U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

NHTSA

DOT HS 812 276 **May 2016**

Commercial Connected-Vehicle Test Procedure Development and Test Results – Intersection Movement Assist

Disclaimer

Suggested APA Format Citation:

Howe, G., Xu, G., Hoover, R., Elsasser, D., & Barickman, F. (2016, May). *Commercial connected-vehicle test procedure development and test results – Intersection movement assist* (Report No. DOT HS 812 276). Washington, DC: National Highway Traffic Safety Administration.

Technical Report Documentation Page

1. Report No. DOT HS 812 276	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Commercial Connected-Vehicle Test Procedure Development and Test Results – Intersection Movement Assist		5. Report Date May 2016 6. Performing Organization Code NHTSA/NVS-312
7. Authors Gavin Howe, Guogang Xu, and Dick Hoover of Transportation Research Center Inc. and Devin Elsasser and Frank Barickman of National Highway Traffic Safety Administration		8. Performing Organization Report No.
9. Performing Organization Name and Address National Highway Traffic Safety Administration Vehicle Research and Test Center P.O. Box 37 East Liberty, OH 43319		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE. Washington, DC 20590		13. Type of Report and Period Covered: Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

The authors would like to acknowledge the efforts of Randy Landes, Thomas Gerlach, Charles Feeney, Don Thompson, Michael Thompson, Nathan Rae, and Preston Shobe for their efforts in completing this research.

16. Abstract

This report is one of four that documents NHTSA's test track research performed to support development of objective test procedures to evaluate the safety applications of commercial vehicles with vehicle-to-vehicle (V2V) equipment. The primary focus of this research was on developing the test procedures, with a secondary goal of evaluating the performance of the prototype V2V safety applications. Objective test procedures were developed to evaluate a range of safety applications including intersection movement assist (IMA), blind spot warning/lane change warning (BSW/LCW), forward collision warning (FCW), and emergency electronic brake light (EEBL) warning. This report documents the IMA test procedures and the results of testing commercial vehicles with the developed procedures.

The prototype V2V equipment was observed to track potential IMA threats, but the IMA warnings and alerts issued from the V2V equipment on the trucks evaluated in this study occurred very early. Due to the early warnings it was not possible to fully evaluate some of the test procedures.

Future testing with commercial vehicles equipped with V2V technology will be required to fully develop the IMA objective test track procedures and performance metrics.

17. Key Words: Commercial Connected Vehicles, vehicle-to-vehicle, V2V, vehicle-to-infrastructure, V2I, V2X, intersection movement assist, IMA		18. Distribution Statement: This document is available to the public from the National Technical Information Service, www.ntis.gov	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 150	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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List of Acronyms

ASD – aftermarket safety device

BSW – blind spot warning

CAN – controller-area-network

CCV – commercial connected vehicles

DSRC – dedicated short-range communication

DGPS – differential global position system

DVI – driver-vehicle interface

EEBL – electronic emergency brake light

FCW – forward collision warning

GNSS – global navigation satellite system

GPS – global positioning system

GVWR – gross vehicle weight rating

GAWR – gross axle weight rating

HV – host vehicle

ICA – intersection collision avoidance

IMA – intersection movement assist

IMU – inertial measurement unit

ISS – integrated safety equipment

LCW – lane change warning

LCM – lane change-merge

OBE – on-board equipment

PCAP – packet capture

RSD – retrofit safety device

RV – remote vehicle

TTC – time-to-collision

TTC_{NA} – time-to-collision no acceleration

V2V – vehicle-to-vehicle

V2I – vehicle-to-infrastructure

V2X – V2V and/or V2I and/or other communication capabilities

VAD – vehicle awareness device

VRTC – Vehicle Research and Test Center

WSU – wireless safety unit

Executive Summary

The National Highway Traffic Safety Administration is developing test procedures to evaluate the safety applications of vehicle-to-vehicle equipped commercial vehicles. For this research, a commercial vehicle is defined as a medium or heavy truck (including tractor-trailer combinations) or bus with a gross vehicle weight rating of more than 10,000 pounds. The primary focus of this research was on developing the test procedures, with a secondary goal of evaluating the performance of the prototype V2V safety applications. Objective test procedures were developed to evaluate a range of safety applications including intersection movement assist, blind spot warning/lane change warning, forward collision warning, and emergency electronic brake light warning. This report documents the IMA test procedures and the results of testing commercial vehicles equipped with prototype V2V equipment with the developed procedures. An initial set of 6 IMA test scenarios were selected and test procedures were developed. A series of intersection collision avoidance maneuvers that were being developed by OST-R [5] for evaluating IMA safety applications were also evaluated as part of this study. Two false positive test procedures were also developed as a result of reviewing data from the model deployment study. One was designed to evaluate a bridge scenario and the other a highway on-ramp scenario.

The primary test vehicles for the V2V study were two Freightliner Cascadia Class 8 tractors that were initially used in the model deployment study [1]. One was used as a host vehicle (HV – test subject) and the other was generally used as a remote vehicle (RV – collision threat). A 2007 Honda Odyssey equipped with a vehicle awareness device was also used as an RV. For IMA/ICA testing the Honda Odyssey was the generally the RV.

In general, the V2V equipment tracked the potential IMA threats, but the IMA warnings and alerts issued from the V2V equipment on these trucks occurred very early, especially for lower speed tests, and well before when a driver would normally begin to slow down for a stop or turn at an intersection.

The alerts also did not extinguish after the driver had taken corrective action and had slowed the vehicle enough that the collision threat had been diminished.

The IMA bridge test procedure was the one scenario where the V2V equipment did not track an IMA threat, due to the V2V equipment failing to recognize that the vehicles were not on a collision course since one vehicle was on the bridge and the other was going beneath the bridge.

Due to the early warnings it was not possible to conduct or fully evaluate several of the test procedures, especially the false positive tests that were designed to determine if the V2V equipment could suppress warnings/alerts.

Future testing with commercial vehicles equipped with V2V technology will be required to fully develop the IMA objective test track procedures and performance metrics.

1 Introduction

This report documents NHTSA's test track research performed to support development of objective test procedures to evaluate the safety applications of V2V-equipped commercial vehicles. The tests were to be developed to evaluate the various safety applications available in V2V systems including IMA, BSW/LCW, FCW, and EEBL warning. This report documents the results of IMA testing. An initial set of six IMA tests scenarios were selected and test procedures were developed. In *Characterization Test Procedures for Intersection Collision Avoidance Systems Based on Vehicle-to-Vehicle Communications* [5] a series of ICA maneuvers are documented that were being developed for evaluating IMA safety applications and these test procedures were also evaluated as part of this study. Two false positive test procedures were developed to evaluate a bridge and a highway on-ramp scenario. The bridge test is designed to see if the V2V systems will falsely produce IMA alerts as vehicles pass over/under bridges and the highway on-ramp scenario is designed to see if the V2V systems will falsely produce IMA alerts on vehicles driving on the highway by vehicles entering the highway on a clover leaf type on-ramp.

2 Test Vehicles

The primary test vehicles for the V2V study were two Freightliner Cascadia Class 8 tractors (Example shown in Figure 1). One was a mid-roof sleeper and the other was a day cab. The two Freightliners were initially developed for the U.S. DOT Safety Pilot Program under a contract with Battelle in 2011 and were used in the heavy truck Driver Clinics and Model Deployment study. A summary of the vehicle build is presented below including a brief overview of the V2V equipment on the tractors. Further details are provided in *Connected Commercial Vehicle Integrated Truck Project – Vehicle Build and Build Test Plan Final Technical Report* [1].

Figure 1: Freightliner Cascadia

Vehicle data for the two Freightliner Cascadia trucks used in this V2V study are listed in Table 1. Vehicle data include cab configuration, VIN, color, build date, GVWR, GAWR for each axle, and tire size.

Table 1: Freightliner Cascadia Vehicle Data

Cab Configuration	VIN	Color	Build Date	GVWR (lbs)	GAWR (lbs)			Tire Size
					Front	1st	Rear	
Mid-Roof Sleeper	1FUJGHDV0CLBP8896	Red	12/11	52,000	12,000	20,000	20,000	295/75R22.5
Day Cab	1FUJGBDV8CLBP8898	Blue	12/11	52,000	12,000	20,000	20,000	295/75R22.5

The Cascadia trucks were delivered to VRTC after the model deployment study. The vehicles were equipped with prototype on-board equipment that enables safety and other applications by supporting: safety and other applications' processes, V2V or V2I communications, vehicle positioning, communications security, J1939 interface for vehicle data, data acquisition and recording, input of vehicle configuration, and both visual and auditory driver notifications. The V2V communications were performed with a pair (primary and secondary) of Denso dedicated short-range communication radio/computer platforms called mini wireless safety units model 1.5, each of which has a single board computer and a two-channel 5.9 GHz DSRC radio. Vehicle positioning was performed with a differential global position system receiver (Novatel OEMV-1 FlexPak-G2-L1). The data acquisition system logger in the OBE was not used as part of this study. Instead, an extended version of the VRTC-owned data acquisition equipment was applied and is detailed in Chapter 3. For the driver vehicle interface, a wireless, dash-mounted tablet display with touchscreen (I-Pad) was used to input vehicle parameters (cab configuration and trailer length) and to provide visual driver notification of various alert types including IMA, BSW, EEBL, and FCW. The cab configuration and trailer length are selectable because the WSU broadcasts the vehicle size (length and width), which is represented as a single rigid body that is adjusted based on the vehicle configuration and trailer (or trailers – double 28' trailers are an option on the DVI) selected by the driver through the DVI. The rigid-body model was used because the trailers are not equipped with V2V systems and the WSU does not estimate the angle of articulation between the tractor and a towed semi-trailer. This study did not investigate how an articulated model representing the tractor and trailer as two bodies (or three bodies in the case of double trailers) would affect system performance or how it would affect the development of objective test procedures. The OBE system architecture is shown in Figure 2. Example IMA application Level 2 "Inform" and Level 3 "Warning" icons that are displayed on the tablet are shown in Figure 3. These icons show a remote vehicle approaching from the left. Similar icons also show the remote vehicle approaching from the right.

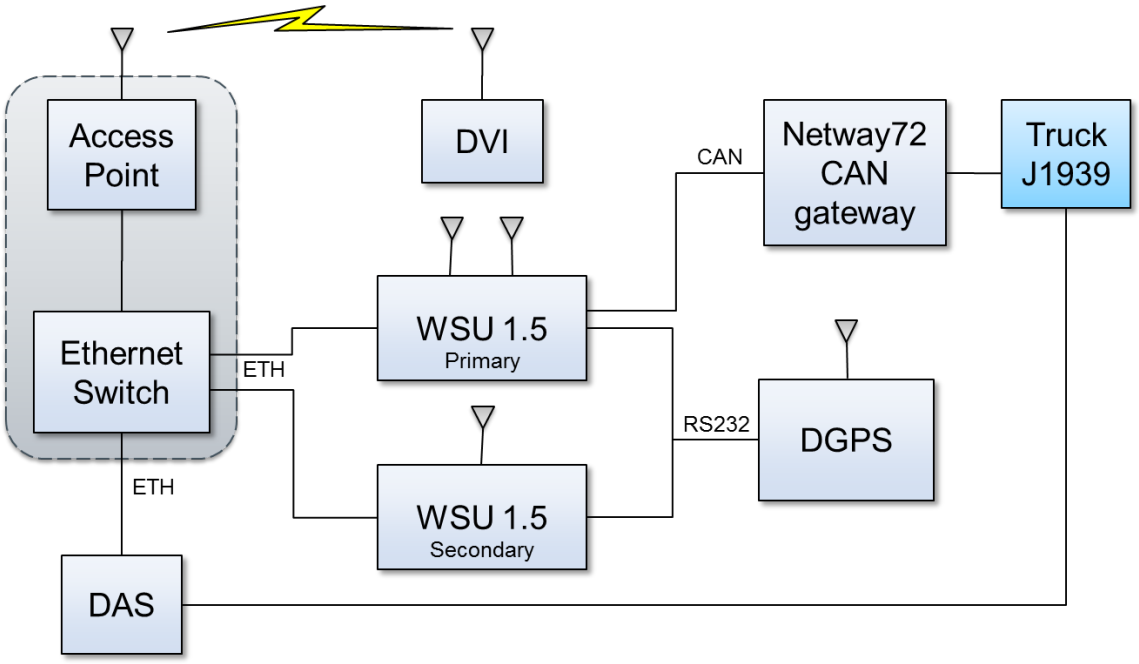


Figure 2: OBE System Architecture

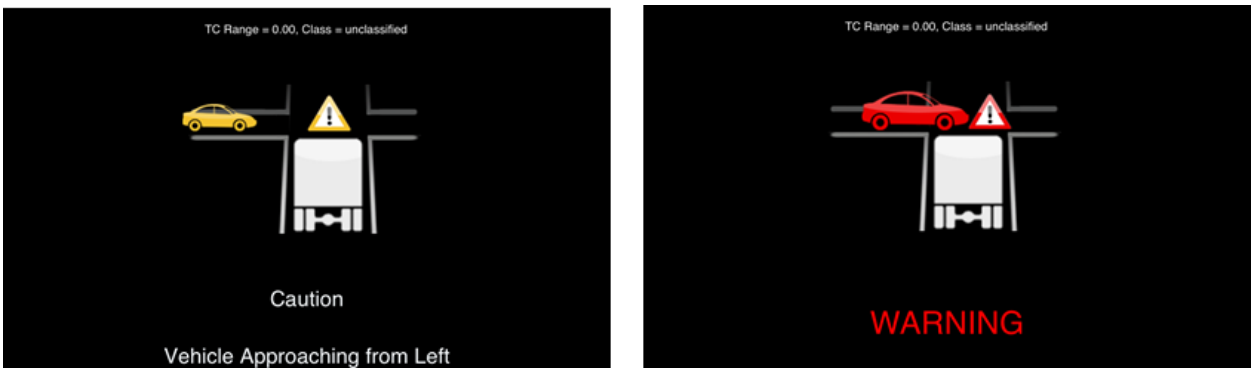


Figure 3: "Inform" Level 2 Alert and "Warning" Level 3 Alert [2]

A third vehicle was also used in testing: a 2007 Honda Odyssey LX mini-van (VIN 5FNRL382X7B104352). The Odyssey had a 3.5L V6 SOHC 24V engine, 4-wheel ABS disc brakes, and a curb weight of 4384 lbs. The Odyssey was equipped with a Denso WSU vehicle awareness device, Model: WSU-015 (A) and S/N: 10364.

3 Instrumentation

Data from three different GNSS receivers were collected during the course of this study. They are labeled RT, GPS, and WSU. The following sections briefly described how this data were collected.

3.1 RT Data Collected on UEI

A United Electronic Industries "Cube" data acquisition system was installed to collect data from the numerous data sources. The J1939 truck CAN bus (on –the HV Red Cascadia tractor) was monitored to identify truck health and activity signals. A second CAN bus interfaced the Oxford Technologies RT Hunter differential GPS unit, while a third CAN bus interface merged the independent RT 3000 inertial measurement unit (IMU) data. The data from the RT Hunter and the RT 3000 is referred to as RT data. For each remote vehicle (Blue Cascadia and Honda Odyssey), an RT 3000 was connected to an RT Target box, which broadcasts its data stream wirelessly and is collected on the RT Hunter box.

3.2 GPS Data

For each vehicle, a single Novatel ProPak-V3 RT2 triple-frequency GNSS receiver (without IMU) was separately monitored through USB connection to the laptop PC. A magnetically roof-mounted Pinwheel antenna (GPS-702-GG) combined both L1 and L2 GPS frequencies with GLONASS for signal reception. The data from this set up is referred to as GPS data.

3.3 WSU Data

On the Cascadia tractors, the Denso WSU output DAS packets that were collected on a laptop computer through a hardwired Ethernet. The DAS packets included V2V basic safety messages and some intermediate data. A laptop computer was used to collect the data saved as packet capture (PCAP) files. The PCAP files were parsed during data post processing. The parsed data contained position, speed, acceleration, heading, tracking, and alert data, amongst other channels.

4 Timing of Intersection Warnings

The following is excerpted from a NHTSA-sponsored intersection collision avoidance study, *Intersection Collision Avoidance Using ITS Countermeasures Final Report: Performance Guidelines* [3]. While not specifically stated below the speed limits at the intersections being discussed in the following are 35 mph.

