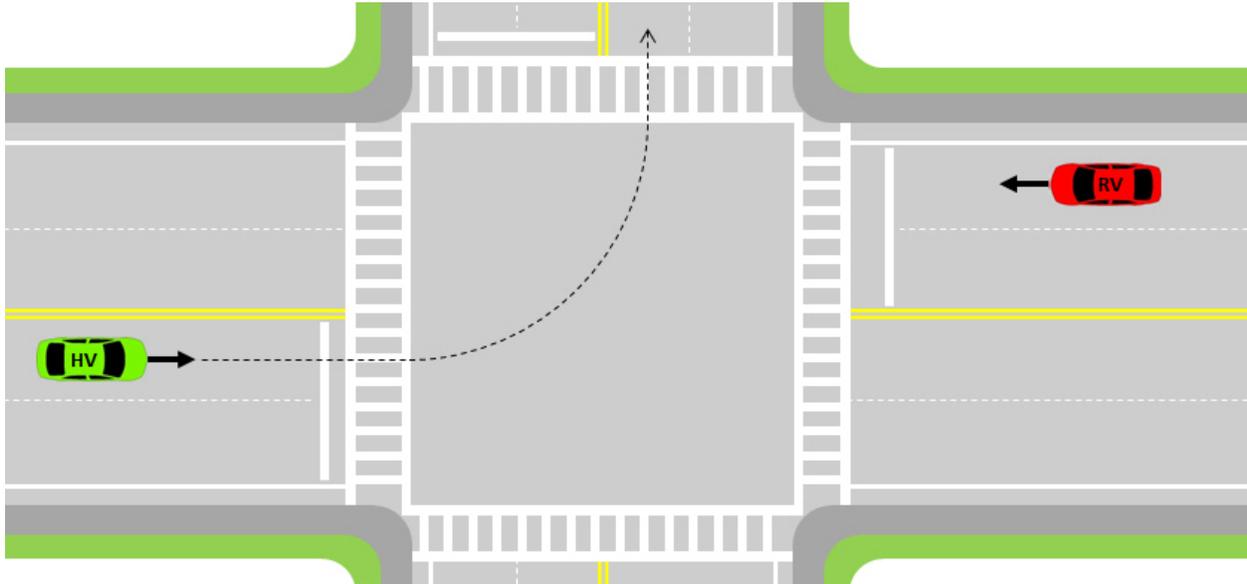


Figure 12: ICA-5A Test Initial Conditions

Figure 13 illustrates the transitional and final conditions of the LTAP/OD test. As the HV approaches the intersection and intends to make a left turn, the ICA system warns the HV driver at a range  $R_{Warning}$ . The OEMs may have included an earlier advisory alert in addition to the warning. The warning may be audible, visual, haptic, or any combination thereof. Subsequently, at a range  $R_{Control}$ , the ICA system applies an automatic control action after the warning is ignored. In case of automatic control, the action may consist of several sub-actions: transmission downshift, throttle cut-off, brake pre-charging, multiple levels of braking, etc., or any combination thereof. If applicable, ICA automatic control should bring the HV to a full stop before contacting the RV, preferably at a range  $R_{Safety}$ , as depicted below.

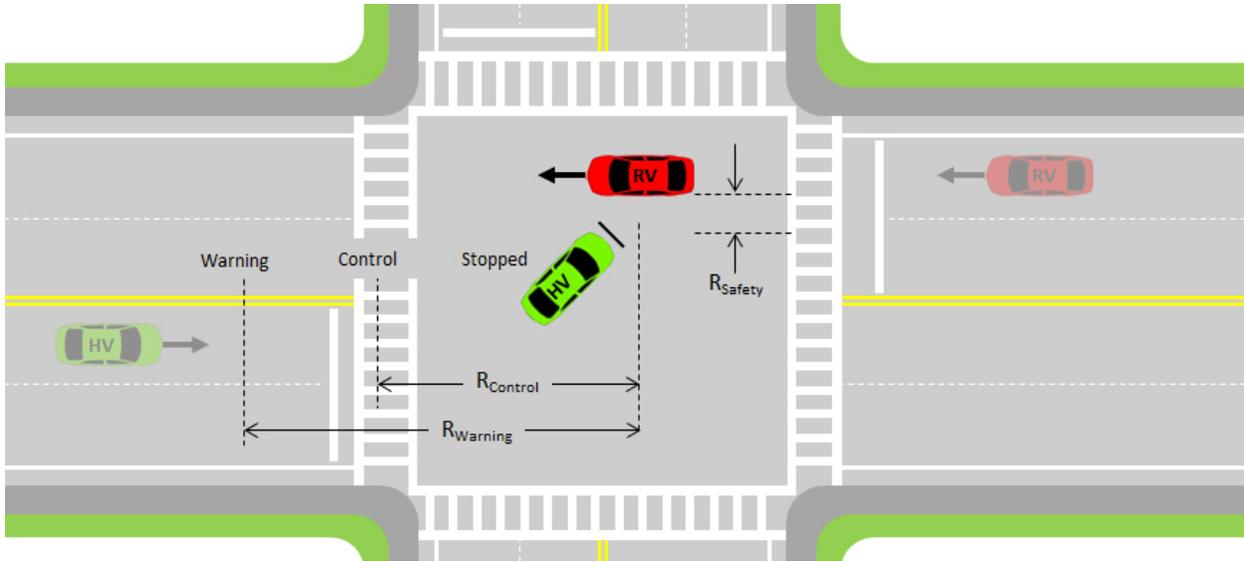


Figure 13: ICA-5A Transitional and Final Conditions

### 9.5.2. Run Validity Criteria

Table 7 shows the initial conditions for each test. The test runs are considered valid if the initial conditions are satisfied. The initial, transitional, and final conditions are recorded and used for system characterization.

Table 7: ICA-5 Tests Setup and Run Validity for LTAP/OD Scenarios

Parameter	ICA-5A		ICA-5B	
	Value	Tolerance	Value	Tolerance
$V_{HV}$ (Approach)	22 mph	$\pm 1.1$ mph	0 mph	N/A
$V_{HV}$ (Turn)	12 mph	$\pm 1.1$ mph	0 mph	N/A
$A_{HV}$	-0.15 g	$\pm 0.05$ g	N/A	N/A
$V_{RV}$	35 mph	$\pm 1.8$ mph	35 mph	$\pm 1.8$ mph
$R_{HVInitial}$	49 m	4.9 m	0 m	0 m
$R_{RVInitial}$	78 m	7.8 m	78 m	7.8 m

### 9.5.3. Test Setup and Driving Instructions

This test requires a straight crossing path road with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

#### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ , and maintain a constant speed.

3. Cross through the intersection.
4. Stop the RV after clearing the intersection.

HV Driving Instructions:

1. Position the HV in the left-hand lane on a road opposite the RV.
2. ICA-5A: Accelerate to the test speed,  $V_{HV}$ , and maintain constant speed.  
ICA-5B: Drive the HV to the stop line and wait until the RV approaches.
3. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Activate the left-turn signal, begin slowing to the target speed using the throttle and/or brakes, and start turning left into the path of the RV.
5. Maintain a constant accelerator pedal position and speed until an ICA warning, then apply the brakes to bring the HV to a stop.
6. If the vehicle has an ICA system with automatic control, ignore the expected ICA warning and maintain a constant accelerator pedal position and speed.
7. Maintain a constant accelerator pedal position when the ICA automatic control activates.
8. When the HV comes to a full stop, apply the brakes.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision.

## **10. PROCEDURES FOR NO-ACTION TEST SCENARIOS**

The purpose of the no-action test scenarios is to verify that the HV suppresses all ICA warnings and control actions in test scenarios where there is no threat of collision with the RV.

Table 8 lists the five no-action test scenarios.

Table 8: Summary of No-Action ICA Test Scenarios

Type	Test No.	Test Description
No-Action	ICA-6	Straight Crossing Paths with stopping RV
No-Action	ICA-7	SCP with stopping HV
No-Action	ICA-8	Left Turn across Path/Opposite Direction with stopping RV
No-Action	ICA-9	Both HV and RV Turning Right
No-Action	ICA-10	HV Turning Right, RV Continuing Straight

### 10.1. ICA-6: SCP, RV Slowing to Stop

This test verifies that the ICA system does not issue warnings or initiate automatic control when the HV and RV simultaneously approach an intersection and no collision threat is present. This test especially verifies the ability of the ICA system to accurately identify braking cross-path targets at a flat, straight intersection and not generate any countermeasure actions. This test is run at one set of initial conditions.