> "The timing of a driver warning is critical to its usefulness. A warning too late in the intersection approach sequence will not allow adequate time for the driver to respond to a stop requirement. Warnings given too early can violate the expectations of drivers who intend to comply with the stop requirement.
>
> The following delineates an on-road baseline study that was an initial step in determining when driver warnings can be implemented during an intersection approach [4]. This on-road baseline study monitored driver input to vehicle controls during the approach to stop sign-controlled intersections.
>
> The data showed that, while driver inputs occurred over a relatively wide range of time, the range of standard deviations from the mean values was narrow (e.g., standard deviations for throttle release and brake application were 1.21 and 0.91 seconds, respectively). On the average, drivers released the accelerator approximately nine seconds prior to intersection entry and applied the brakes two seconds later. Steering input occurred significantly later in the approach. This tended to preclude the usefulness of steering input as a predictive cue for determining the timing of warnings to drivers.
>
> A timeline of driver control input was constructed to determine the feasibility of providing warnings to the driver in time for compliance with the intersection traffic control (stop sign). This time line is depicted in Figure 4.

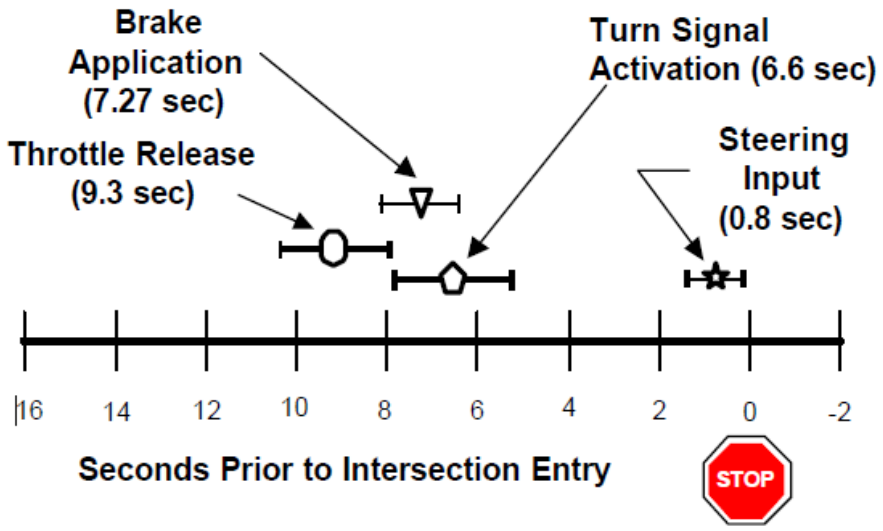


Figure 4: Timeline of Control Inputs during Intersection Approach

Examining the timeline, it may be seen that input to throttle and brakes occur in a relatively narrow time band (i.e., 7 to 9 seconds prior to intersection entry). This implies

that a sufficient temporal span is typically available to both alert drivers of a stop requirement and allow drivers to manually react to the warning.

Control input events occur at a considerable distance from intersection entry. Mean throttle release was 68 meters (227 feet) from the intersection and brakes were applied 50 meters (165 feet) prior to entry. Interestingly, turn signals were activated after these events, at 46 meters (154 feet). Maximum longitudinal acceleration applied by the drivers were within a very narrow band. All subjects, with one exception, utilized -0.2 +/- 0.05g during braking maneuvers. The distances indicated above provide an opportunity to present alerts/warnings to the driver, and potentially prevent traffic control violation under manual braking.

….

The results also provide insight regarding how driver control inputs can be used to set threshold levels for transmission of warnings to drivers. Thresholds, it is important to note, should be set so as not to violate the expectations of the driver. Specifically, warnings should be presented after drivers would normally make control inputs. Premature presentation of warnings may be viewed as false, or nuisance alarms, hence decreasing the perceived value of the warning and reducing drivers' acceptance of the collision avoidance system (likewise—in keeping with the psychological refractory period (PRP) phenomenon—they could serve to delay driver inputs)."

Research in this area has continued and is continuing and will be important in the development of IMA test procedures and in particular evaluation metrics related to the timing of alerts and warnings. It should be noted that the above research was conducted for passenger vehicles and commercial vehicle drivers may tend to stop earlier.

5 Intersection Collision Avoidance Results

The ICA test procedures evaluated were developed by OST-R and are documented in *Characterization Test Procedures for Intersection Collision Avoidance Systems Based on Vehicle-to-Vehicle Communications* [5].

The report documents 10 ICA test procedures with each procedure having multiple test conditions. The test procedures:

- ICA-1: Straight Crossing Paths
- ICA-2: Right Turn Into Path
- ICA-3: Left Turn Into Path
- ICA-4: Left Turn Across Path/Lateral Direction
- ICA-5: Left Turn Across Path/Opposite Direction
- ICA-6: Straight Crossing Paths, RV Slowing to Stop
- ICA-7: Straight Crossing Path, HV Slowing to Stop
- ICA-8: Left Turn Across Path/Opposite Direction RV Slowing to Stop
- ICA-9: Both HV and RV Turning Right
- ICA-10: HV Turning Right, RV Continuing Straight

Some details for each procedure are presented below, but the reader should refer to the report listed above for further details. The figures that diagram the test procedures shown below are taken directly from that report.

In the following discussion HV and RV are used to distinguish the roles of different vehicles in testing. An HV is a vehicle that carries a V2V system (ISS or RSD - definitions for the V2V system types can be found in Appendix A, Section A.3) and is the test subject. An RV is a vehicle that carries a V2V system (ISS, RSD, ASD, or VAD), and represents a collision threat to the HV. The RV V2V system broadcasts many data elements including the RV's position, speed, direction of travel, and path history. The HV V2V system features an IMA application.

The ICA-1 through ICA-5 test procedures are crash-imminent test scenarios to characterize the behavior of the HV to detect a collision threat, while the ICA-6 through ICA-10 procedures are no-action test scenarios that should result in the HV suppressing all warning/alerts.

The test vehicles for all of the ICA tests:

- HV = Red Freightliner Cascadia with WSU, and
- RV = Honda Odyssey with Denso VAD.

5.1 ICA-1: Straight Crossing Paths

The ICA-1 test begins with the 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 Figure 5.

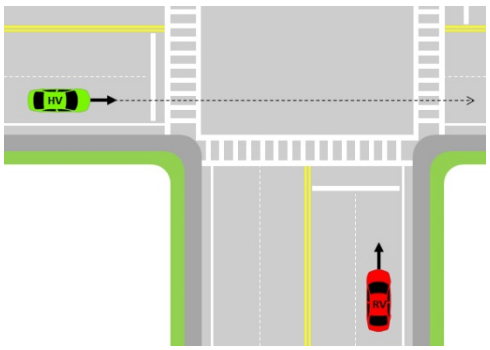


Figure 5: ICA-1A Test Initial Condition

Five test conditions for this scenario are detailed in Table 2. The ICA-1A Tests 1 through 3 have the HV moving toward the intersection and the ICA-1B Tests 1 and 2 have the HV sitting at the intersection and pulling into the intersection as the RV approaches.

Table 2: ICA-1 Test Conditions

	ICA-1A Test 1		ICA-1A Test 2		ICA-1A Test 3		ICA-1B Test 1		ICA-1B Test 2	
Parameter	Value	Tolerance	Value	Tolerance	Value	Tolerance	Value	Tolerance	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

5.1.1 ICA-1A Test 1: V_{HV}=25, V_{RV}=25

The HV and RV TTC to Intersection and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 3. The TTC and range values are based on the WSU data. RT, GPS, and WSU data for the Level 2 and Level 3 Alert onsets and offsets are given in Appendix B, Section B.1.1. Four tests were conducted for ICA-1A Test 1. Since the HV and RV speeds are the same (25 mph), the range to intersection values at alert onset should be fairly similar if the vehicles were to arrive at the intersection at the same time. This was generally the case except for Test 1272, where the RV Range to Intersection is much lower than the HV range (58 versus 81 meters). Despite the earlier RV arrival, the HV alert occurred in the same range of values for HV TTC and Range to Intersection for this test as it did for the others. The HV TTC was very consistent with an average value of 7.4 seconds and a standard deviation less than 0.1 seconds, giving a coefficient of variation of 0.5 percent.

Table 3: ICA-1A Test 1 WSU Based TTC, Range, and RT Speeds at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1271	7.4	7.6	82	82	25.0	24.6
1272	7.4	5.2	81	58	25.0	25.0
1273	7.3	6.8	81	76	24.7	25.1
1274	7.4	7.7	82	84	25.0	24.6
Ave.	7.4	6.8	81	75	24.9	24.8
Std.	0.0	1.2	1	12	0.2	0.3
C. of V. (%)	0.5	16.9	1	16	0.6	1.1

A vehicle position map for Test 1273 is shown in Figure 6. The position of the HV and RV at the alert onsets and offsets are shown (yellow vehicle – Level 2, red vehicle – Level 3, blue vehicle – Alert Off) as well as a line across the road designating when the HV and RV drivers applied the brakes. The data represented in the plot show that the alerts come on very early and much earlier than what would happen if the HV was doing a normal stop at the intersection. As shown in the figure, the HV was observed to travel a fairly long distance after the HV brakes have been applied before the alert is extinguished.

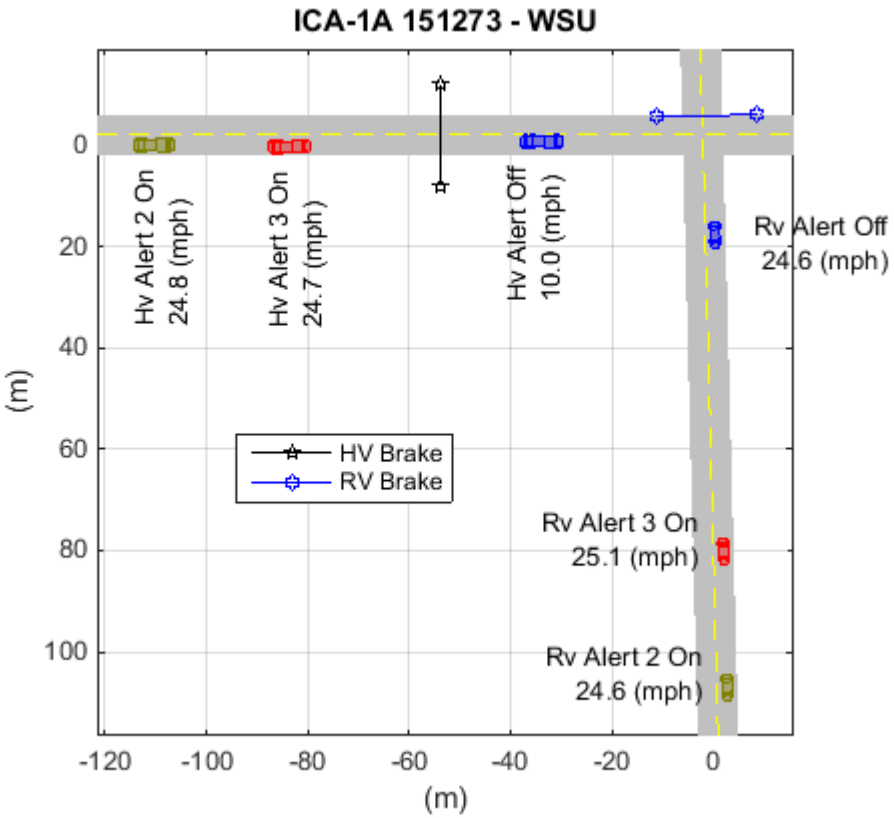


Figure 6: Vehicle Position Map for Test 1273

HV and RV TTC, TTC_{NA}, Range to Intersection, and Speed traces for Test 1273 are plotted in Figure 7. The TTC and TTC_{NA} are plotted, respectively, in the top two subplots along with the IMA alert level channel. The IMA alert goes to Level 2 at 10 seconds and then to Level 3 at approximately 12.5 seconds. The alert then turns off (goes to zero) at approximately 18 seconds. The TTC goes to infinity (which means the vehicle will not reach the intersection at the current speed and deceleration rate) at approximately 15 seconds, well before the alert extinguishes. The TTC_{NA} does not go to infinity until approximately 20 seconds, which is after the alert extinguishes. The Range to Intersection is shown in the third subplot along with the onset of braking for both the HV and RV. The HV and RV speeds are shown in the fourth subplot.

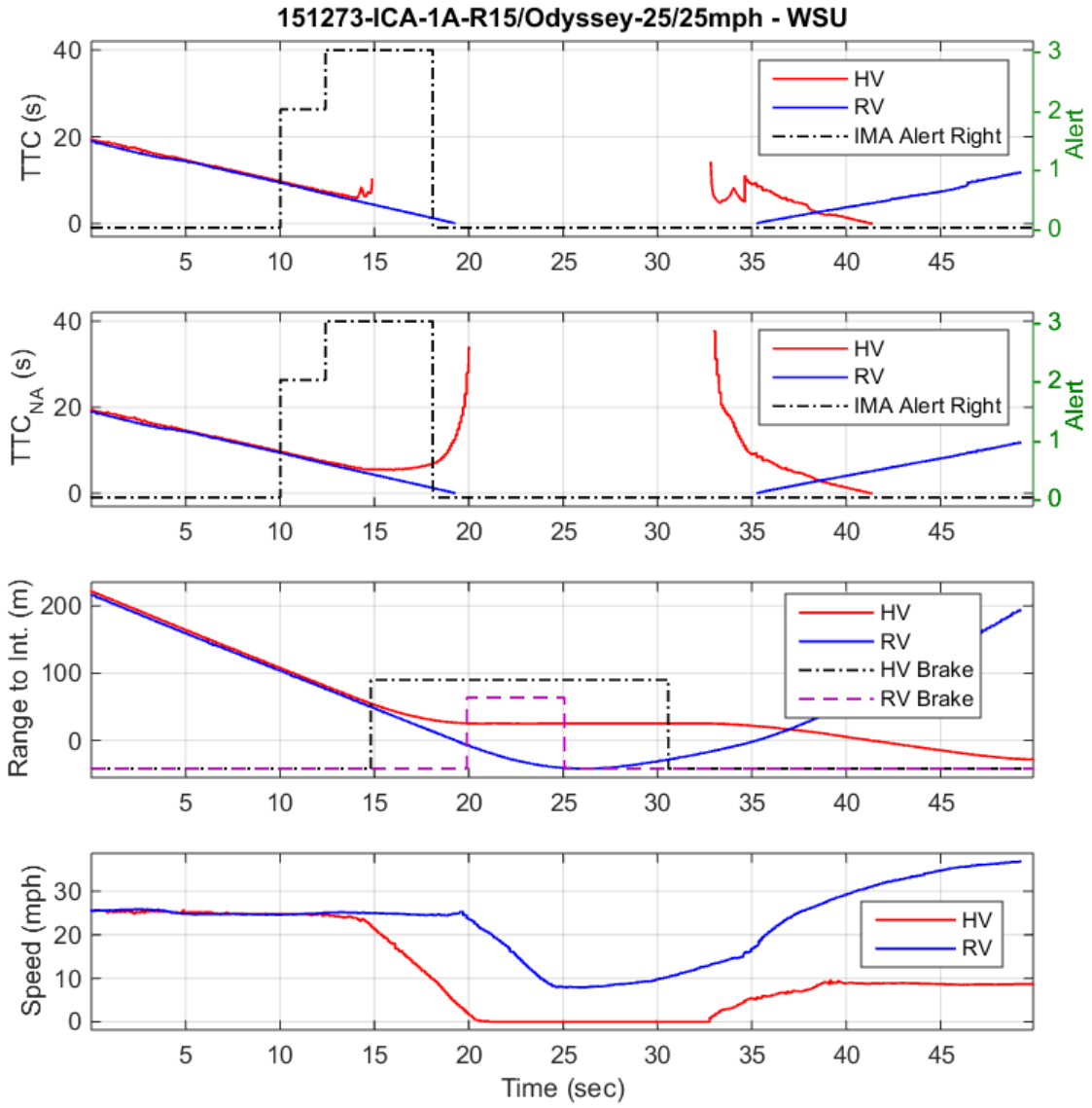


Figure 7: HV and RV TTC, TTC_{NA}, Range to Intersection, and Speed as a Function of Time for Test 1273

5.1.2 ICA-1A Test 2: V_{HV}=45, V_{RV}=45

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 4. RT, GPS, and WSU data for the Level 2 and Level 3 Alert onsets and offsets are given in Appendix B, Section B.1.2. Five tests were conducted for ICA-1A Test 2. Since the HV and RV speeds were supposed to be the same (45 mph), the Range to Intersection values at alert onset should be fairly similar if the vehicles were to arrive at the intersection at the same time. The RV Range to Intersection was generally lower than the HV range for this set of tests (163 versus 142 meters on average), but the average TTC were fairly

similar (7.1 versus 7.2 seconds). This happens in part due to the alert occurring so early that that HV (Red Cascadia) is still not up to the test speed of 45 mph and is therefore still accelerating, which reduces the HV TTC value. This is more evident in the Level 2 alert onset values found in Appendix B. The ICA test procedures [5] state that the RV (or HV) should attain the initial test speed, V_{RV}, at least 3 seconds from the intersection. Due to early warnings from the WSU, this length of time is not long enough. In the future, some initial testing should be performed to determine when the IMA alerts are occurring for the V2V systems being evaluated and then the HV/RV should be at the desired initial test speed at least 2 seconds earlier than this time.

Table 4: ICA-1A Test 2 WSU Based TTC, Range, and RT Speeds at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1276	7.2	6.6	171	131	43.9	44.8
1277	6.9	7.5	165	148	43.6	44.5
1278	7.1	7.3	169	145	43.9	44.5
1279	7.0	6.9	167	137	43.8	44.6
1280	7.1	7.6	141	151	44.9	44.6
Ave.	7.1	7.2	163	142	44.0	44.6
Std.	0.1	0.4	12	8	0.5	0.1
C. of V. (%)	1.3	5.8	8	6	1.1	0.2

5.1.3 ICA-1A Test 3: V_{HV}=25, V_{RV}=45

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 5. RT, GPS, and WSU data for the Level 2 and Level 3 Alert onsets and offsets are given in Appendix B, Section B.1.3. Five trials were run. Except for Test 1285, the TTC values are fairly similar for the HV and RV, which suggests that the vehicles would arrive at the intersection at approximately the same time if the speeds for both vehicles were kept constant. The TTC average values were 7.4 and 7.1 seconds, respectively, for the HV and RV. Both the HV and RV were near the test conditions of 25 and 45 mph for all tests.

Table 5: ICA-1A Test 3 WSU Based TTC, Range, and RT Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1282	7.4	7.0	83	140	25.2	44.5
1283	7.3	7.4	84	148	25.7	44.8
1284	7.4	7.3	83	144	25.1	44.5
1285	7.4	6.4	83	126	25.3	44.3
1286	7.4	7.5	84	148	25.5	44.6
Ave.	7.4	7.1	83	141	25.4	44.5
Std.	0.0	0.5	1	9	0.3	0.2
C. of V. (%)	0.6	6.4	1	7	1.0	0.4

5.1.4 ICA-1A General Discussion

Boxplots for the HV TTC to Intersection values for each ICA-1A test and alert level are shown in Figure 8. The box lengths represent the interquartile range, the horizontal line inside the box represents the group median, and the vertical lines (whiskers) extending beyond the box are the group minimum and maximum values. The first line of the label is the vehicle combination where R15 represents the Red Freightliner Cascadia, the third line represents the HV/RV speeds in mph, and the fourth line is the alert level and number of tests. There is a very limited sample size for each test condition (only 4 to 5 data points) and therefore no definitive conclusions can be made, but the ICA-1A Test 1 (25/25) produced a very tight range of values for the HV TTC for both Level 2 and Level 3 alert onsets. The ICA-1A Test 2 (45/45) had a tight range of values for the HV TTC for Level 3 alert onsets, but not Level 2. This is primarily explained by the HV not being up to the test speed prior to the onset of alerts, as discussed in Section 5.1.2. The vehicle acceleration has a large influence on the TTC variability. The reduced variability for the Level 3 alert is probably due to the vehicle being closer to the designated speed (reduced acceleration). The ICA-Test 3 (25/45) also had a tight range of values for the HV TTC for Level 3 alert onsets, but the range of values for the Level 2 alerts is much wider. The higher variability is primarily due to one test (Test 1285), which had a much higher difference in the TTC values for the HV and RV than the other tests in this group.

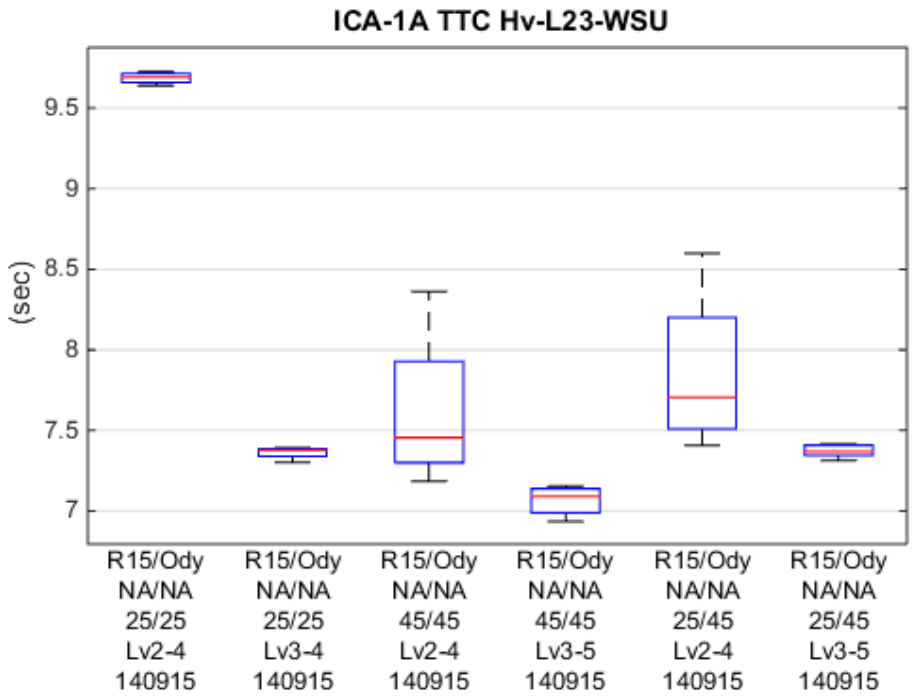


Figure 8: Boxplots for HV TTC at Level 2 and Level 3 Alert Onsets

Across the various speed ranges for the ICA-1A tests, the HV TTC for the Level 3 alert onsets fell within a small range of values (approximately 6.9 to 7.5 seconds). The Level 2 alerts had a much wider range, from approximately 7.2 to 9.8 seconds. Part of the explanation for the higher range of values is due to some of the variability in testing discussed above, but most of it appears to be due to the test conditions because the 25/25 tests had Level 2 alerts much earlier than the other speed combinations evaluated.

5.1.5 ICA-1B Test 1: V_{HV}=0, V_{RV}=25

The ICA-1B test procedure is designed to elicit a Level 3 warning after the driver starts to move into the intersection. The WSU on the Cascadia tractor gives a yellow alert (Level 2) when sitting still at an intersection with the parking brake on. If the parking brake is off, it gives a red alert (Level 3) even if the tractor is not moving. Since this warning occurs prior to the vehicle starting to move, the ICA-1B test procedure cannot be performed with this WSU. This is also true for the other ICA stationary HV test procedures. Example HV and RV TTC, TTC_{NA}, Range to Intersection, and Speed traces for a test with the parking brake off are shown in Figure 9. As seen respectively in the third and fourth subplots, the HV brake is applied and the HV speed remains zero throughout the test. Despite these conditions, a Level 3 alert occurs at approximately 21 seconds and extinguishes at approximately 26 seconds (first and second subplots) when the RV reaches the intersection (TTC and TTC_{NA} go to zero).

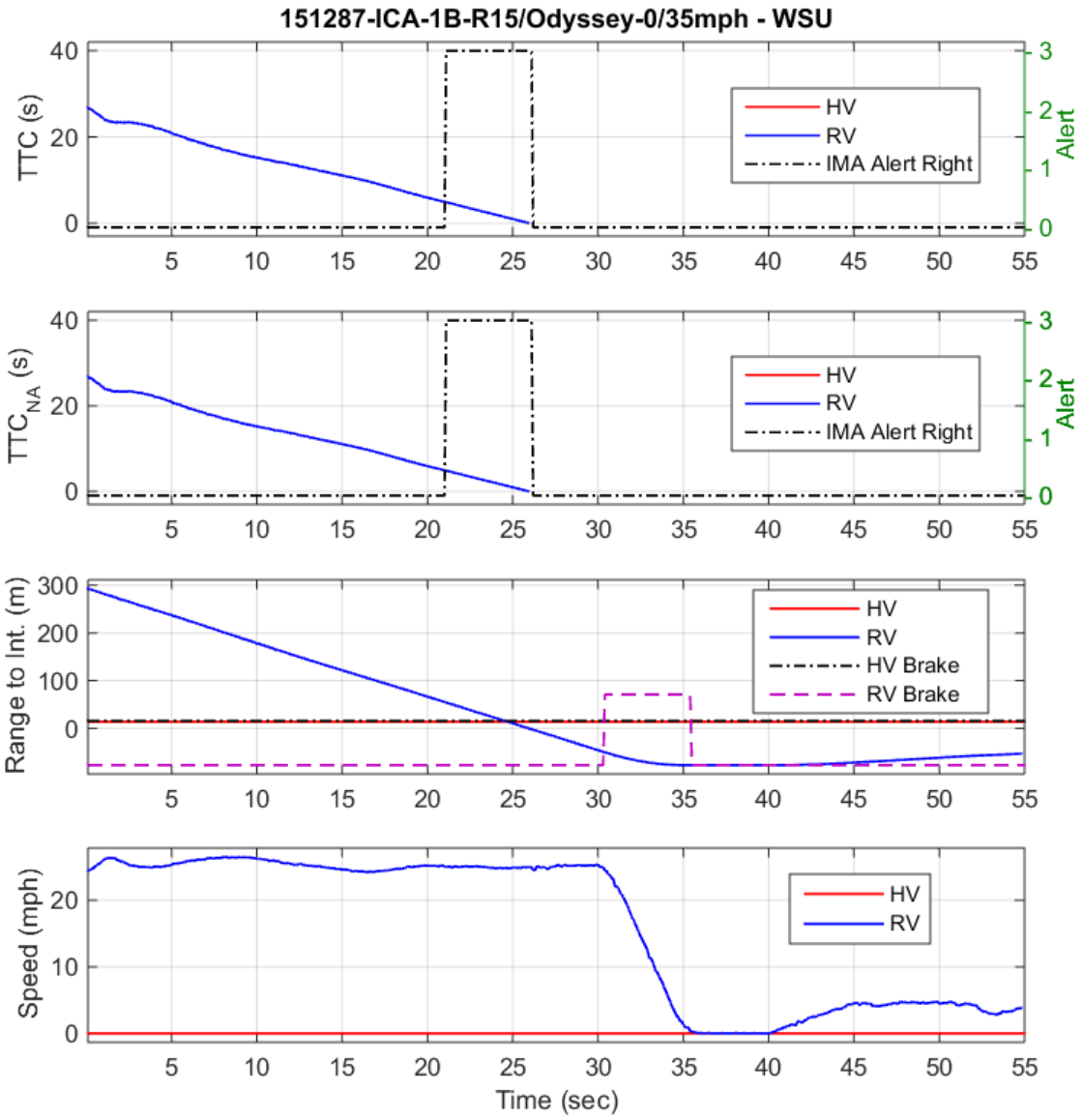


Figure 9: TTC, TTC_{NA}, Range, and Speeds for Test 1287

5.2 ICA-2: Right Turn Into Path

The ICA-2 test begins with the 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 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.

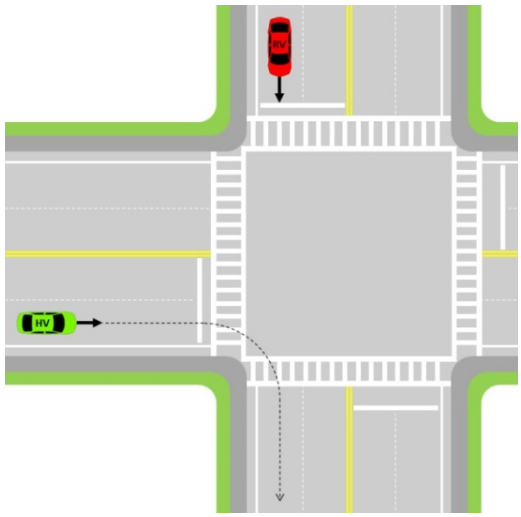


Figure 10: ICA-2A Test Initial Conditions

The test conditions for the ICA-2 tests are listed in Table 6. The 2A test is an HV moving test and the 2B test has the HV initially stationary. Except for the RV test speed, the 2B scenario is not fundamentally different from the 1B test procedures, and since the IB test procedures gave a Level 3 alert prior to the vehicle moving into the intersection, the 2B test procedure was not evaluated.

Table 6: ICA-2 Test Conditions

	ICA-2A		ICA-2B	
Parameter	Value	Tolerance	Value	Tolerance
V_{HV} (Approach)	22 mph	±1.1 mph	0 mph	N/A
V_{HV} (Turn)	12 mph	±1.1 mph	0 mph	N/A
V_{RV}	35 mph	±1.8 mph	35 mph	± 1.8 mph

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 7. RT, GPS, and WSU data for the Level 2 and Level 3 Alert onsets are given in Appendix B, Section B.2. Five tests were conducted. Test 1290 had a fairly large difference in HV and RV TTC for the Level 3 Alert onset, which means the vehicles would not have arrived at the intersection at the same time and therefore would not have been considered a valid test. This test was left in the analysis to show that even with a large difference in the TTC, the WSU did still issue a Level 3 alert. The WSU alerts the driver of a potential threat very early (HV TTC of 7.1 seconds on average) and for the given test speed, is much sooner than when a driver would naturally slow down to make the turn at the intersection. Because of the early alerts, these test results are not fundamentally different than the ICA-1 test results because the driver never has a chance to slow down to start to make the turn prior to the alerts.

Table 7: ICA-2A WSU Based TTC, Range, and RT Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1290	6.7	9.9	66	150	21.9	33.8
1291	7.2	6.6	71	102	22.5	34.5
1292	7.1	7.5	71	113	22.4	34.0
1293	7.2	6.4	71	98	22.3	34.1
1294	7.2	8.5	70	128	21.7	33.9
Ave.	7.1	7.8	70	118	22.2	34.1
Std.	0.2	1.4	2	21	0.3	0.2
C. of V. (%)	2.9	18.6	3	18	1.4	0.7

An example vehicle position map of the HV and RV positions at the alert onsets and offsets is given in Figure 11 (Test 1291). As was the case in the ICA-1A tests, the data represented in the figure show that the alerts come on very early and much earlier than what would happen if the HV was doing a normal stop at the intersection. The HV also travels a fairly long distance after the brakes have been applied before the alert is extinguished.

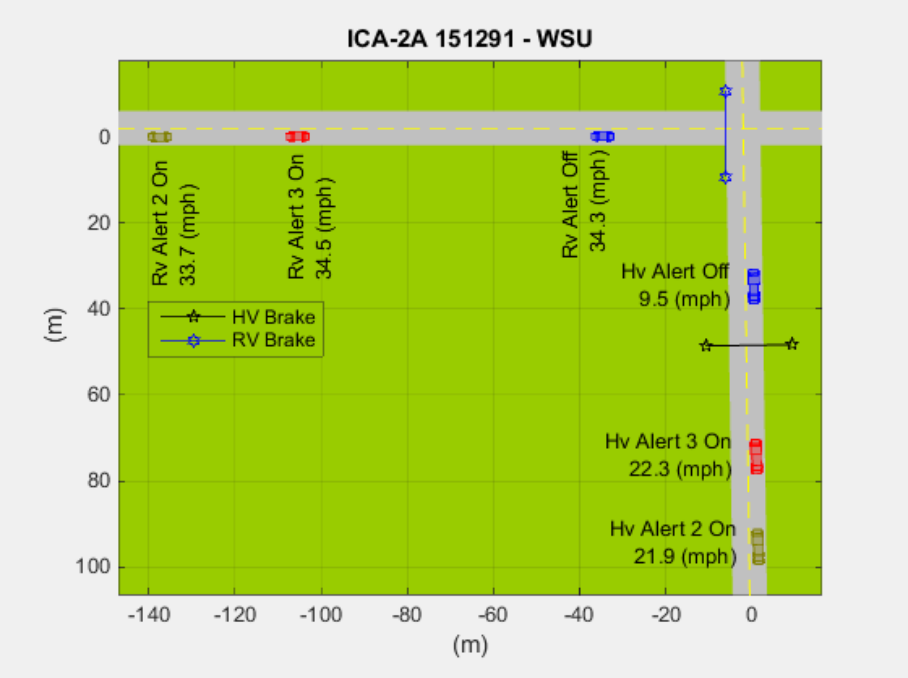


Figure 11: Vehicle Position Map for Test 1291

HV and RV TTC, TTC_{NA}, Range to Intersection, and Speed traces are shown in Figure 12 for this same test. TTC is shown in the top subplot along with the IMA alert level. The HV TTC trace goes to infinity near 18 seconds. TTC_{NA} is shown in the second subplot and the HV TTC_{NA} goes to infinity near 22 seconds when the HV stops – much later than TTC due to not accounting for acceleration. The range to intersection and braking onsets are shown in the third subplot. The HV braking onset occurs when the driver reacts to the Level 3 alert. The vehicle speeds are shown in the bottom subplot.