#### 10.1.1. Test Overview

The test begins with HV traveling on straight, flat road at constant speed toward an intersection. In the crossing path ahead of the HV, the RV is traveling on a straight, flat road slowing to stop before the intersection as shown in Figure 14. The HV should attain the initial test speed of  $V_{HV}$  at least 6 seconds from the intersection, measured by the corresponding range between HV and the intersection. The HV continues at constant speed towards the intersection, without cruise control, and without the test driver manually activating the brakes. The RV should attain the initial test speed of  $V_{RV}$  at least 6 seconds from the intersection, then brake manually to a stop and does not enter the intersection.

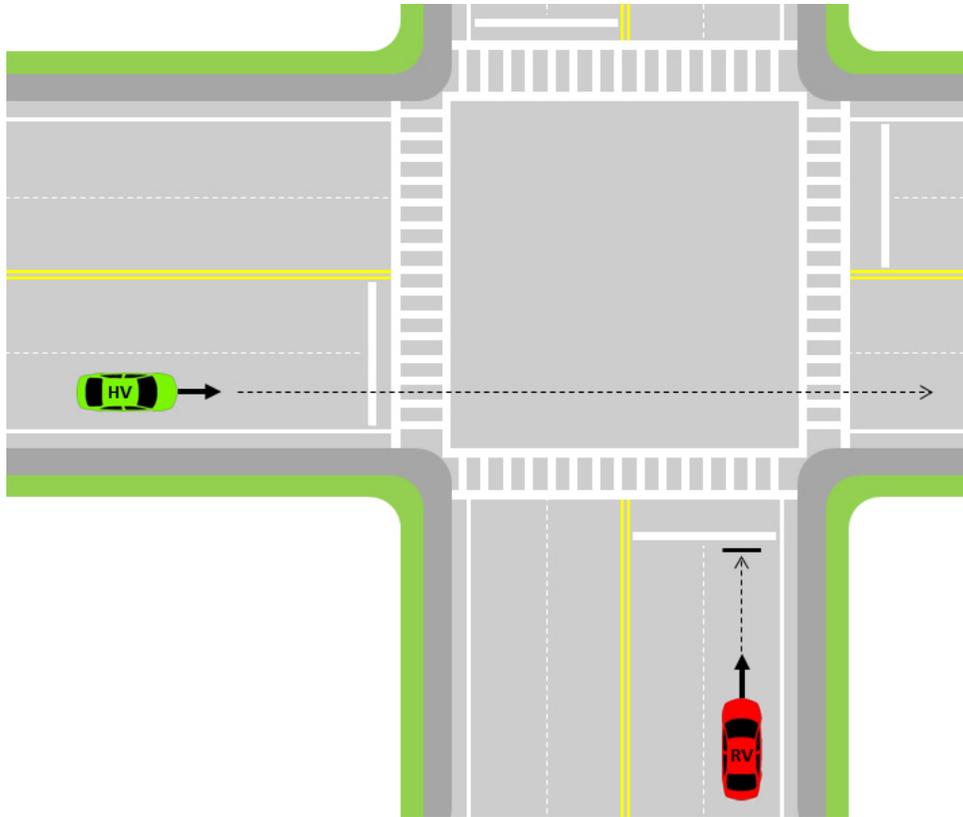


Figure 14: ICA-6 Test Initial Conditions

Figure 15 illustrates the transitional and final conditions of the test. As the HV and the RV approach the intersection, the ICA system should not trigger any countermeasure action. The HV continues through the intersection past the RV and comes to a stop.

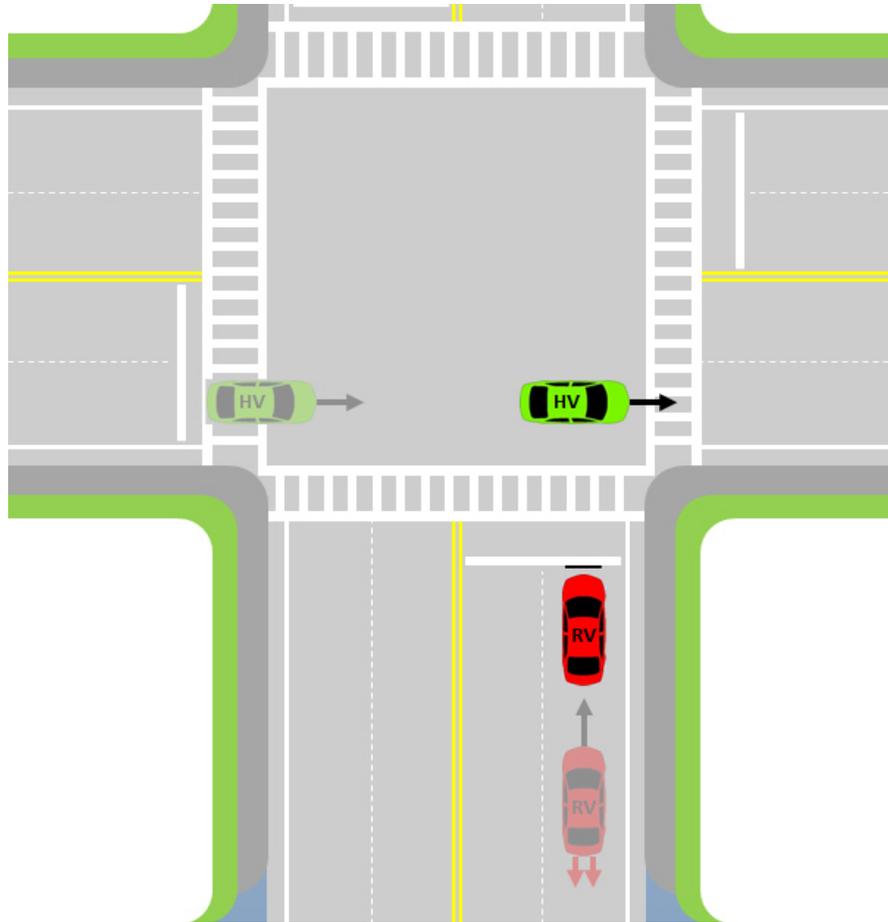


Figure 15: ICA-6 Transitional and Final Conditions

### 10.1.2. Run Validity Criteria

Table 9 shows the initial conditions for the test. The test runs are considered valid if the initial conditions are satisfied.

Table 9: ICA-6 Test Setup and Run Validity for SCP With Slowing RV Scenario

Parameter	Value	Tolerance
$V_{HV}$	35 mph	$\pm 1.8$ mph
$V_{RV}$	35 mph	$\pm 1.8$ mph
$A_{RV}$	-0.15 g	$\pm 0.1$ g

### 10.1.3. Test Setup and Driving Instructions

This test requires a straight crossing path road with a minimum of two lanes in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ .
3. Slow to a stop before entering the intersection.

### HV Driving Instructions:

1. Position the HV in the right-hand lane on a road perpendicular to the RV.
2. Accelerate to the test speed,  $V_{HV}$ , and maintain constant speed.
3. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Maintain constant speed and continue through the intersection.
5. After clearing the intersection, apply the brakes.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision.

## **10.2. ICA-7: SCP, HV Slowing to Stop**

This test verifies that the ICA system does not issue warnings or initiate automatic control when the HV and RV simultaneously approach an intersection and no collision threat is present. This test especially verifies the ability of the ICA system to accurately identify cross-path targets at a flat, straight intersection while the HV is braking and not generate any countermeasure actions. This test is run at one set of initial conditions.

### 10.2.1. Test Overview

The test begins with HV traveling on straight, flat road before braking to a stop at an intersection. In the crossing path ahead of the HV, the RV is traveling on a straight, flat road at constant speed toward the intersection, as shown in Figure 16. The HV should attain the initial test speed of  $V_{HV}$  at least 6 seconds from the intersection, measured by the corresponding range between HV and the intersection. The HV then brakes manually to a stop and does not enter the intersection. The RV should attain the initial test speed of  $V_{RV}$  at least 6 seconds from the intersection.

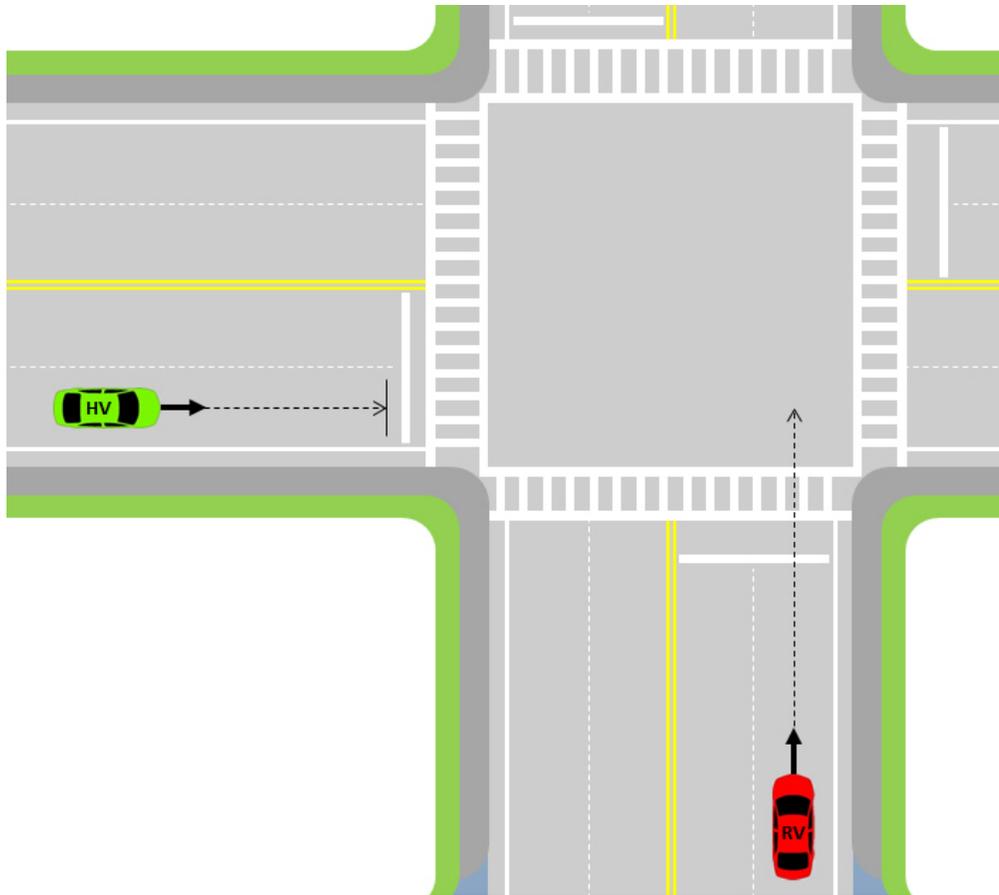


Figure 16: ICA-7 Test Initial Conditions

Figure 17 illustrates the transitional and final conditions of the test. As the HV and the RV approach the intersection, the ICA system should not trigger any countermeasure action. The RV continues through the intersection past the HV and comes to a stop.

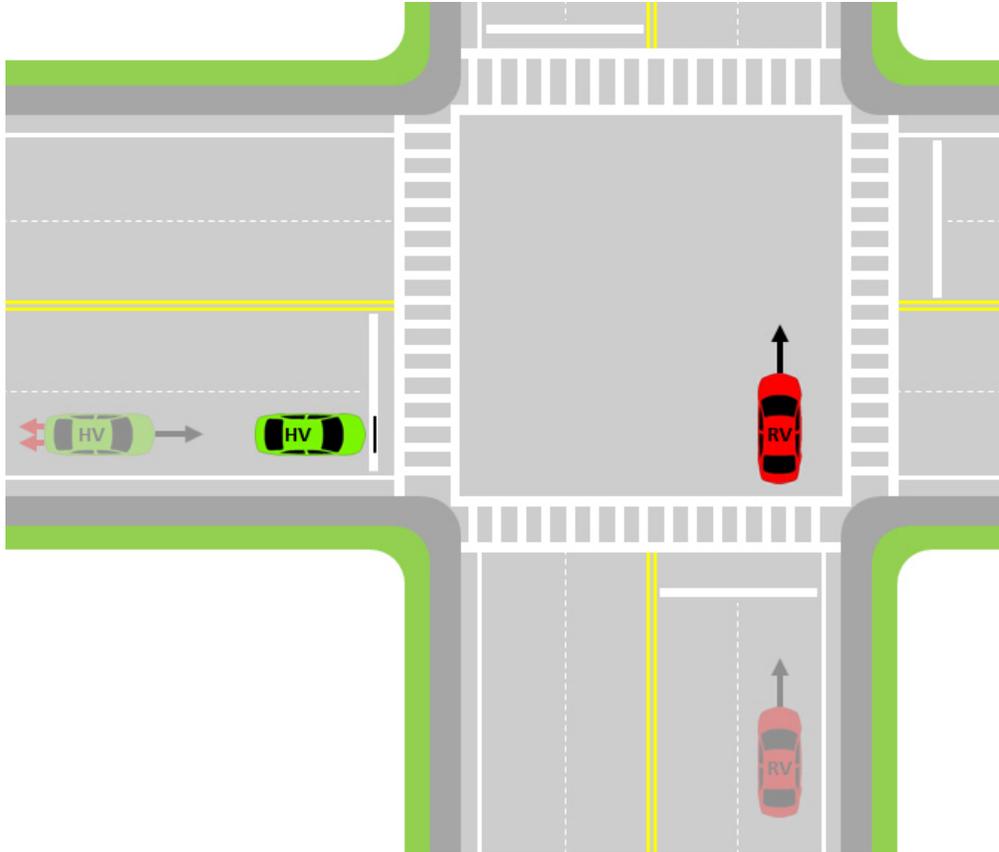


Figure 17: ICA-7 Transitional and Final Conditions

### 10.2.2. Run Validity Criteria

Table 10 shows the initial conditions for the test. The test runs are considered valid if the initial conditions are satisfied.

Table 10: ICA-7 Test Setup and Run Validity for SCP With Stopping HV Scenario

Parameter	Value	Tolerance
$V_{HV}$	35 mph	$\pm 1.8$ mph
$V_{RV}$	35 mph	$\pm 1.8$ mph
$A_{HV}$	-0.15 g	$\pm 0.1$ g

### 10.2.3. Test Setup and Driving Instructions

This test requires a straight crossing path road with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ , and maintain a constant speed.
3. Cross through the intersection.
4. Stop the RV after clearing the intersection.

### HV Driving Instructions:

1. Position the HV in the right-hand lane on a road perpendicular to the RV.
2. Accelerate to the test speed,  $V_{HV}$ , before slowing to a complete stop short of the intersection.
3. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Slow to a stop before entering the intersection.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision.

## **10.3. ICA-8: LTAP/OD, RV Slowing to Stop**

This test verifies that the ICA system does not issue warnings or initiate automatic control when the HV and RV simultaneously approach an intersection and no collision threat is present. This test especially verifies the ability of the ICA system to accurately identify braking opposite-direction targets at a flat, straight intersection and not generate any countermeasure actions. This test is run at one set of initial conditions.

### **10.3.1. Test Overview**

The test begins with HV traveling on straight, flat road at constant speed toward an intersection intending to make a left turn. In the opposite lane ahead of the HV, the RV is traveling on a straight, flat road toward the intersection as shown in Figure 18. The HV should attain the initial test speed of  $V_{HV}$  at least 6 seconds from the intersection, measured by the corresponding range between HV and the intersection. The RV should attain the initial test speed of  $V_{RV}$  at least 6 seconds from the intersection, then brake manually to a stop and does not enter the intersection.