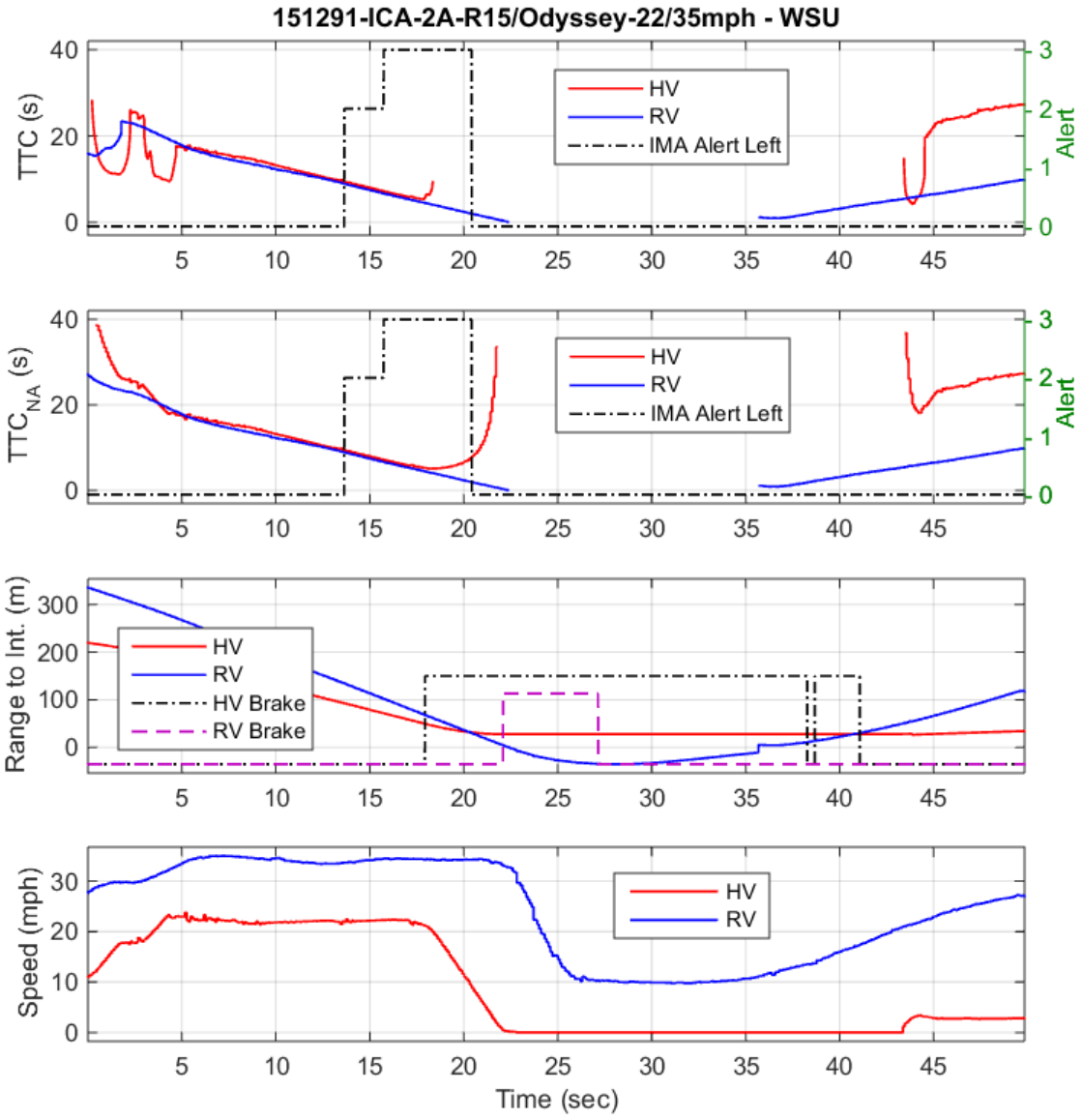


Figure 12: HV and RV TTC, TTC_{NA}, Range to Intersection, and Speed for Test 1291

5.3 ICA-3: Left Turn Into Path

The ICA-3 test begins with the 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 13. 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.

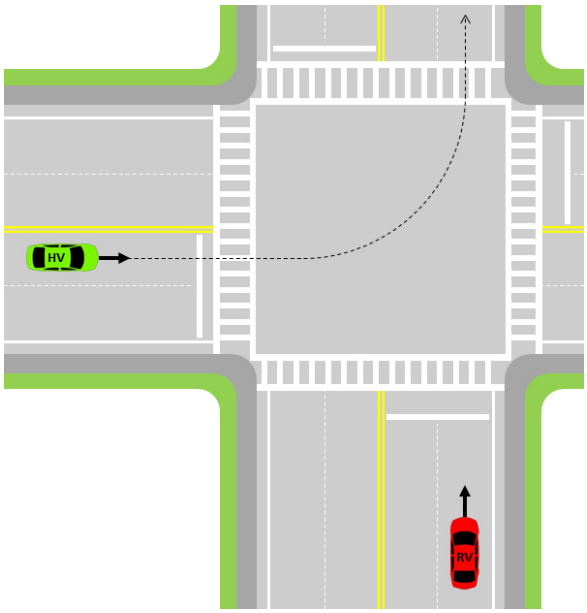


Figure 13: ICA-3A Test Initial Conditions

The test conditions for the ICA-3 tests are listed in Table 8. The 3A test is an HV moving test and the 3B test has the HV stationary. Except for the RV test speed, the 3B scenario is not fundamentally different from the 1B test procedures and since the IB test procedures gave a Level 3 alert prior to the vehicle moving into the intersection, the 3B test procedure was not evaluated.

Table 8: ICA-3 Test Conditions

	ICA-3A		ICA-3B	
Parameter	Value	Tolerance	Value	Tolerance
V_{HV} (Approach)	22 mph	±1.1 mph	0 mph	N/A
V_{HV} (Turn)	12 mph	±1.1 mph	0 mph	N/A
V_{RV}	35 mph	±1.8 mph	35 mph	±1.8 mph

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 9. RT, GPS, and WSU data for the Level 2 and Level 3 Alert onsets are given in Appendix B, Section B.3. Five tests were conducted. This data shows that the WSU alerts the driver of a potential threat very early (HV TTC of 7.2 seconds on average) and for the given test speed, is much sooner than when a driver would naturally slow down to make the turn at the intersection. These values are very consistent with what was found with the ICA-2A test procedure, which had the same HV and RV initial speeds. Because of the early alerts, these test results are not fundamentally different than the ICA-1 test results because the driver never has a chance to slow down to start to make the turn prior to the alerts.

Table 9: ICA-3A TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1296	7.1	7.2	67	112	21.0	34.8
1297	7.1	6.7	70	103	22.1	34.5
1298	7.4	7.8	73	121	22.3	34.5
1299	7.2	7.6	72	118	22.5	34.6
1300	7.1	7.5	72	115	22.4	34.5
Ave.	7.2	7.4	71	114	22.1	34.6
Std.	0.1	0.4	3	7	0.6	0.1
C. of V. (%)	1.4	6.0	4	6	2.9	0.3

An example overhead view showing the HV and RV positions at the alert onsets and offsets is given in Figure 14 (Test 1300). HV and RV TTC, TTC_{NA}, Range to Intersection, and Speed traces are shown in Figure 15 for this same test. The results presented in these figures are very similar to the example plots shown for the ICA-2 test results.

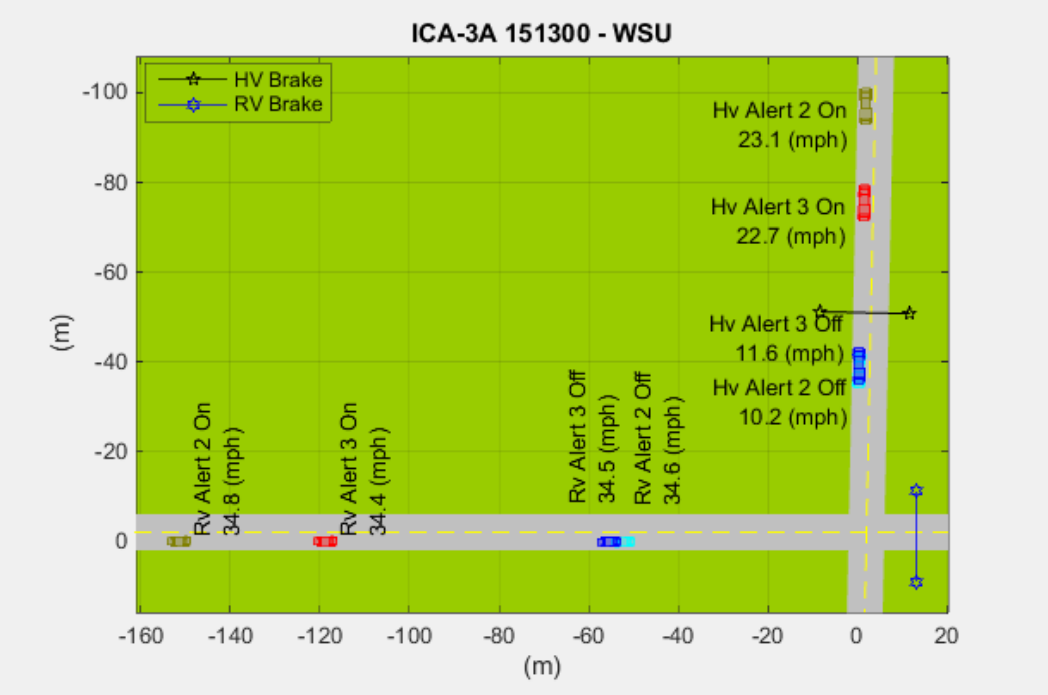


Figure 14: Vehicle Position Map at Alert Onset for Test 1300

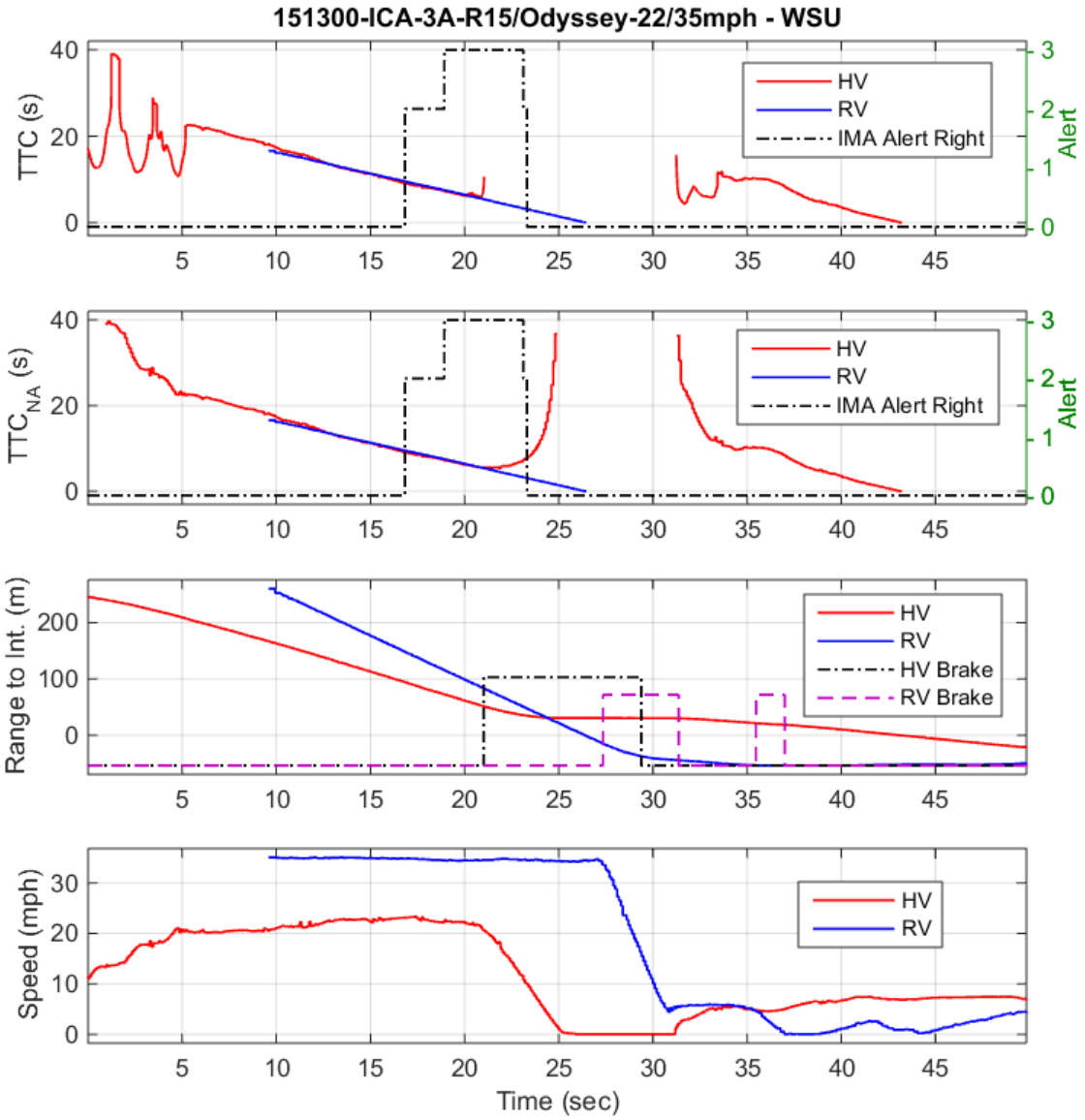


Figure 15: TTC, TTC_{NA}, Range to Intersection, and Speeds for Test 1300

5.4 ICA-4: Left Turn Across Path/Lateral Direction

The ICA-4 test begins with the 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 Figure 16. The HV should attain the initial test speed of V_{HV} at least 5 second time headway from the intersection, measured by the corresponding range between the 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 5 seconds from the intersection and drive straight through the intersection at constant speed.

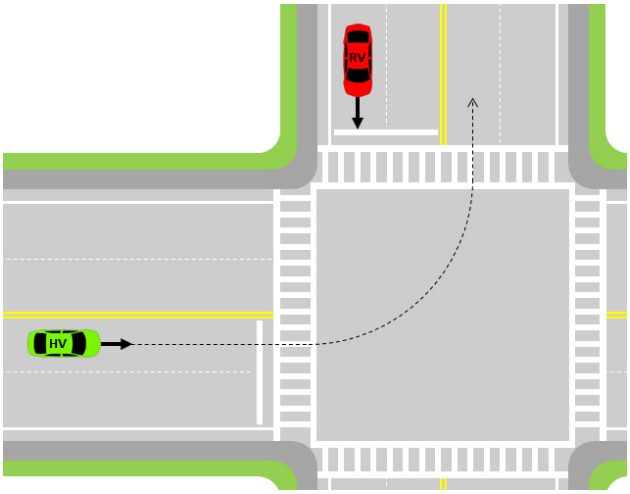


Figure 16: ICA-4A Test Initial Conditions

The test conditions for the ICA-4 tests are listed in Table 10. The 4A test is an HV moving test and the 4B test has the HV stationary. Except for the RV test speed, the 4B scenario is not fundamentally different from the 1B test procedures and since the IB test procedures gave a Level 3 alert prior to the vehicle moving into the intersection, the 4B test procedure was not evaluated.