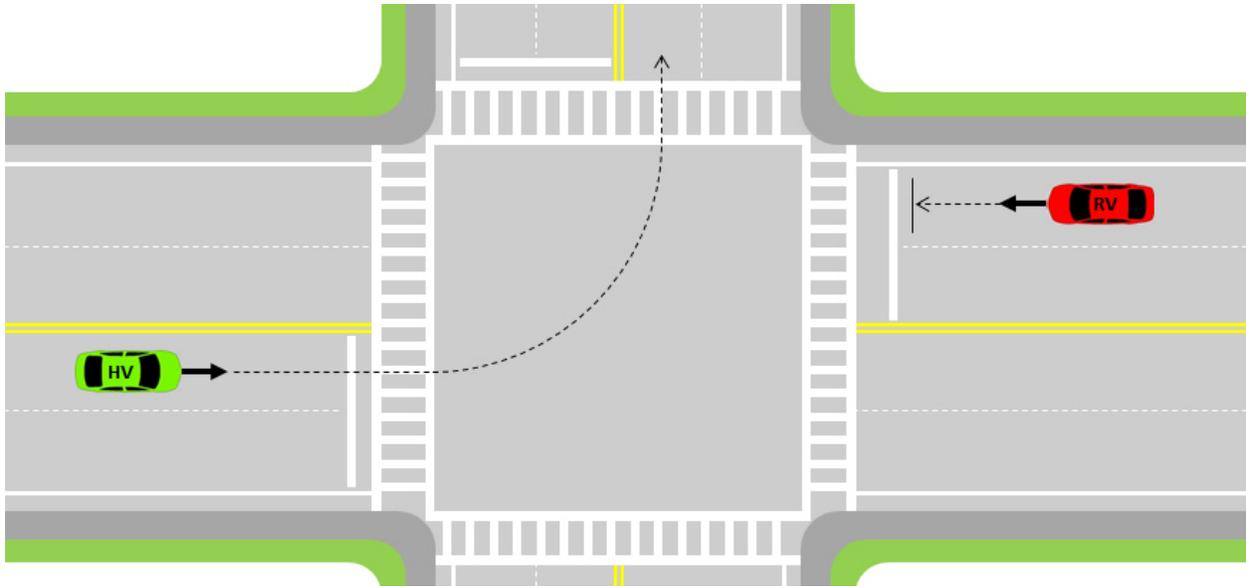


Figure 18: ICA-8 Test Initial Conditions

Figure 19 illustrates the transitional and final conditions of the test. As the HV and the RV approach the intersection, the ICA system should not trigger any countermeasure action. The HV executes a left turn through the intersection and comes to a stop.

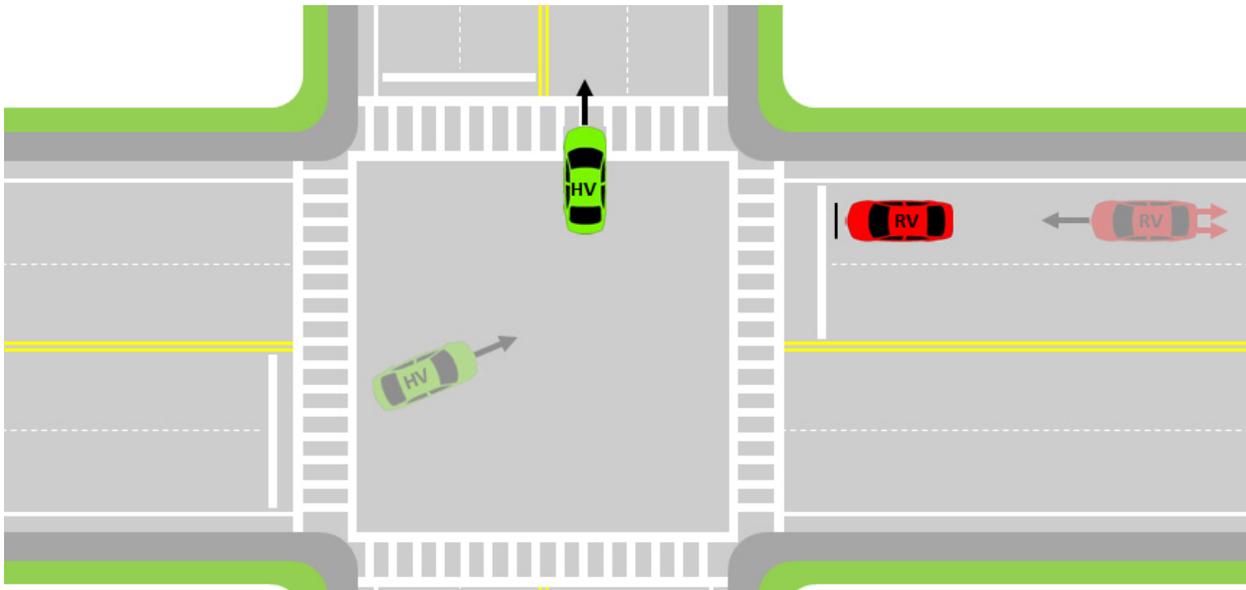


Figure 19: ICA-8 Transitional and Final Conditions

### 10.3.2. Run Validity Criteria

Table 11 shows the initial conditions for the test. The test runs are considered valid if the initial conditions are satisfied.

Table 11: ICA-8 Test Setup and Run Validity for LTAP/OD With Slowing RV Scenario

Parameter	Value	Tolerance
V <sub>HV</sub>	25 mph	±1.3 mph
V <sub>RV</sub>	25 mph	±1.3 mph
A <sub>RV</sub>	-0.15 g	±0.1 g

### 10.3.3. Test Setup and Driving Instructions

This test requires a straight crossing path road with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

#### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed, V<sub>RV</sub>.
3. Slow to a stop before entering the intersection.

#### HV Driving Instructions:

1. Position the HV in the left-hand lane on a road opposite to the RV.
2. Accelerate to the test speed, V<sub>HV</sub>, maintain constant speed, and activate the left-turn signal.
3. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Maintain constant speed and continue through the intersection.
5. After clearing the intersection, apply the brakes.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision.

### 10.4. **ICA-9: Both HV and RV Turning Right**

This test verifies that the ICA system does not issue warnings or initiate automatic control when the HV and RV simultaneously approach an intersection, both intending to turn right without any threat of collision. This test especially verifies the ability of the ICA system to accurately identify the intent of the two vehicles to turn right (as evidenced within the BSM part II “turn signal” information of HV and RV) at a flat, straight intersection and not generate any countermeasure actions. This test is run at one set of initial conditions.

#### 10.4.1. Test Overview

The test begins with HV traveling on straight, flat road at constant speed toward an intersection intending to make a right turn with the right-turn signal activated. In the crossing lane ahead of the HV, the RV is traveling on a straight, flat road at constant speed toward the intersection, as shown in Figure 20, also intending and signaling a right turn. The intended paths of the HV and RV do not cross. The HV should attain the initial test speed of  $V_{HV}$  at least 6 seconds from the intersection, measured by the corresponding range between HV and the intersection. The RV should attain the initial test speed of  $V_{RV}$  at least 6 seconds from the intersection.

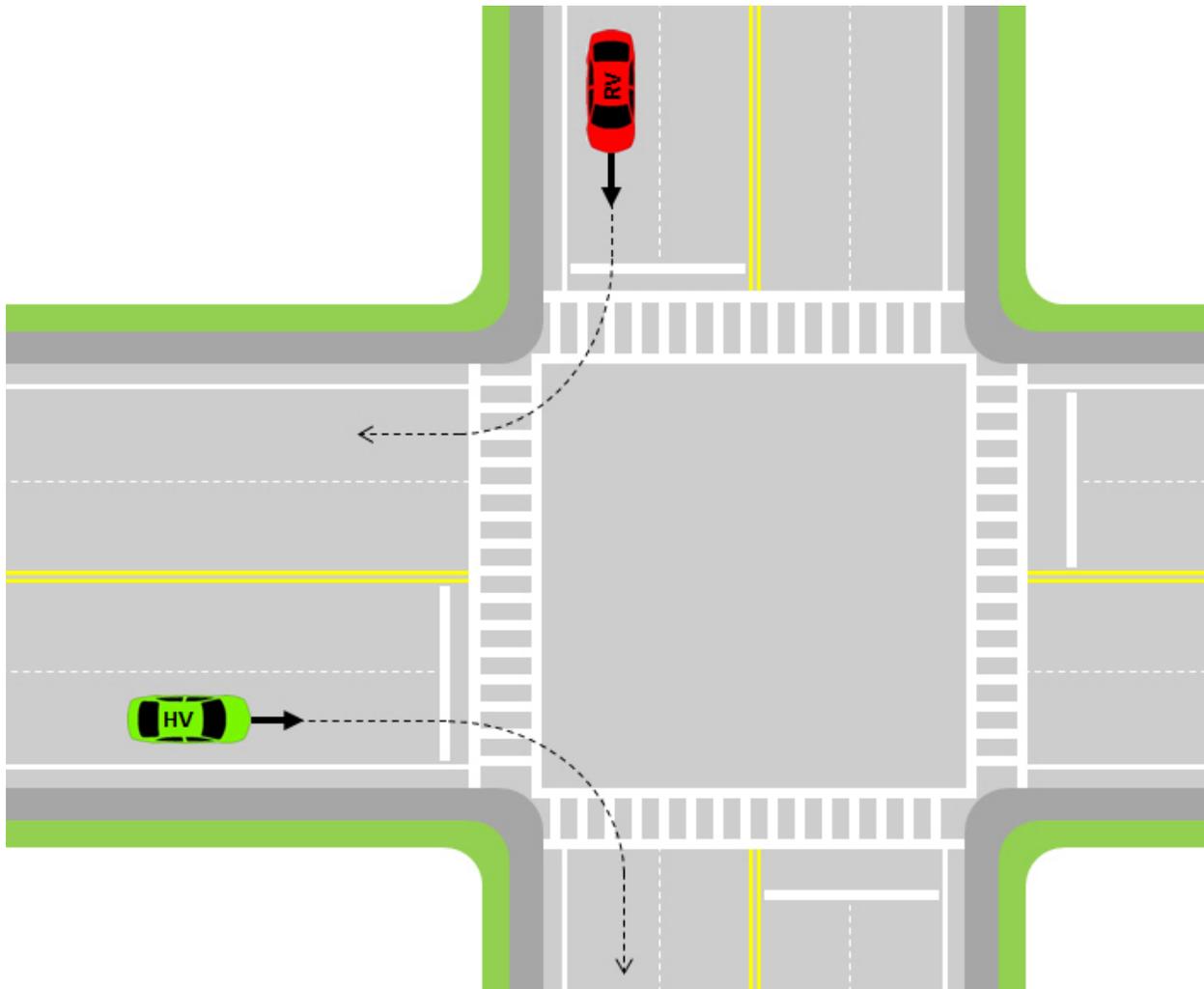


Figure 20: ICA-9 Test Initial Conditions

Figure 21 illustrates the transitional and final conditions of the test. As the HV and the RV approach the intersection, the ICA system should not trigger any countermeasure action. The HV and RV both execute right turns through the intersection and come to a stop.

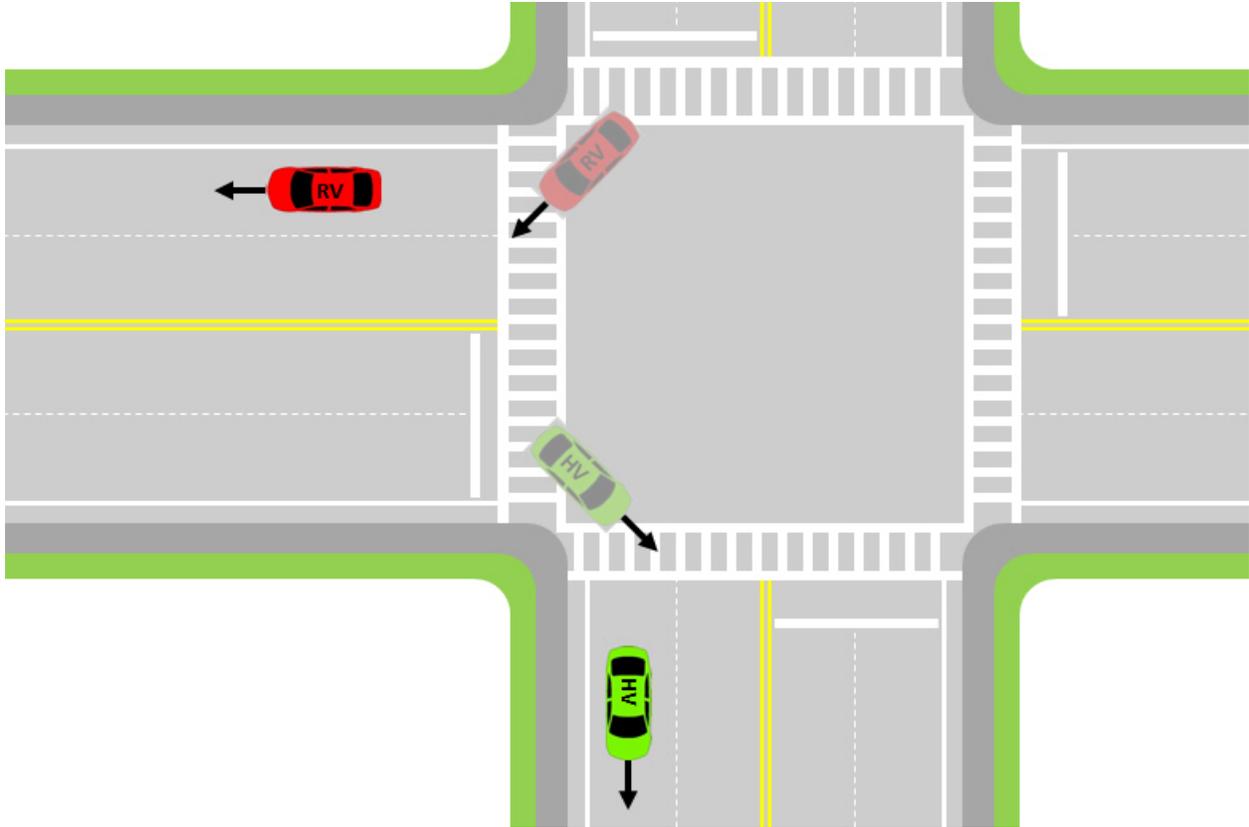


Figure 21: ICA-9 Transitional and Final Conditions

#### 10.4.2. Run Validity Criteria

Table 12 shows the initial conditions for the test. The test runs are considered valid if the initial conditions are satisfied.

Table 12: ICA-9 Test Setup and Run Validity for HV and RV Turning Right

Parameter	Value	Tolerance
$V_{HV}$	25 mph	$\pm 1.3$ mph
$V_{RV}$	25 mph	$\pm 1.3$ mph

#### 10.4.3. Test Setup and Driving Instructions

This test requires a straight crossing path road with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

##### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ , activate the right-turn signal, and maintain a constant speed.

3. Slow to the turn speed (any speed between 12 and 22 mph) then turn right at the intersection.

#### HV Driving Instructions:

1. Position the HV in the right-hand lane on a road perpendicular to the RV.
2. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
3. Accelerate to the test speed,  $V_{HV}$ , activate the right-turn signal, and maintain constant speed.
4. Slow to the turn speed (any speed between 12 and 22 mph) then turn right at the intersection.
5. After clearing the intersection, apply the brakes.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision.

### **10.5. ICA-10: HV Turning Right, RV Continuing Straight**

This test verifies that the ICA system does not issue warnings or initiate automatic control when the HV and RV simultaneously approach an intersection, HV turning right and RV going straight, and both vehicles traveling in separate lanes without any threat of collision threat. This test especially verifies the ability of the ICA system to accurately identify the intent of the HV to turn before crossing into the path of the RV at a flat, straight intersection and not generate any countermeasure actions. This test is run at one set of initial conditions.

#### 10.5.1. Test Overview

The test begins with HV traveling on straight, flat road at constant speed toward an intersection intending to make a right turn. In the right perpendicular lane ahead of the HV, the RV is traveling on a straight, flat road at constant speed toward the intersection, as shown in Figure 22. The HV should attain the initial test speed of  $V_{HV}$  at least 6 seconds from the intersection, measured by the corresponding range between HV and the intersection. The RV should attain the initial test speed of  $V_{RV}$  at least 6 seconds from the intersection.