Table 10: ICA-4 Test Conditions

	ICA-4A		ICA-4B	
Parameter	Value	Tolerance	Value	Tolerance
V_{HV} (Approach)	22 mph	±1.1 mph	0 mph	N/A
V_{HV} (Turn)	12 mph	±1.1 mph	0 mph	N/A
V_{RV}	35 mph	±1.8 mph	35 mph	±1.8 mph

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 11. RT, GPS, and WSU data for the Level 2 and Level 3 Alert onsets are given in Appendix B, Section B.4. Five tests were conducted. There was a drop out in the RT data for the final test (Test 1305). Test 1301 had a much larger TTC for the HV at the Level 3 alert onset due to the driver letting off the throttle, which caused a slight deceleration that increased the TTC. This test would normally not be considered valid, but the results were left in for this analysis. The WSU alerts the driver of a potential threat very early (7.6 seconds on average for Level 3 alerts – 7.3 seconds if Test 1301 removed) and for the given test speed, is much sooner than when a driver would naturally slow down to make the turn at the intersection. The TTC values are very consistent with what was found with the ICA-2A test procedure that had the same HV and RV initial speeds. Due to the early alerts, this test procedure is not fundamentally different than the ICA-1 test procedures because the driver never has a chance to slow down to start to make the turn prior to the alerts.

Table 11: ICA-4A WSU Based TTC, Range, and RT Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1301	8.8	6.1	68	94	21.4	34.7
1302	7.2	8.4	73	129	22.9	34.5
1303	7.3	8.0	72	122	22.3	34.2
1304	7.3	8.0	75	124	23.2	34.7
1305	7.3	6.9	71	107	21.8	34.8
Ave.	7.6	7.5	72	115	22.4	34.5
Std.	0.7	1.0	2	14	0.8	0.2
C. of V. (%)	8.7	12.8	3	12	3.4	0.6

An example overhead view showing the HV and RV positions at the alert onsets and offsets is given in Figure 17 (Test 1304). HV and RV TTC, TTC_{NA}, Range to Intersection, and Speed traces are shown in Figure 18 for this same test. The results presented in these figures are very similar to the example plots shown for the ICA-2 test results.

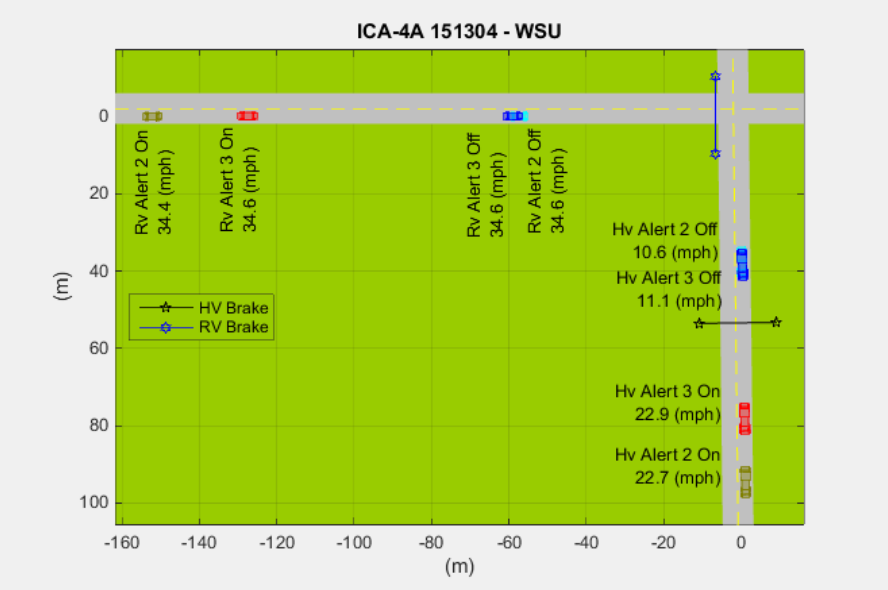


Figure 17: Vehicle Position Map at Alert Onset for Test 1304

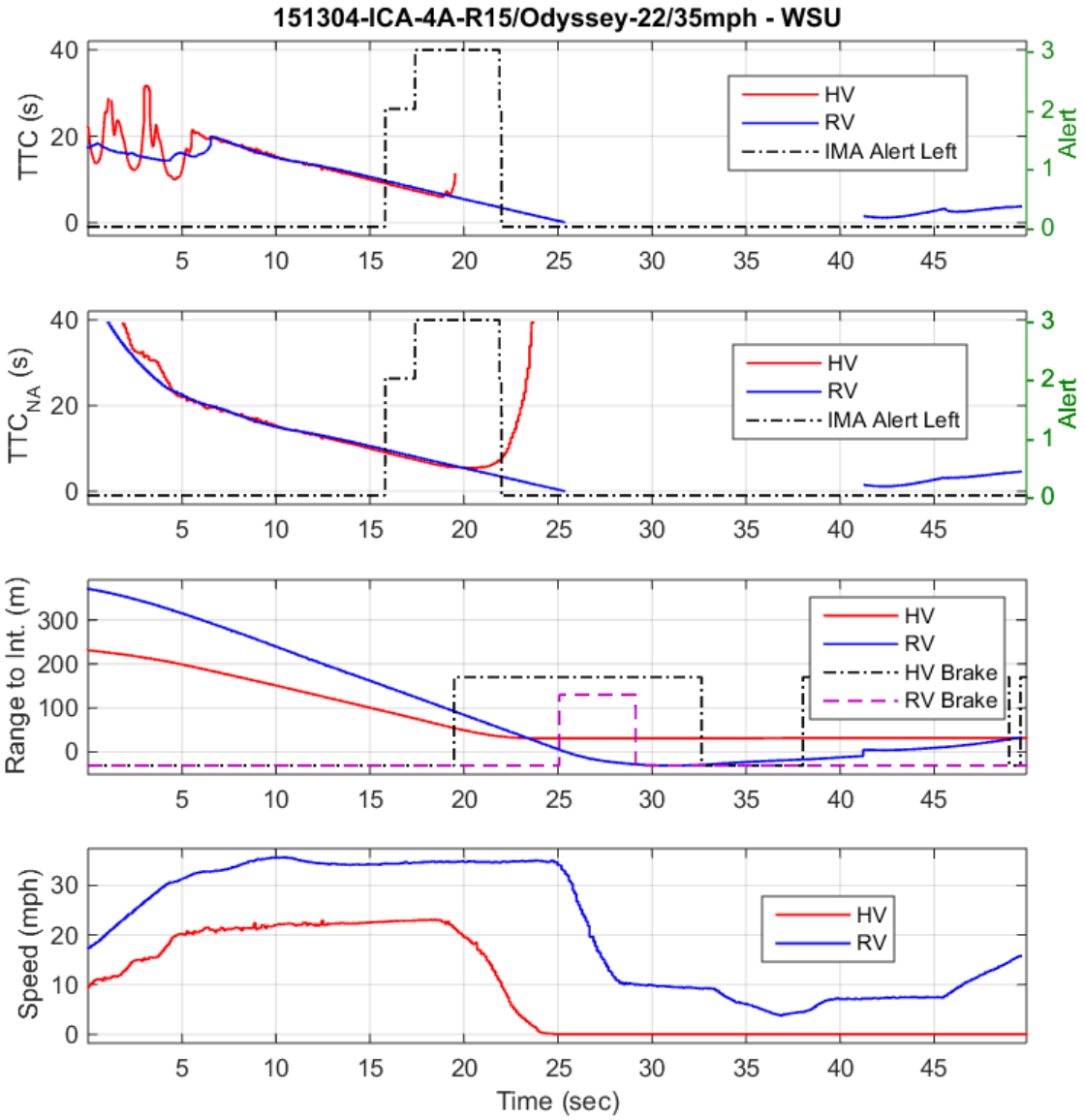


Figure 18: TTC, TTC_{NA}, Range to Intersection, and Speeds for Test 1304

5.5 ICA-5: Left Turn Across Path/Opposite Direction

The ICA-5 test begins with the 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 19. The HV should attain the initial test speed of V_{HV} at least 5 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 and signals the intention using

the turn signal indicator (which would need to be monitored by the IMA safety application to determine driver intent). The RV should attain the initial test speed of V_{RV} at least 5 seconds from the intersection and drive straight through the intersection at constant speed.

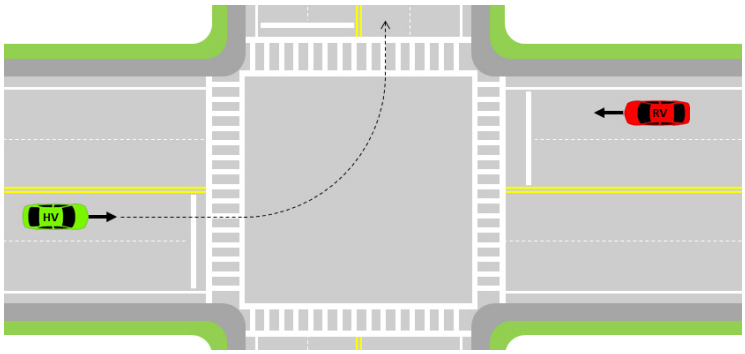


Figure 19: ICA-5A Test Initial Conditions

The test conditions for the ICA-5 tests are listed in Table 12. The 5A test is an HV moving test and the 5B test has the HV stationary. The HV WSU system does have access to turn signal information from the HV and turn signal usage is displayed on the WSU tablet. The turn signal data were collected from the vehicle CAN to monitor the turn signal application.

Table 12: ICA-5 Test Conditions

	ICA-5A		ICA-5B	
Parameter	Value	Tolerance	Value	Tolerance
V_{HV} (Approach)	22 mph	±1.1 mph	0 mph	N/A
V_{HV} (Turn)	12 mph	±1.1 mph	0 mph	N/A
V_{RV}	35 mph	±1.8 mph	35 mph	±1.8 mph

Three tests were conducted using the ICA-5A test conditions and no warning occurred. It does not appear that the WSUs have an application for addressing this type of scenario. Since no warning occurred with the 5A test procedure, no 5B tests were conducted.

5.6 ICA-6: Straight Crossing Paths, RV Slowing to Stop

The ICA-6 test begins with the HV traveling on a 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 and is slowing to stop before the intersection, as shown in Figure 20. The HV should attain the initial test speed of V_{HV} at least 5 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 5 seconds from the intersection. The RV driver should brake manually to a stop so the RV does not enter the intersection.

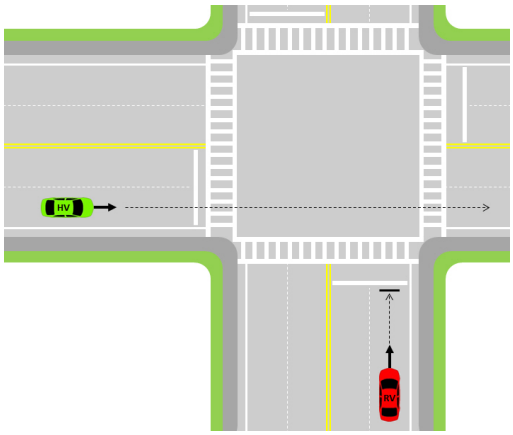


Figure 20: ICA-6 Test Initial Conditions

The test conditions for the ICA-6 test are listed in Table 13.

Table 13: ICA-6 Test Conditions

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

This test is designed to not produce any warnings or interventions for the HV. Because the WSU on the Cascadia truck alerts so early, the test procedure did produce alerts. It was decided to conduct tests where the RV brakes earlier for successive tests to see if there is a point where the WSU stops warning. That point was not determined in this set of tests despite the RV stopping well before the intersection for the later tests in the series. Seven tests were conducted. The HV Range to the Intersection at RV Brake Onset, HV Range to Intersection when RV Stopped, RV Stopping Distance, Average RV Brake Deceleration, and Range to Intersection, TTC_{NA} to Intersection, and RT Speed at IMA Level 3 Alert Onset are listed in Table 14. RT, GPS, and WSU data for these metrics and others are given in Appendix B, Section B.5.

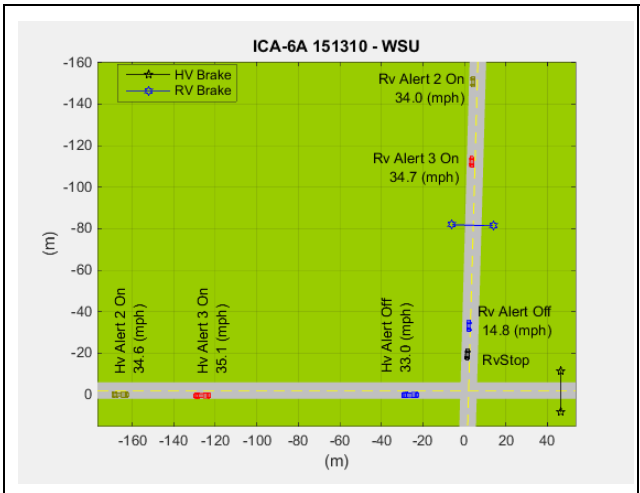
The HV Range to Intersection at RV Brake Onset varied from 80 meters to 147 meters. The average RV deceleration was generally higher than the A_{RV} test condition of 0.15 g, but as will be shown later, did not appear to affect results for the HV.

Due to the RV to Intersection TTC going to infinity, TTC_{NA} data (TTC with no acceleration) are presented in Table 14. Despite the increase in RV TTC_{NA} values for successive tests at IMA Level 3 alert onset (6.8 to 12.9 seconds), the HV TTC_{NA} values stayed steady at approximately 8.0 seconds. The fairly wide range in average RV brake deceleration did not produce any variance in the HV TTC_{NA} to intersection time. The effect of average brake deceleration may be more influential if the WSU warned at a lower TTC_{NA} value. The RV speed starts to be reduced below the nominal test speed for Level 3 alert onset with Test 1312.

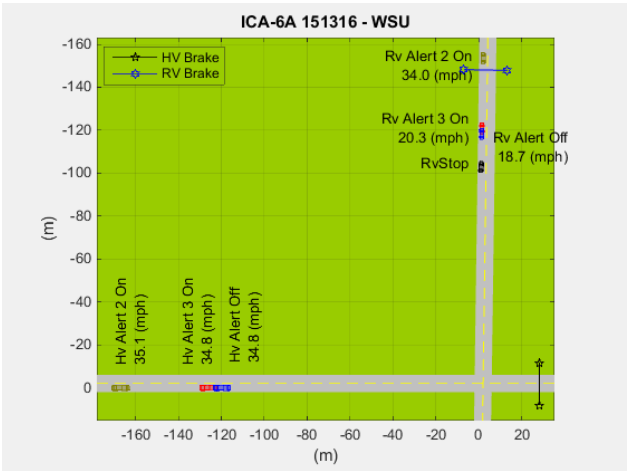
Table 14: ICA-6A WSU Based HV Range to Intersection at RV Brake Onset and RV Stopped, RV Braking Distance and Average Deceleration, and TTC_{NA}, Range, and RT Speed at IMA Level 3 Alert Onset

Trial	HV Range to Int. (m)		RV Stop Dist. (m)	RV Avg. Decel (m/s^2)	Level 3 Onset					
	RV Brake Onset	RV Stop			Range to Int. (m)		TTC_{NA} to Int. (s)		Speed RT (mph)	
					HV	RV	HV	RV	HV	RV
1310	80.4	15.6	64.8	1.7	123	108	7.9	7	35.5	34.7
1311	95.3	47.5	47.8	2	123	105	8	6.8	35.1	34.6
1312	104.4	59	45.5	2.1	126	123	8	8.4	35.5	32.7
1313	112.2	69	43.3	2.3	123	105	7.9	8	35	29.7
1314	126.6	79.1	47.5	2.3	124	97	8	10.7	34.8	20.7
1315	136.9	98.9	38	2.5	122	115	7.9	12.5	34.7	20.5
1316	146.8	99.1	47.7	2.3	123	117	7.9	12.9	35.1	21

Example vehicle position maps that show the HV and RV positions at alert onsets and offsets and when the RV stops are shown in Figure 21. The first and last test in the sequence are shown to visually demonstrate how much earlier the RV begins to brake and how far it is from the intersection when it stops for the last test when compared to the first.



Test 1310



Test 1316 – RV Braked early

Figure 21: Example Vehicle Position Maps at Alert Onsets and Offsets and RV Stopped for ICA-6 Tests

5.7 ICA-7: Straight Crossing Paths, HV Slowing to Stop

The ICA-7 test begins with the HV traveling on a 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 22. The HV should attain the initial test speed of V_{HV} at least 5 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 5 seconds from the intersection.

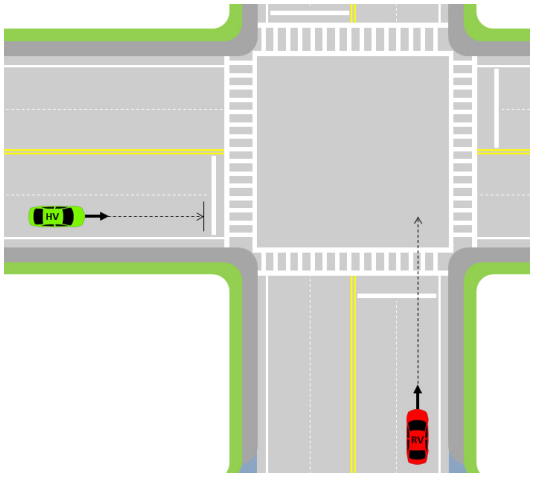


Figure 22: ICA-7 Test Initial Conditions

The test conditions for the ICA-7 test are listed in Table 15.

Table 15: ICA-7 Test Conditions

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

This test is designed to not produce any warnings or interventions for the HV. Because the WSU on the Cascadia truck alerts so early, the test procedure did produce alerts. It was decided to conduct tests where the HV brakes earlier for successive tests to see if there is a point where the WSU stops producing alerts. That point for Level 3 alerts was determined, but Level 2 alerts were still being issued in this set of tests despite the HV stopping well before the intersection for the later tests in the series. Six tests were conducted, but the first test had the HV arriving at the intersection too early and therefore it is not included in the discussion. The HV Range to the Intersection at HV Brake Onset, HV Range to Intersection when HV Stopped, HV Braking Distance, and Average HV Brake Deceleration, and Range to Intersection, TTC to Intersection, and RT Speed at IMA Level 3 Alert Onset are listed in Table 16. RT, GPS, and WSU data for these metrics and others are given in Appendix B, Section B.6.

The HV Range to Intersection at HV Brake Onset varied from 72 meters to 126 meters. The average HV deceleration was generally higher than the A_{HV} test condition of 0.15 g, but did not affect results because the braking onset was generally well after the alert onsets.

The HV TTC to Intersection for Level 3 alert onset consistently came on at approximately 7.9 seconds.

Table 16: ICA-7A WSU Based HV Range to Intersection at HV Brake Onset and HV Stopped, HV Braking Distance and Average Deceleration, and TTC, Range, and RT Speed at IMA Level 3 Alert Onset

Trial	HV Range to Int. (m)		HV Stop Dist. (m)	HV Avg. Decel (m/s^2)	Level 3 Onset					
	HV Brake Onset	HV Stop			Range to Int. (m)		TTC to Int. (s)		Speed RT (mph)	
					HV	RV	HV	RV	HV	RV
1318	71.8	15.6	56.2	1.7	121	131	7.9	8.5	34.7	34.5
1319	89.7	22.6	67.1	1.7	122	128	7.9	8.3	34.7	34.7
1320	101.1	42.9	58.2	1.9	121	127	7.9	8.3	34.2	34.2
1321	116.6	43.9	72.7	1.6	126	111	7.9	7.2	35.8	34.5
1322	126.0	59.6	66.4	1.7						

Example vehicle position maps that show the HV and RV positions at alert onsets and offsets are shown in Figure 23. The earlier braking onset reduces the duration of the Level 3 alert until it is eliminated in Test 1322 (bottom right corner map).

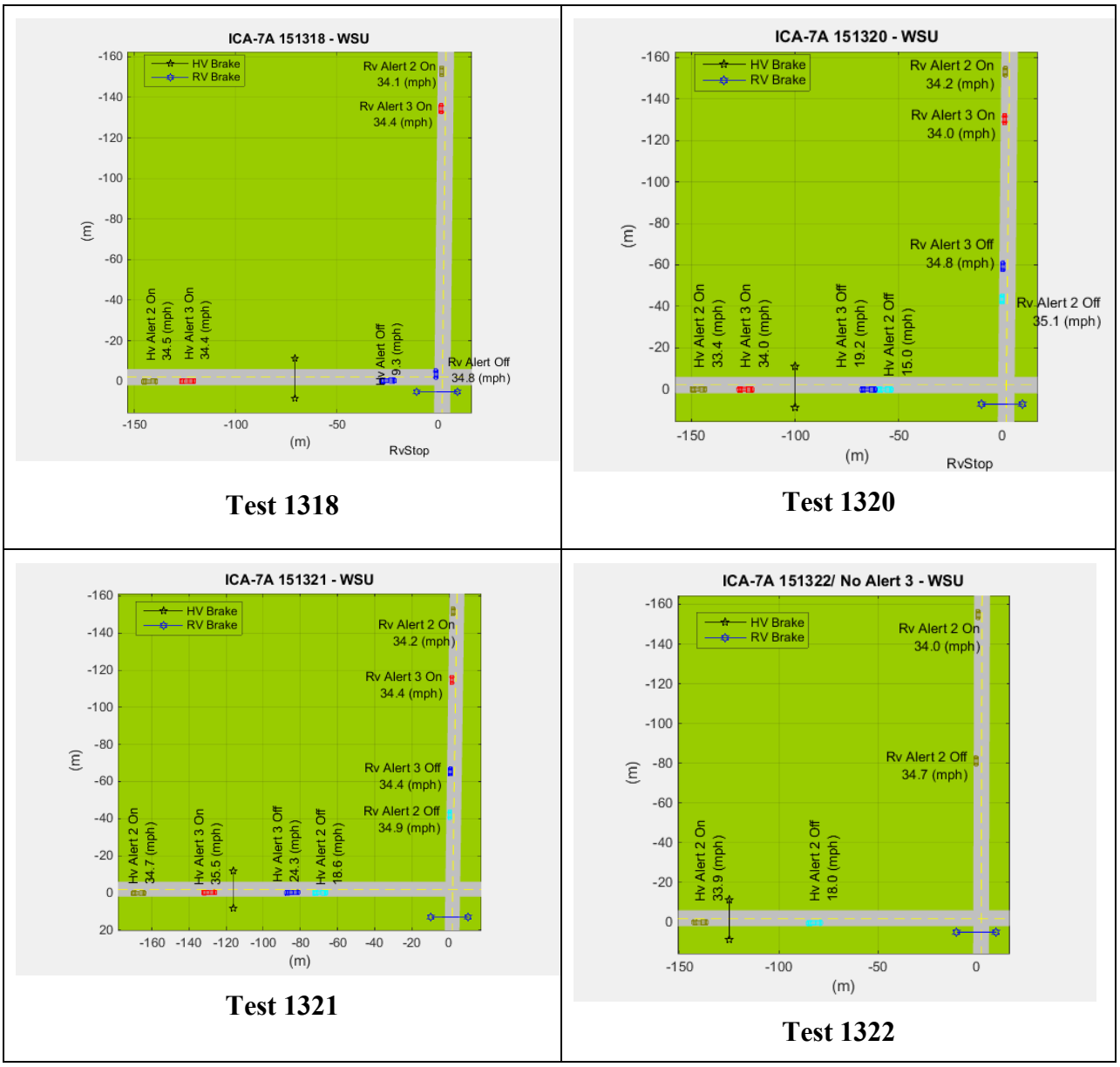


Figure 23: Vehicle Position Maps at Alerts for ICA-7 Tests

5.8 ICA-8: Left Turn Across Path/Opposite Direction RV Slowing to Stop

The ICA-8 test begins with the HV traveling on a 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 at constant speed toward the intersection, as shown in Figure 24. The HV should attain the initial test speed of V_{HV} at least 5 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 5 seconds from the intersection. The RV driver should brake manually to a stop so the RV does not enter the intersection.

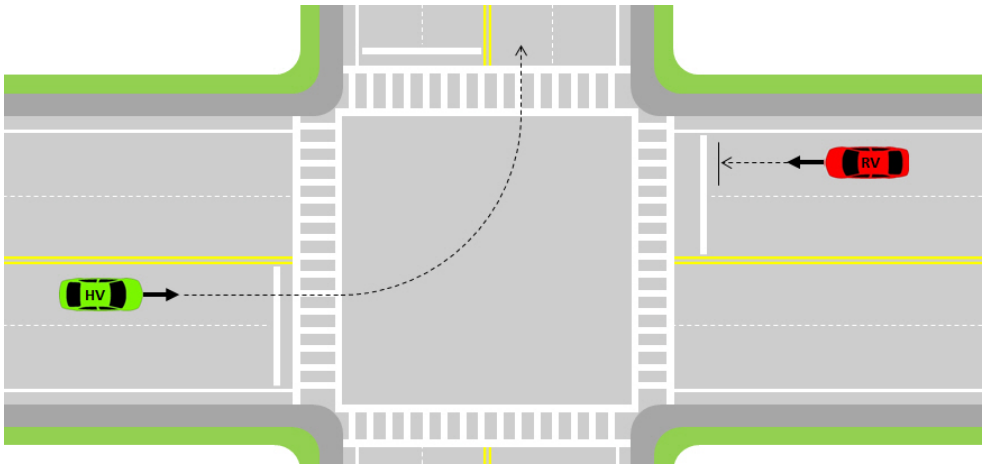


Figure 24: ICA-8 Test Initial Conditions

The test conditions for the ICA-8 test are listed in Table 17.

Table 17: ICA-8 Test Conditions

Parameter	Value	Tolerance
V_{HV}	25 mph	±1.3 mph
V_{RV}	25 mph	±1.3 mph
A_{RV}	-0.15 g	±0.1 g

As was noted in the ICA-5 test results, the WSUs on the Cascadia trucks do not appear to have an application for addressing crossing the path of an opposite direction (on-coming) vehicle. As stated at the beginning of this chapter, the ICA-8 procedure is a no-action test scenario that should result in the HV suppressing all warning/alerts, but because no alerts occurred during the ICA-5 testing, there would be no warnings/alerts to suppress in this test procedure. For completeness, a few tests were performed and no alerts occurred, but again it is not believed that the warnings were suppressed, but instead the WSUs do not have an application for this type of test.

5.9 ICA-9: Both HV and RV Turning Right

The ICA-9 test begins with the HV traveling on a 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 25, 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 5 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 5 seconds from the intersection.

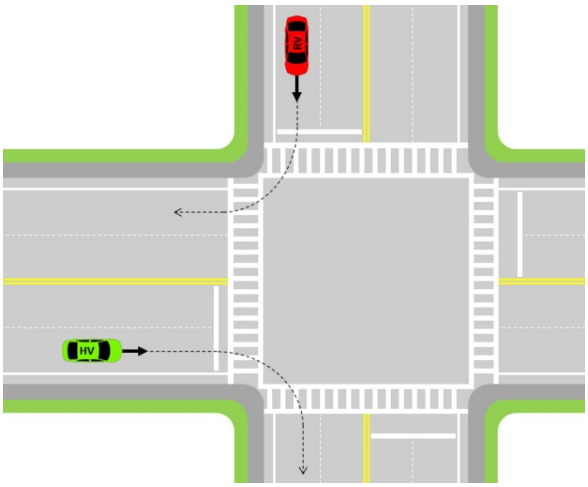


Figure 25: ICA-9 Test Initial Conditions

The test conditions for the ICA-9 test are listed in Table 18.

Table 18: ICA-9 Test Conditions

Parameter	Value	Tolerance
V_{HV}	25 mph	±1.3 mph
V_{RV}	25 mph	±1.3 mph

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at Level 3 alert onset are listed in Table 19. RT, GPS, and WSU data for these metrics and others are given in Appendix B, Section B.7. The Level 3 alert consistently came on at an HV TTC to Intersection of 7.4 to 7.5 seconds. The corresponding Range of the HV to Intersection also had a very small range of values (81 to 85 meters). This consistency occurred even though there was a relatively wide range of values for the Range of the RV to Intersection distance (90 to 115 meters).

Table 19: ICA-9A WSU Based TTC, Range, and RT Speed at IMA Level 3 Alert Onset

Test No.	Level 3 Alert Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1328	7.4	10.5	81	114	25.0	24.3
1329	7.5	7.7	85	90	25.7	26.2
1330	7.4	8.4	81	99	24.9	26.2
1331	7.5	9.7	83	111	25.0	25.7
1332	7.4	10.4	82	115	25.1	24.9
Ave.	7.4	9.3	83	106	25.1	25.5
Std.	0.1	1.2	2	11	0.3	0.8
C. of V. (%)	1.1	13.1	2	10	1.2	3.3

An example vehicle position map is shown for Test 1329 in Figure 26. The position of the HV and RV are shown for the HV alert onset and offset points. The initiation of braking for both the HV and RV are shown as well. The alert onsets issued by the WSU are too early and are not suppressed until well after braking onset occurs even though both vehicles slow down to make a reasonable low speed turn.

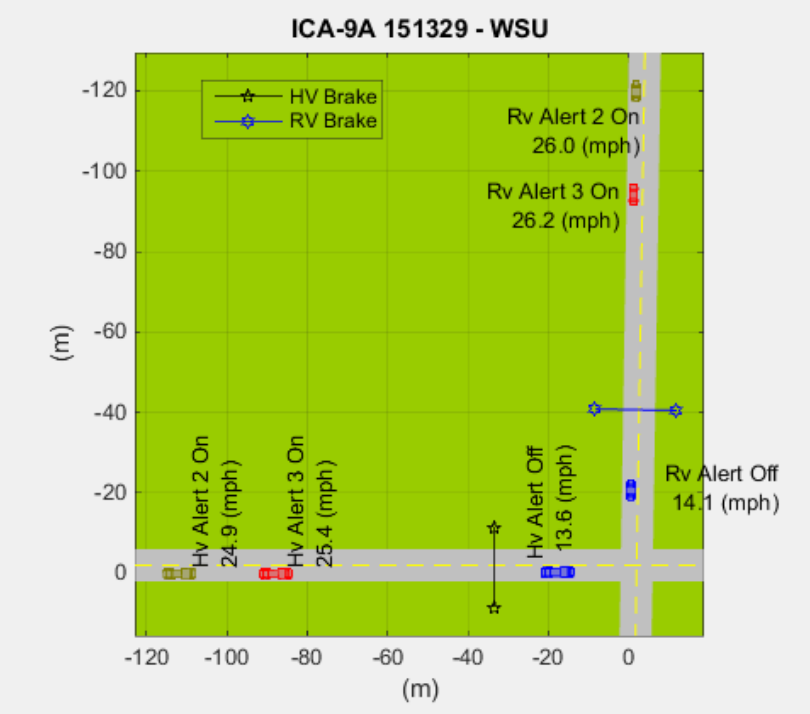


Figure 26: Example Vehicle Position Map showing Alert Onsets and Offsets for ICA-9 Test

5.10 ICA-10: HV Turning Right, RV Continuing Straight

The ICA-10 test begins with the HV traveling on a 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 27. The HV should attain the initial test speed of V_{HV} at least 5 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 5 seconds from the intersection.

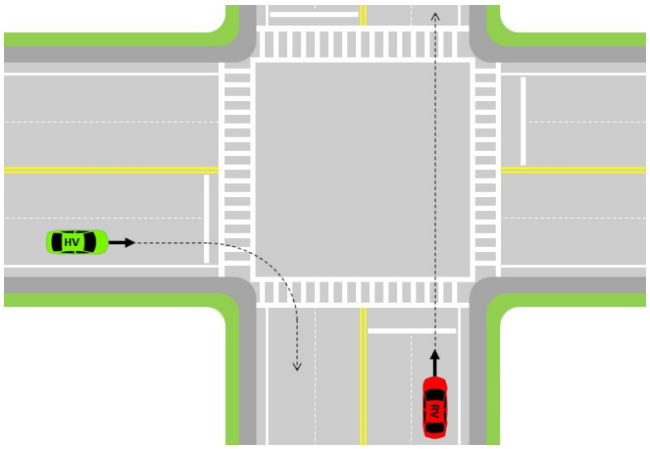


Figure 27: ICA-10 Test Initial Conditions

The test conditions for the ICA-9 test are listed in Table 20.