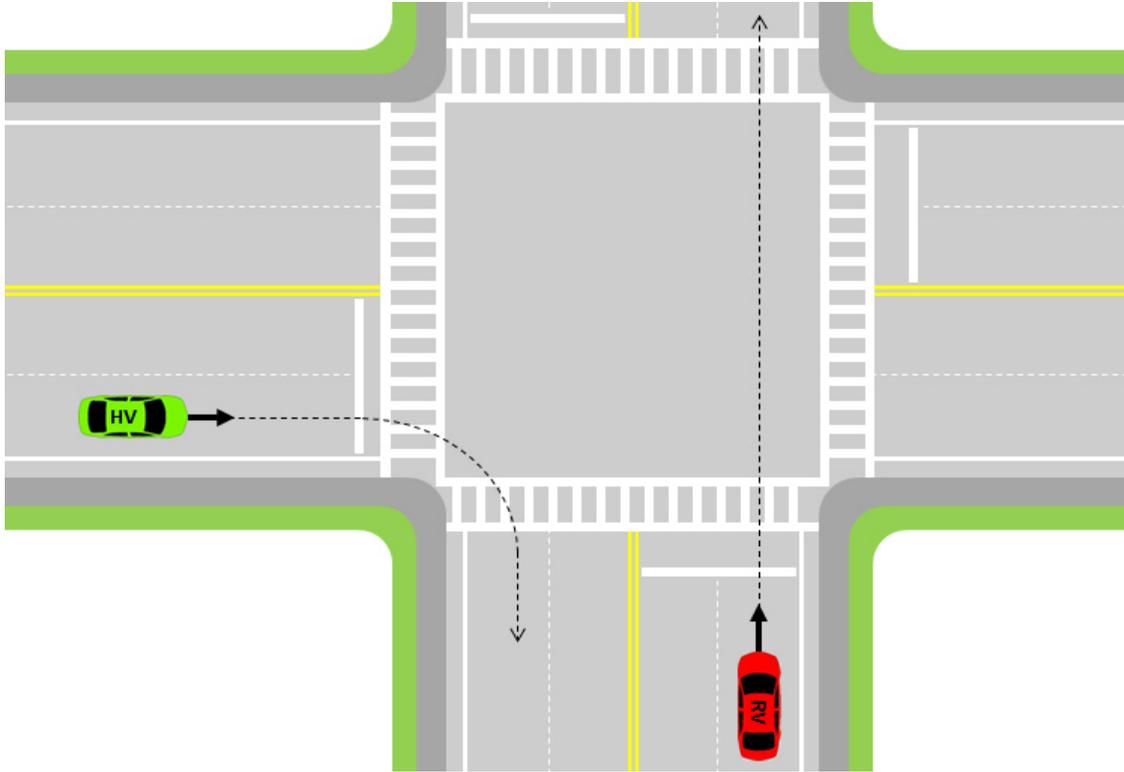


Figure 22: ICA-10 Test Initial Conditions

Figure 23 illustrates the transitional and final conditions of the test. As the HV and the RV approach the intersection, the ICA system should not trigger any countermeasure action. The HV executes a right turn through the intersection and comes to a stop.

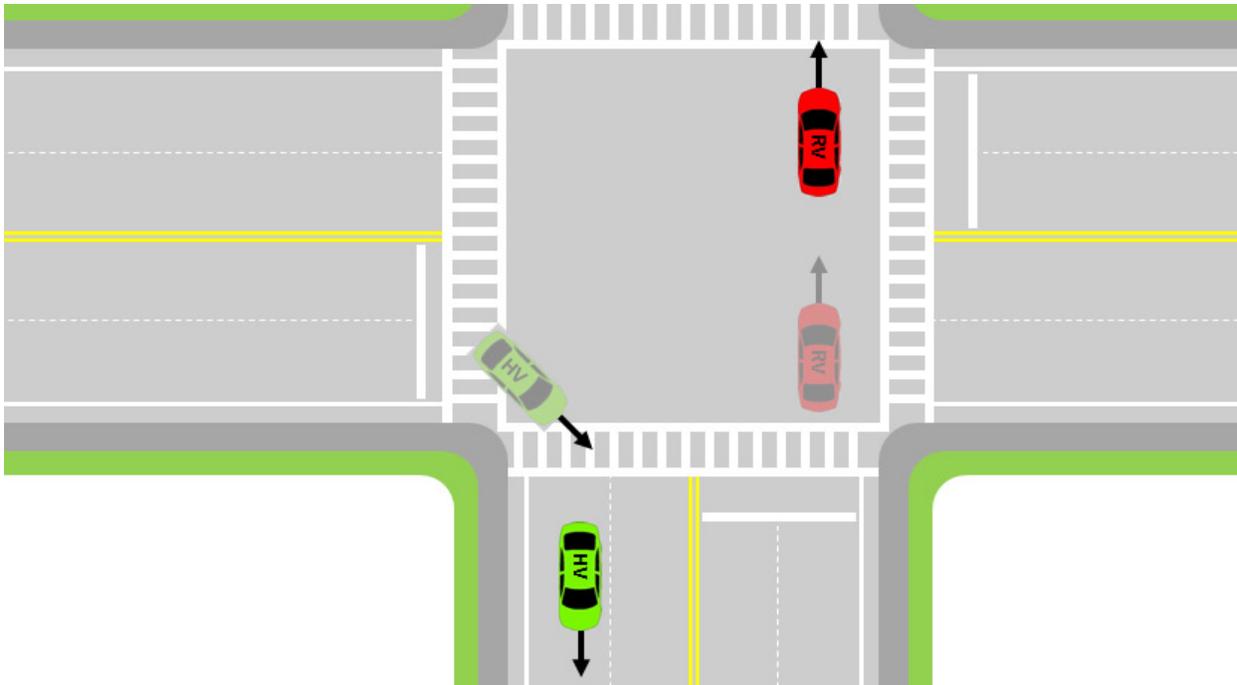


Figure 23: ICA-10 Transitional and Final Conditions

### 10.5.2. Run Validity Criteria

Table 13 shows the initial conditions for the test. The test runs are considered valid if the initial conditions are satisfied.

Table 13: ICA-10 Test Setup and Run Validity for HV Turning Right, RV Continuing Straight

Parameter	Value	Tolerance
$V_{HV}$	25 mph	$\pm 1.3$ mph
$V_{RV}$	35 mph	$\pm 1.8$ mph

### 10.5.3. Test Setup and Driving Instructions

This test requires a straight crossing path road with a minimum of one lane in each direction. The site must be sufficiently large to establish steady-state initial conditions, generate the conflict, and resolve the conflict safely.

#### RV Driving Instructions:

1. Position the RV in the right-hand lane of the test road towards the intersection.
2. Accelerate to the test speed,  $V_{RV}$ , and maintain a constant speed.
3. Cross through the intersection.
4. Stop the RV after clearing the intersection.

### HV Driving Instructions:

1. Position the HV in the right-hand lane on a road perpendicular to the RV.
2. Accelerate to the test speed,  $V_{HV}$ , and maintain constant speed.
3. The HV and the RV drivers should communicate such that vehicles arrive at the intersection at the same time.
4. Activate the right-turn signal, slow to the turning speed (any speed between 12 and 22 mph), and turn right at the intersection.
5. After clearing the intersection, apply the brakes.

At any time during the test, if the HV driver determines that the test conditions are unsafe, the HV driver manually avoids the collision.

## **11. CONCLUSION**

This report described test procedures to characterize the performance of prototype ICA systems based on V2V communications and relative positioning between the HV and RV. These procedures were initially applied to a number of prototype OEM systems on a closed-course test track, as part of Track 4 of the Connected Vehicle Safety program by NHTSA and the Intelligent Transportation Systems Joint Program Office. Based on the experience gained and lessons learned from these trials at the test track, these characterization test procedures were refined as described in this report. This test description delineated the test data variables, instrumentation, validity criteria, safety requirements, and driving instructions.