Table 20: ICA-10 Test Conditions

Parameter	Value	Tolerance
V_{HV}	25 mph	±1.3 mph
V_{RV}	35 mph	±1.8 mph

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 21. RT, GPS, and WSU data for these metrics and others are given in Appendix B, Section B.8. Based on TTC values, for Test 1334 the RV would have arrived at the intersection earlier than the HV and for the other tests the RV would have arrived later than the HV if the HV had maintained its speed. The wide range in timing of the RV relative to HV TTC to Intersection values led to some relatively higher variability in the timing of the alerts. Better timing of the vehicles' arrival to the intersection would not have resulted in the alerts being suppressed and therefore better timing was not pursued during this phase of testing.

Table 21: ICA-10A TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	Level 3 Alert Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT(mph)	
	WSU	WSU	WSU	WSU	HV	RV
1334	7.5	5.4	86	83	25.8	34.6
1335	7.3	8.2	79	127	24.4	34.7
1336	7.3	9.1	82	140	25.2	34.7
1337	6.8	9.4	74	146	24.5	35.0
Ave.	7.2	8.0	80	124	25.0	34.8
Std.	0.3	1.8	5	29	0.7	0.2
C. of V. (%)	4.2	22.8	6	23	2.6	0.5

An example vehicle position map is shown for Test 1337 in Figure 28. The position of the HV and RV are shown for the HV alert onset and offset points. The initiation of braking for both the HV and RV are shown as well (RV does not brake until after intersection is cleared). The alert onset issued by the WSU is too early and is not suppressed until well after braking onset occurs even though the HV slows down to make a reasonable low speed turn.

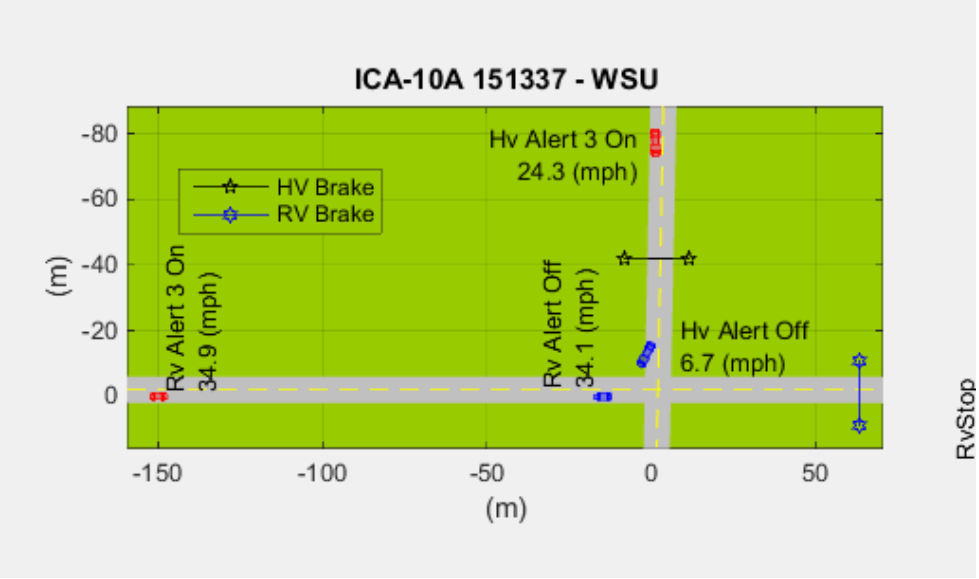


Figure 28: Example Vehicle Positions at IMA Alerts for ICA-10 Test

5.11 ICA-Summary Plots and Discussion

All of the ICA tests that have the HV and RV driven on perpendicular roadways (including: ICA-1A Tests 1-3, ICA-2A, ICA-3A, ICA-4A, ICA-6, ICA-7, ICA-9, and ICA-10) triggered alerts on the HV (Red Cascadia/WSU) that were very early and well before the HV would

normally begin to brake/slow down before coming to a stop at the intersection. Therefore the data were grouped by HV/RV test speed combinations for further analysis. The speed combinations and the corresponding test procedures are listed in Table 22. The 45/45 speed combination for Test ICA-1A Test 2 were not included due to the HV not being up to the test speed at alert onset, as discussed in Section 5.1.2.

Table 22: Test Procedures Grouped by HV/RV Speed Combination

HV/RV Speed Combination	Test Procedures	No. of Tests/Procedures	Total No. of Tests
22/35	ICA-2A ICA-3A ICA-4A	4 5 4	13
25/25	ICA-1A Test 1 ICA-9	4 5	9
25/35	ICA-10	4	4
25/45	ICA-1A Test 3	5	5
35/35	ICA-6 ICA-7	7 5	12

Boxplots of the HV TTC_{NA} to Intersection values for each speed combination are shown in Figure 29 for both the Level 2 and Level 3 alert onset. The box lengths represent the interquartile range, the horizontal line inside the box represents the group median, and the vertical lines (whiskers) extending beyond the box are the group minimum and maximum values. Values considered to be outliers are plotted with a + sign. The ranges for the HV TTC_{NA} were generally tighter for the Level 3 alert than they were for the Level 2 alert. The 25/35 speed combination had a wider range of values than the other speed combination even though it had a very limited number of tests (4 at Level 3 alert level). These tests are for the ICA-10 test procedure, which had significant timing issues between the HV and RV that probably contributed to increased variability (see Section 5.10 for further detail). The 35/35 combination had a relatively wide range of values for the Level 2 alert, but not the Level 3 alert. The ICA-6 and ICA-7 test procedures make up the data set for this speed combination and the ICA-7 TTC_{NA} values at the Level 2 alert were lower than those for the ICA-6 test procedure. It is not clear why there would be a difference because the braking onsets for both tests occurred after the Level 2 alert was issued.

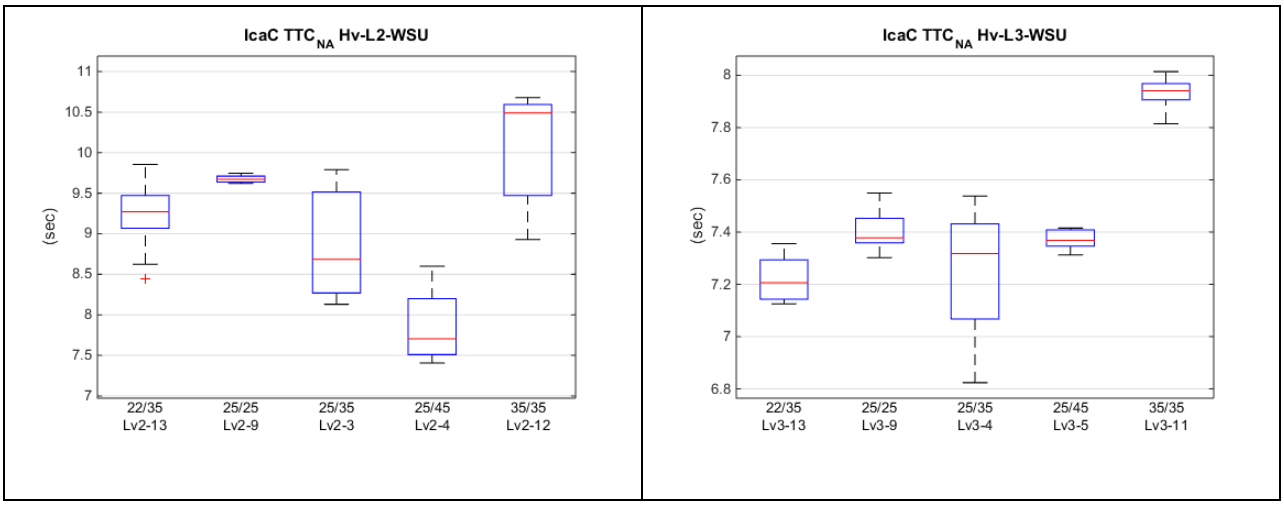


Figure 29: Boxplots of HV TTC_{NA} to Intersection at Level 2 and Level 3 Alert Onset

For all speed combinations, the HV TTC_{NA} ranged from approximately 7.4 to 10.7 seconds at Level 2 alerts and approximately 6.8 to 8.0 seconds for Level 3 alerts. The range for Level 3 alerts would reduce to 7.1 to 8.0 seconds if the ICA-10 (testing had timing issues between HV and RV for this procedure) results were not included. The alert times for this HV (Red Cascadia/WSU) are early and occur before a vehicle would start to slow down to come to a stop at the intersection. This would lead to many false alerts that drivers would likely find annoying. The early alerts resulted in the "no action" tests having alerts.

The WSU on the Cascadia tractor gives a yellow alert (Level 2) when sitting still at an intersection with the parking brake on. If the parking brake is off, it gives a red alert (Level 3) even if the tractor is not moving. Since this warning occurs prior to the vehicle starting to move, the ICA test procedures with the HV initially sitting at the intersection could not be performed properly because these test procedures are designed to elicit a red alert (Level 3) as the vehicle starts to move into the intersection.

6 Intersection Movement Assist Results

There were six IMA test procedures evaluated.

- IMA-1: RV Brakes to Stop at Intersection, HV Passes Through
- IMA-2: HV Moves Toward Intersection from Stop
- IMA-3: RV at Rest at Intersection, HV Passes Through
- IMA-4: RV Moves Slowly Toward Intersection, HV Passes Through
- IMA-5: HV Brakes to Avoid Intersection Collision, RV Passes Through
- IMA-6: HV and RV Move Slowly Toward Intersection

The test vehicles for all of the IMA tests:

- HV = Red Freightliner Cascadia with WSU, and
- RV = Honda Odyssey with Denso VAD.

The test procedures for these tests are documented in Appendix A - IMA Test Procedures.

6.1 IMA-1 RV Brakes to Stop at Intersection, HV Passes Through

For the IMA-1 test procedure, both the HV and RV approach the intersection at the same speed and would arrive at the same time if neither vehicle were slowed to avoid the collision. The RV brakes to a stop at the intersection. This test is designed to evaluate the V2V system's ability to suppress warnings as the RV slows down for the intersection. This test procedure is very similar to the ICA-6 test procedure depicted in Figure 20. The test conditions for the IMA-1 test are listed in Table 13. Details for this test procedure can be found in Appendix A, Section A.8.

Table 23: IMA-1 Test Conditions

Parameter	Value
V_{HV}	45 mph
V_{RV}	45 mph

The WSU was observed to issue alerts in this suppression test. Four tests were conducted. A limited number of tests were performed because the ICA tests were evaluated shortly after these tests were conducted and since the ICA-6 test is very similar to the IMA-1 test (main difference is a 35 mph test speed for both the HV and RV in ICA-6), it was decided not to go back and conduct further IMA-1 tests. The RV Range to Intersection at RV Brake Onset, RV Range to Intersection when RV Stopped, RV Braking Distance, Average RV Brake Deceleration, and Range to Intersection, TTC to Intersection, and RT Speed at IMA Level 3 Alert Onset are listed in Table 24. RT, GPS, and WSU data for these metrics and others are given in Appendix B, Section B.9.

The RV Range to Intersection at RV Brake Onset on average was 86 meters and the RV Range to Intersection at RV stopped on average was 13 m. The average RV deceleration was 2.3 m/s/s, which gave a 73 m average stopping distance.

There was quite a bit of variability in the HV and RV TTC to Intersection values (blank values indicate that the TTC was infinite – RV would not reach intersection at deceleration level). This probably occurred for a variety of reasons. The HV was not up to the test speed of 45 mph because the alerts occurred so early. Also, the timing of the RV and HV was such that they would not have arrived at the intersection at the same time. Finally, the RV had slowed much more in Tests 1124 and 1125 than it had in Tests 1126 and 1127 when the alerts came on. Further testing would normally be performed with the vehicles at the correct test speeds and with timing such that the vehicles would arrive at the intersection at the same time if the RV were not to brake, but it was thought that the ICA-6 test results in Section 5.6 provided enough information for this type of test procedure.

Table 24: IMA-1 WSU Based RV Range to Intersection at RV Brake Onset and RV Stopped, RV Braking Distance and Average Deceleration, and TTC, Range, and RT Speed at IMA Level 3 Alert Onset

Trial	RV Range to Int. (m)		RV Stop Dist. (m)	RV Avg. Decel (m/s^2)	Level 3 Onset					
	RV Brake Onset	RV Stop			Range to Int. (m)		TTC to Int. (s)		Speed RT (mph)	
					HV	RV	HV	RV	HV	RV
1124	84.1	13.4	70.7	2.3	150	49	7.5		41.3	30.1
1125	82.0	13.2	68.7	2.2	152	63	7.5		41.4	35.4
1126	84.4	12.3	72.2	2.5	144	84	6.2	4.6	39.5	42.6
1127	92.8	11.6	81.2	2.2	144	85	6.2	5.1	39.3	41.8
Ave.	85.8	12.6	73.2	2.3	147	70	6.8	4.9	40.4	37.5
Std.	4.8	0.8	5.5	0.1	4	18	0.7	0.4	1.1	5.9
C. of V. (%)	5.5	6.7	7.5	5.3	2	25	10.8	7.2	2.7	15.7

6.2 IMA-2 HV Moves Toward Intersection From Stop

For the IMA-2 test procedure the RV passes through the intersection at speed and the HV is stopped at the intersection. The HV driver inches into the intersection upon a Level 2 warning to determine if the V2V system (WSU in this case) will then issue a Level 3 alert. This is very similar to the ICA-1B test procedure depicted in Figure 5. The test conditions for the IMA-2 test are listed in Table 25. Details for this test procedure can be found in Appendix A, Section A.9.

Table 25: IMA-2 Test Conditions

Parameter	Value
V_{HV}	0 mph
V_{RV}	45 mph

Eight tests were performed and five tests gave a Level 3 alert prior to the HV moving towards the intersection. The other three tests did not produce an alert and it is believed this occurred because the HV had moved backward away from the intersection prior to one of the tests and then moved slightly forward prior to the next two tests. After observing that these three tests did not produce an alert, the HV was moved back 50 feet or more from the intersection and then driven back to the intersection and stopped. The HV then started to alert again as the RV approached the intersection. The process of moving the HV slightly backward and slightly forward may have caused the WSU to lose path information.

The RV TTC to Intersection, Range to Intersection, and Speed at Level 3 alert onset and offset are given in Table 26. RT, GPS, and WSU data for these metrics and others are given in Appendix B, Section B.10. The TTC and Range at alert onset was very consistent at

approximately 6.1 seconds and 125 meters on average. The alert consistently extinguished after the RV had reached the intersection (negative values mean the front of the vehicle is through the intersection point by the given distance). In a couple of tests the HV driver did start to move into the intersection when the Level 3 alert was issued and therefore there is an HV speed at Level 3 alert offset for these tests.

Table 26: IMA-2 TTC, Range, and Speed at IMA Level 3 Alert Onset and Offset

Test No.	IMA Level 3 Onset				IMA Level 3 Offset		
	TTC RV to Intersection (sec)	Range RV to Intersection (m)	Speed RT (mph)		Range RV to Intersection (m)	Speed RT (mph)	
			HV	RV		RV	HV
1111	6.1	123	0.0	45.0	-1.8	0.3	45.1
1112	6.1	121	0.0	44.6	-1.8	0.0	45.0
1113	6.1	126	0.0	46.0	-1.8	2.2	44.9
1117	6.2	126	0.0	45.7	-3.8	0.0	44.7
1118	6.2	127	0.0	46.0	-2.9	0.0	43.5
Ave.	6.1	125	0.0	45.5	-2.4	0.5	44.6
Std.	0.0	2	0.0	0.6	0.9	1.0	0.6
C. of V. (%)	0.7	2		1.4	38.4	194.6	1.4

The intent of this test is to elicit a Level 2 warning as the RV approaches the intersection, then the HV driver should start to pull into the intersection, and finally the driver stops the HV upon onset of the Level 3 alert. Since the Level 3 alert occurs before the HV even starts to move into the intersection, the test cannot be performed as intended.

This test procedure is very similar to the ICA-1B test procedures. Similar results can be found in the ICA-1B Test 1 results in Section 5.1.5.