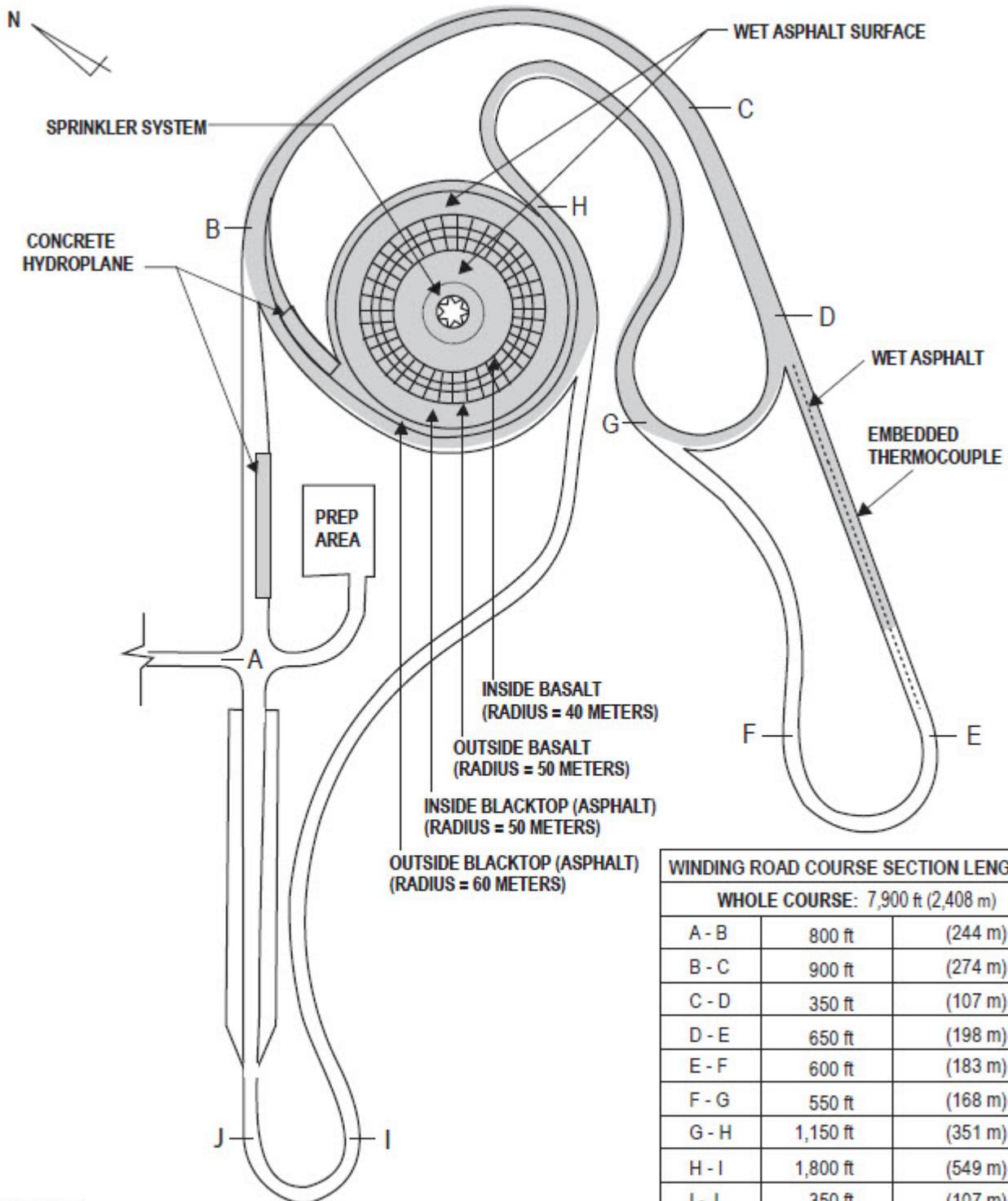
This report presented a set of crossing-path crash-imminent test scenarios (i.e., countermeasure-action scenarios) to collect data on the crash avoidance capability of the ICA systems under various initial conditions. These scenarios represented the most common crossing-path pre-crash scenarios reported in national crash databases. In addition, this report provided another set of test scenarios to collect data on the ability of the ICA systems to ignore benign driving scenarios (i.e., no-countermeasure-action scenarios).

The application of these characterization test procedures will enable data collection to better understand the capability of prototype ICA systems and help estimate their potential safety benefits. These test procedures did not incorporate pass-fail criteria that judge how well the prototype ICA systems meet some pre-determined performance requirements. Moreover, these test procedures as described in the report provided insight into ways by which V2V-based ICA applications may be evaluated on the test track. Finally, these procedures may be used by NHTSA as a basis for future system testing as part of any rulemaking activity regarding V2V-based ICA products.

## 12. REFERENCES

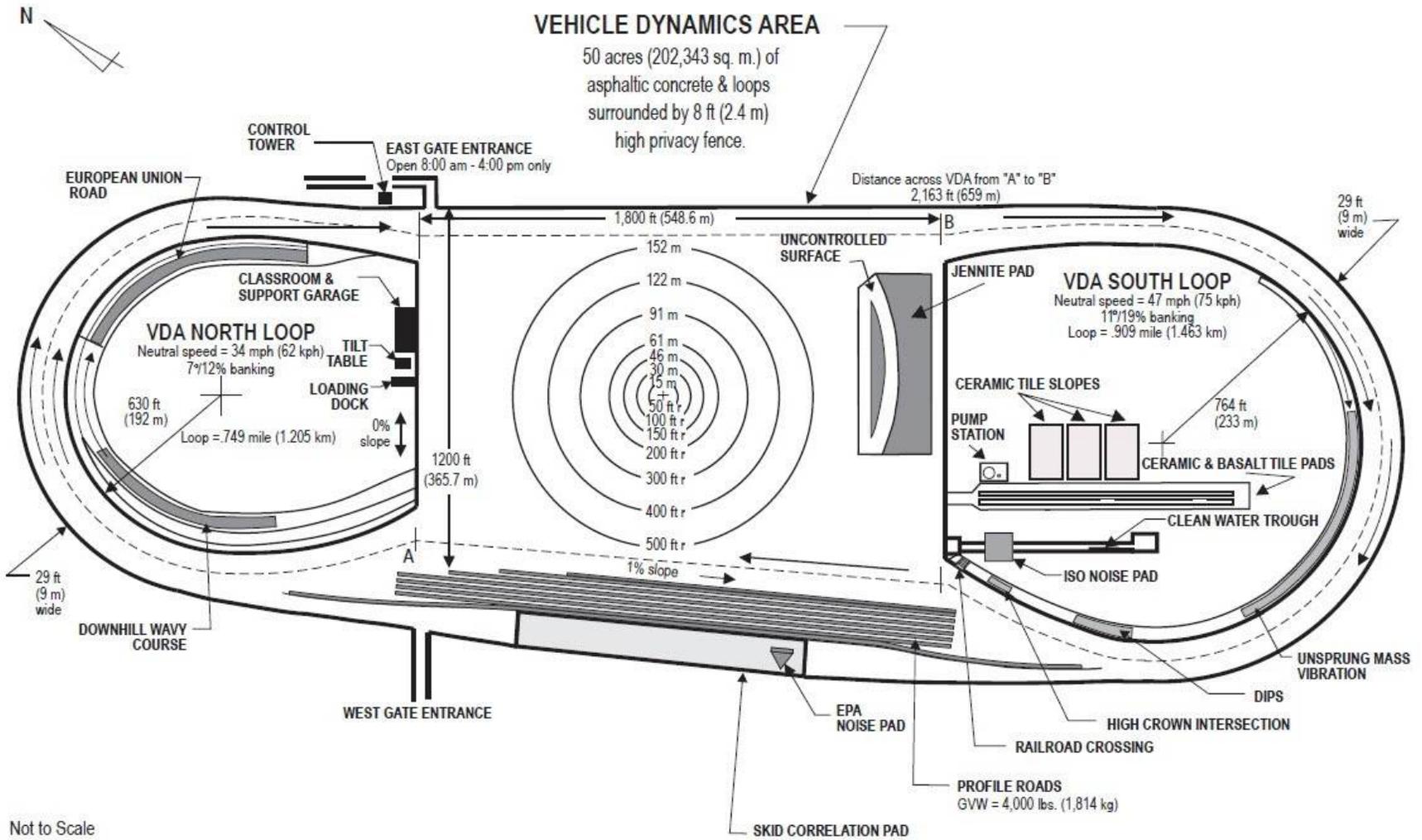
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- [2] Harding, J., Powell, G., Yoon, R., Fikentscher, J., Doyle, C., Sade, D., ... & Wang, J. (2014, August). *Vehicle-to-vehicle communications: Readiness of V2V technology for application* (Report No. DOT HS 812 014) Washington, DC: National Highway Traffic Safety Administration.
- [3] Ahmed-Zaid, F., Bai, F., Bai, S., Basnayake, C., Bellur, B., Brovold, S., ... & VanSickle, S. (2011, September).. (2010, May). *Vehicle Safety Communications – Applications (VSC-A)*. (Final Report. Report No. DOT HS 811 492A). Washington, DC: National Highway Traffic Safety Administration.
- [4] Crash Avoidance Metrics Partnership. (2011, October 10). *CAMP VSC3 – Model Deployment Safety Device DSRC BSM Communication Minimum Performance Requirements, Revision 11*. (Internal document). Washington, DC: National Highway Traffic Safety Administration.
- [5] Oxford Technical Solutions. (n.d.). *RT Inertial and GNSS Measurement Systems User Manual* (Revision 140611) Oxfordshire, UK: Author.

# Appendix A: Transportation Research Center Test Areas



WINDING ROAD COURSE SECTION LENGTHS		
WHOLE COURSE: 7,900 ft (2,408 m)		
A - B	800 ft	(244 m)
B - C	900 ft	(274 m)
C - D	350 ft	(107 m)
D - E	650 ft	(198 m)
E - F	600 ft	(183 m)
F - G	550 ft	(168 m)
G - H	1,150 ft	(351 m)
H - I	1,800 ft	(549 m)
I - J	350 ft	(107 m)
J - A	750 ft	(229 m)
D - G	300 ft	(91 m)
H - B	1,200 ft	(366 m)
B - B	3,900 ft	(1,189 m)

Not to Scale  
 Bi-Directional Course  
 A  $\mu$  value represents the Friction Coefficients on Surfaces and is subject to change according to measurement method  
 Road course shaded areas are equipped with sprinklers  
 GVW = 7,000 lbs (3,182 kgs)



## Appendix B: High-Level Functional Block Diagram of In-Vehicle Test Equipment

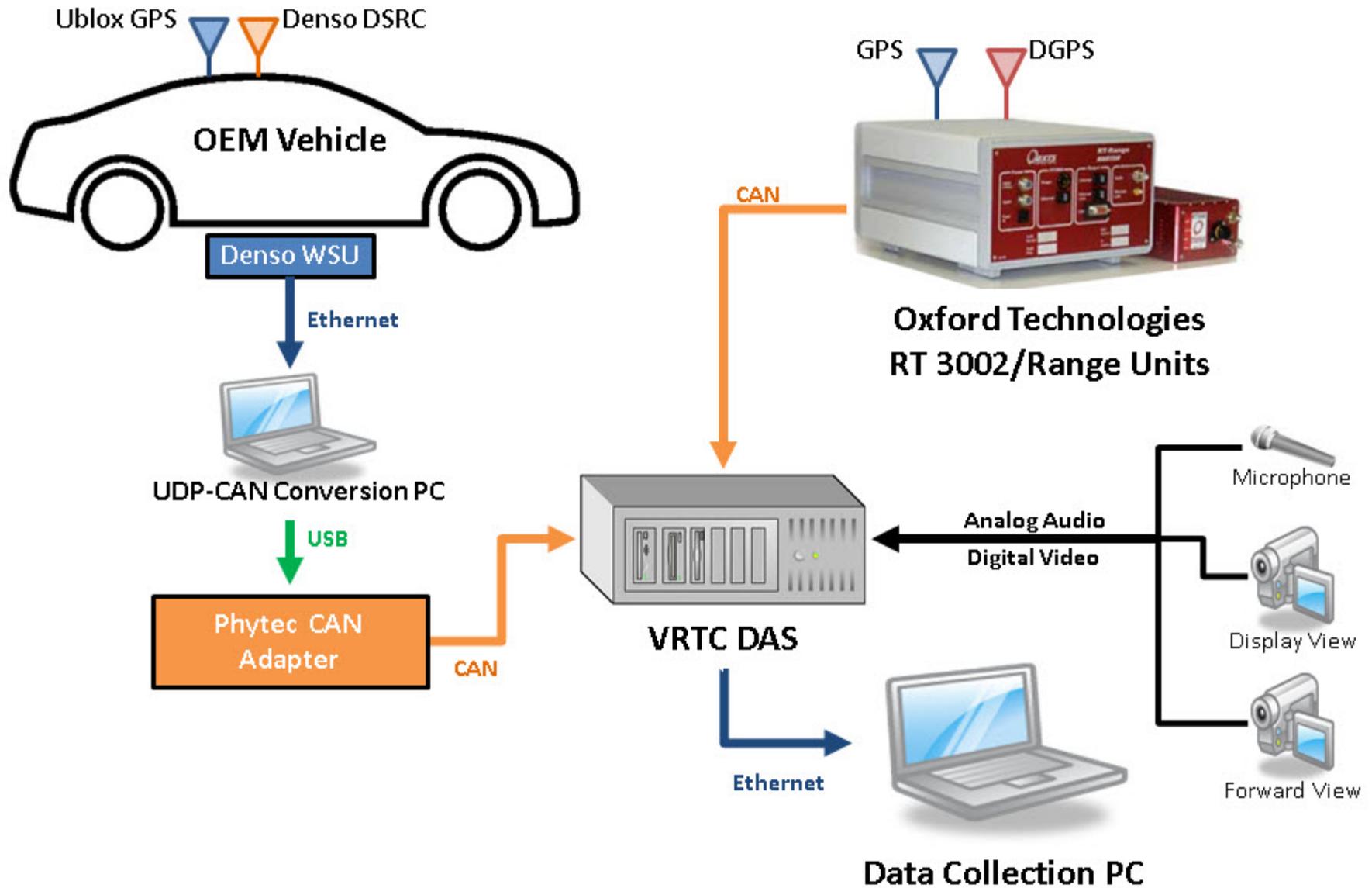


Figure 24: HV Test Equipment

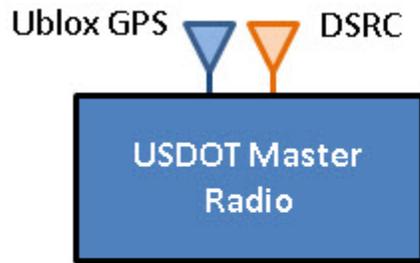


Figure 25: RV Test Equipment

## Appendix C: Track 4 DAS Data Requirements

Block	No	Parameters
In-Host Vehicle Sensors	1	Longitudinal velocity
	2	Lateral velocity
	3	Heading
	4	Longitudinal acceleration
	5	Lateral acceleration
	6	Accelerator pedal state
	7	Throttle position
	8	Brake pedal state
	9	Brake applied status
	10	Yaw rate
	11	Steering angle
	12	Turn signal state
	13	Transmission state
	14	ABS state
	15	Traction control state
	16	Electronic stability control state
	17	Cruise control state
ICA Controller	18	BSM of host vehicle
	19	BSM of all remote vehicles
	20	ICA system status
	21	Predicted path of host vehicle
	22	Target ID for all remote vehicles
	23	Target status for all remote vehicles
	24	Target range for all remote vehicles
	25	Target range rate for all remote vehicles
	26	Target longitudinal acceleration for all remote vehicles
	27	Target yaw rate for all remote vehicles
	28	Threat level (alert and/or control)
	29	Transmission control messages
	30	Throttle control messages
	31	Brake control messages
	32	DVI messages

DOT HS 812 223  
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U.S. Department  
of Transportation  
**National Highway  
Traffic Safety  
Administration**