6.3 IMA-3 RV at Rest at Intersection, HV Passes Through

For the IMA-3 test procedure the RV sits at rest at the intersection as the HV passes through at speed. The RV does not move during this test. The initial set up of the test procedure is similar to the ICA-1B test procedures except the RV is at rest for the IMA-3 test procedure while the HV is at rest for the ICA-1B test. The test conditions for the IMA-3 test are listed in Table 27. No IMA alert should be issued on the HV. Details for this test procedure can be found in Appendix A, Section A.10.

Table 27: IMA-3 Test Conditions

Parameter	Value
V_{HV}	45 mph
V_{RV}	0 mph

Ten tests were conducted (two sets of five). No alerts were issued for all of the tests and therefore the WSU passed this test procedure. There is an IMA location classification channel

available in the data broadcast by the WSU. The HV Range to Intersection for when the RV is classified as a potential IMA threat is given in Table 28 and Table 29 for the two sets of tests. RT, GPS, and WSU data for these metrics are given in Appendix B, Section B.11. The WSU consistently classified the RV as a potential threat at approximately 300 m despite a range of HV Speeds (40 to 45 mph). It was not intended that the HV had to be up to the test speed of 45 mph when it was 300 m from the intersection.

Table 28: IMA-3 HV Range, and Speed at Classification as Potential IMA Threat – Day 1

Test No.	IMA Location Classified		
	Range HV to Intersection (m)	Speed RT (mph)	
		HV	RV
1119	300	40.9	0.0
1120	299	44.4	0.0
1121	299	43.4	0.0
1122	300	41.1	0.0
1123	300	43.7	0.0
Ave.	300	42.7	0.0
Std.	1	1.6	0.0
C. of V. (%)	0	3.8	

Table 29: IMA-3 HV Range and Speed at Classification as Potential IMA Threat – Day 2

Test No.	**IMA Location Classified**		
	Range HV to Intersection (m)	**Speed RT (mph)**	
		HV	**RV**
1340	300	42.9	0.0
1341	299	40.0	0.0
1342	298	43.2	0.0
1343	299	44.9	0.0
1344	299	45.3	0.0
Ave.	299	43.2	0.0
Std.	1	2.1	0.0
C. of V. (%)	0	4.8	

6.4 IMA-4 RV Moves Slowly Toward Intersection, HV Passes Through

For the IMA-4 test procedure the RV moves slowly towards the intersection as the HV passes through the intersection. The RV speed is increased for successive runs until the HV V2V system

starts to issue IMA alerts. This test procedure looks very similar to the ICA-1A test procedure depicted in Figure 5. The test conditions for the IMA-4 test are listed in Table 30. Details for this test procedure can be found in Appendix A, Section A.11.

Table 30: IMA-4 Test Conditions

Parameter	Value
V_{HV}	45 mph
V_{RV}	Increase speed until alerts occur

Seven tests were performed. The first two tests and the last test did not issue alerts. The RV speed was lowered for the last test to help define transition speed between no alerts and alerts. The maximum HV and RV speeds for the tests that did not issue alerts are listed in Table 31. The highest RV speed that did not cause the HV to alert was 15.6 mph.

Table 31: IMA-4 Speeds for Tests With No Alerts

Test No.	HV Speed (mph)	RV Speed (mph)
1345	45.0	10.8
1346	44.8	15.6
1351	45.0	15.2

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 32. RT, GPS, and WSU data for the Level 2 and Level 3 Alert onset and offset tabulated data are given in Appendix B, Section B.12. The lowest RV test speed that caused the HV V2V system to issue an alert was 16 mph. Despite a fairly wide range in RV TTC values at the Level 3 alert, the HV TTC values were fairly consistent with an average of 8.7 seconds and a standard deviation of less than 0.1 seconds.

Table 32: IMA-4 TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1347	8.7	5.5	172	48	44.7	19.4
1348	8.8	5.2	176	47	45.6	20.3
1349	8.7	6.6	175	64	45.3	17.9
1350	8.7	6.9	173	65	45.1	16.1
Ave.	8.7	6.1	174	56	45.2	18.4
Std.	0.0	0.8	2	10	0.4	1.9
C. of V. (%)	0.5	13.8	1	18	0.8	10.1

6.5 IMA-5 HV Brakes to Avoid Intersection Collision, RV Passes Through

For the IMA-5 test procedure the HV and RV approach the intersection at the same speed and timing such that if no braking occurs that the vehicles would arrive at the same time. The HV brakes are applied to avoid the intersection collision with the RV and the RV continues through the intersection at the initial test speed. This test procedure is the same as ICA-1A Test 2 procedure (both vehicles initially at 45 mph as they approach intersection) for the Cascadia/WSU because of the early onset of alerts for this vehicle and due to no intervention capabilities (no automatic reduction of engine torque and/or no application of foundation brakes). Please see the ICA-1A Test 2 results for this maneuver (Section 5.1.2). Details for this test procedure can be found in Appendix A, Section A.12.

6.6 IMA-6 HV and RV Move Slowly Toward Intersection

For the IMA-6 test procedure the HV and RV approach the intersection at the same speed, which both are increased on successive trials until the HV V2V system starts to issue alerts. The timing of the vehicles is such that they would arrive at the intersection at the same time if no braking were applied to either vehicle. This test procedure looks very similar to the ICA-1A test procedure depicted in Figure 5. The test conditions for the IMA-6 test are listed in Table 33. Details for this test procedure can be found in Appendix A, Section A.13.

Table 33: IMA-6 Test Conditions

Parameter	Value
V_{HV}	Increase speed until alerts occur
V_{RV}	Increase speed until alerts occur

Five tests were conducted. Only one test did not produce alerts (Test 1352). The HV maximum speed for this test was 10.6 mph and the RV maximum speed was 11.3 mph. The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 34. Alert onset and offset tabulated data are given in Appendix B, Section B.13. For the tests with alerts the HV minimum speed at alert was 14.3 mph and the RV minimum speed was 15.3 mph. Further testing in the 12 to 15 mph range would need to be conducted to better define the exact speeds at which the V2V system starts to issue alerts. The HV TTC to Intersection average value was 7.1 seconds with a standard deviation of less than 0.1 second.

Table 34: IMA-6 TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset					
	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1353	7.1	6.5	46	45	14.3	15.6
1354	7.1	7.0	53	50	16.8	16.2
1355	7.0	7.5	50	53	16.2	15.9
1356	7.1	5.7	47	39	14.5	15.3
Ave.	7.1	6.7	49	47	15.5	15.7
Std.	0.0	0.7	3	6	1.2	0.4
C. of V. (%)	0.4	11.2	7	13	8.1	2.4

7 IMA Bridge Test

The IMA bridge test was developed after reviewing *Integrated Light Vehicle Model Deployment Research Project Update* [6] that showed that V2V-equipped vehicles would get false positive IMA warnings when they would pass each other when crossing over or under a bridge. For this test, one vehicle was driven on the TRC High Speed Test Track (HSTT) and the other was driven on the TRC access road, which has a bridge that crosses over the HSTT.

The test vehicles for all of the IMA bridge tests:

- HV = Red Freightliner Cascadia with WSU – On Test Track/Underneath Bridge
- RV = Blue Freightliner Cascadia with WSU – On Bridge

Tests were conducted on three days. WSU data were collected on both the HV and the RV. On the third day a few tests were conducted with the HV and RV in reversed roles (HV on bridge, RV on test track). The data for the HV are presented first followed by the data for the RV.

The testing conducted did result in IMA alerts on both the HV and the RV even though the vehicles were not directly intersecting with each other due to the different road heights (one vehicle on the bridge and one vehicle going underneath the bridge).

7.1 IMA Bridge Test Results for the HV

On the first day of testing the HV was trying to maintain a speed of 40 mph while the RV was trying to maintain a speed of 45 mph. On the second and third day of testing both vehicles were trying to maintain a speed of 45 mph. Some of the testing on the third day was performed with the HV and RV in reversed roles. The data are grouped by speed combination and HV/RV role.

7.1.1 HV = 40 mph, RV = 45 mph

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 35 for the testing with the HV going 40 mph and the RV going 45 mph. RT, GPS, and WSU data for these metrics are given in Appendix B, Section B.14.1. Six tests were conducted. The HV TTC to Intersection at Level 3 alert onset times were fairly consistent with an average value of 8.1 seconds and a standard deviation of 0.5 seconds. The RV TTC was also consistent with an average value of 6.4 seconds and a standard deviation of 0.5 seconds. For the HV TTC values, Test 1797 is an outlier with a value of 7.0 seconds. In general, the RV would reach the intersection about 1.7 seconds before the HV on average. This timing can be easily reduced with a few practice runs.

Table 35: IMA-Bridge TTC, Range, and Speed at HV IMA Level 3 Alert Onset (HV = 40 mph, RV = 45 mph)

Test No.	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1796	8.1	6.8	145	131	40.3	43.0
1797	7.0	6.7	125	132	40.3	43.9
1798	8.3	6.3	146	123	39.6	44.3
1799	8.2	5.9	146	110	40.0	41.6
1800	8.3	6.9	148	132	40.1	42.7
1801	8.4	5.6	150	110	40.1	44.2
Average	8.1	6.4	143	123	40.1	43.3
Std. Dev.	0.5	0.5	9	10	0.3	1.0
C. of V. (%)	6.5	8.6	6	8	0.6	2.4

The timing of the first alert after the HV has found the RV and after the HV has classified the RV as a potential IMA threat are listed in Table 36 for each test. The First Alert Level Type is also listed (Level 2 or 3). For Test 1797 the timing of the alert was coincident with the RV being

found and classified as an IMA threat (0.00 seconds). This probably explains why the HV TTC for this test is lower than it is for the other tests. The HV was not able to track the RV until it was already a threat.

Table 36: IMA-Bridge Timing of First Alert After the HV Has Found the RV and After RV Is IMA Threat (HV = 40 mph, RV = 45 mph)

Test No.	First Alert Type	Time of Alert After (sec)	
		RV Found	IMA Loc.
1796	Level 3	1.30	1.30
1797	Level 3	0.00	0.00
1798	Level 2	5.49	2.50
1799	Level 2	4.89	2.20
1800	Level 2	0.30	0.30
1801	Level 2	1.80	1.80

The vertical distance between the HV and RV as measured with the RT and WSU at the Level 3 alert onset are listed in Table 37 (GPS data was not working for these tests). The WSU data have over a 2 meter greater average vertical difference than the RT measured values for this set of tests (8.7 versus 6.5 meters). Both have similar standard deviations (0.5 versus 0.7 meters). Using the alert onset as a point of reference for the differences in the vertical distance is not the best choice because the alert onset occurred at different points along the bridge for each test. A better comparison would be to compare vertical distance differences at set points. This is examined further in the next section with the HV = RV = 45 mph test data that had GPS measured data.

Table 37: IMA-Bridge Vertical Distance Between HV and RV at Level 3 Alert Onset (HV = 40 mph, RV = 45 mph)

Test No.	Vertical Dist. RV to HV (m)		
	RT	GPS	WSU
1796	5.6		8.4
1797	6.1		8.8
1798	6.6		9.0
1799	7.3		8.6
1800	6.3		8.1
1801	7.0		9.5
Average	6.5		8.7
Std. Dev.	0.6		0.5
C. of V. (%)	9.4		5.4

7.1.2 HV = RV = 45 mph

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 38 for the testing with the HV and the RV going 45 mph. RT, GPS, and WSU data for these metrics are given in Appendix B, Section B.14.1. There were 14 tests that produced Level 3 alerts. The HV TTC to Intersection at Level 3 alert onset times on average were 7.8 seconds with a standard deviation of 1.2 seconds. One of the tests (Test 1847) was an outlier due to the HV arriving at the intersection well before the RV, which had an HV TTC value of 4.1 seconds. The HV and RV Range to Intersection at alert were fairly different for this test (82 versus 152 meters). This test would not be considered valid due to the large difference in range. The same is true for Test 1849, which had a large difference in range as well, but with the RV arriving before the HV (176 versus 85 meters).

Table 38: IMA-Bridge TTC, Range, and Speed at HV IMA Level 3 Alert Onset (HV = RV = 45 mph)

Test No.	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1847	4.1	7.7	81.6	152.2	45.1	44.6
1849	8.7	4.6	176.0	85.0	45.7	41.6
1850	7.6	7.5	153.3	147.7	45.3	44.4
1851	7.3	7.0	141.8	143.3	43.6	45.9
1852	8.2	7.6	167.4	148.2	46.3	43.9
1855	7.7	7.7	154.3	151.2	45.0	43.7
1856	6.6	6.6	132.5	128.9	44.8	43.4
1858	8.6	6.2	171.5	123.8	45.0	44.4
1859	8.5	7.3	169.6	141.8	44.7	43.3
1861	8.4	6.4	168.7	122.9	45.0	42.7
1862	8.5	7.0	169.6	139.2	44.9	44.4
1863	7.9	7.8	158.4	153.3	44.9	43.5
1864	8.5	7.3	170.0	138.1	44.9	42.5
1865	8.5	7.3	169.8	145.3	45.0	44.7
Average	7.8	7.0	156.0	137.2	45.0	43.8
Std. Dev.	1.2	0.8	24.8	18.0	0.6	1.1
C. of V. (%)	15.7	12.1	15.9	13.1	1.3	2.5

The timing of the first alert after the HV has found the RV and after the HV has classified the RV as a potential IMA threat data are listed in Table 39. The HV was not able to track the RV for very long before issuing an alert for some cases. For the tests where the HV was able to track the RV before a Level 2 Alert, the Level 3 Alert HV TTC times are longer with Tests 1849, 1858, 1859, 1861, 1862, 1864, and 1865 having HV TTC values greater than or equal to 8.4 seconds while the other tests had HV TTC values ranging from 4.0 to 8.1 seconds.

Table 39: IMA-Bridge Timing of First Alert After the HV Has Found the RV and After RV Is IMA Threat (HV = RV = 45 mph)

Test No.	First Alert Type	Time of Alert After (sec)	
		RV Found	IMA Loc.
1847	Level 3	5.3	4.1
1849	Level 2	8.3	0.7
1850	Level 3	1.6	1.6
1851	Level 3	0.1	0.0
1852	Level 3	2.0	1.9
1855	Level 3	4.5	2.7
1856	Level 3	2.2	2.2
1858	Level 2	4.4	1.4
1859	Level 2	2.1	2.0
1861	Level 2	10.3	1.6
1862	Level 2	2.3	2.1
1863	Level 3	1.0	1.0
1864	Level 2	2.8	1.4
1865	Level 2	1.4	1.5

The vertical distance between the HV and RV as measured with the RT, GPS, and WSU at the Level 3 alert onset are listed in Table 40. The WSU average value was 2.5 meters greater than it was from the RT and GPS data, which were in good agreement with each other on average (although individual tests were up to 0.6 meters different). The standard deviation for each measurement type was fairly similar, ranging from 0.8 to 1.1 meters.

Table 40: IMA-Bridge Vertical Distance Between HV and RV at Level 3 Alert Onset (HV = RV = 45 mph)

Test No.	Vertical Dist. RV to HV (m)		
	RT	GPS	WSU
1847	5.1	5.2	7.3
1849	8.6	8.7	11.0
1850	5.8	5.9	10.3
1851	5.9	5.9	8.0
1852	5.7	5.7	10.0
1855	5.7	6.3	9.4
1856	6.7	7.1	7.9
1858	6.7	6.7	8.1
1859	6.3	6.3	8.3
1861	7.0	7.6	8.8
1862	6.4	6.3	7.3
1863	5.7	5.6	8.3
1864	6.4	6.4	9.2
1865	6.1	6.0	9.1
Average	6.3	6.4	8.8
Std. Dev.	0.8	0.9	1.1
C. of V. (%)	13.4	14.0	12.7

The measured altitude for each test is plotted as a function of Eastings position for the RV and the HV in Figure 30. Neither vehicle is traveling in a true east direction so neither set of plots is a true indication of how far the vehicle is traveling in the ground plane. The vehicles are starting on the right side and moving to the left in the plots. The RV data are plotted in the top row of figures and the HV data are plotted in the bottom row. The WSU data are in the left column and the GPS data are in the right. The HV alert onset is designated with a +. The degree of scatter in the + symbols indicates how variable the alert onset was. The HV goes underneath the bridge at approximately 509250 Eastings, which explains why the HV altitude traces have major jumps in value at this point (the bridge blocks satellites from the GPS antenna, thus reducing the position accuracy). One of the WSU RV traces has a major jump in value near the peak point on the bridge.

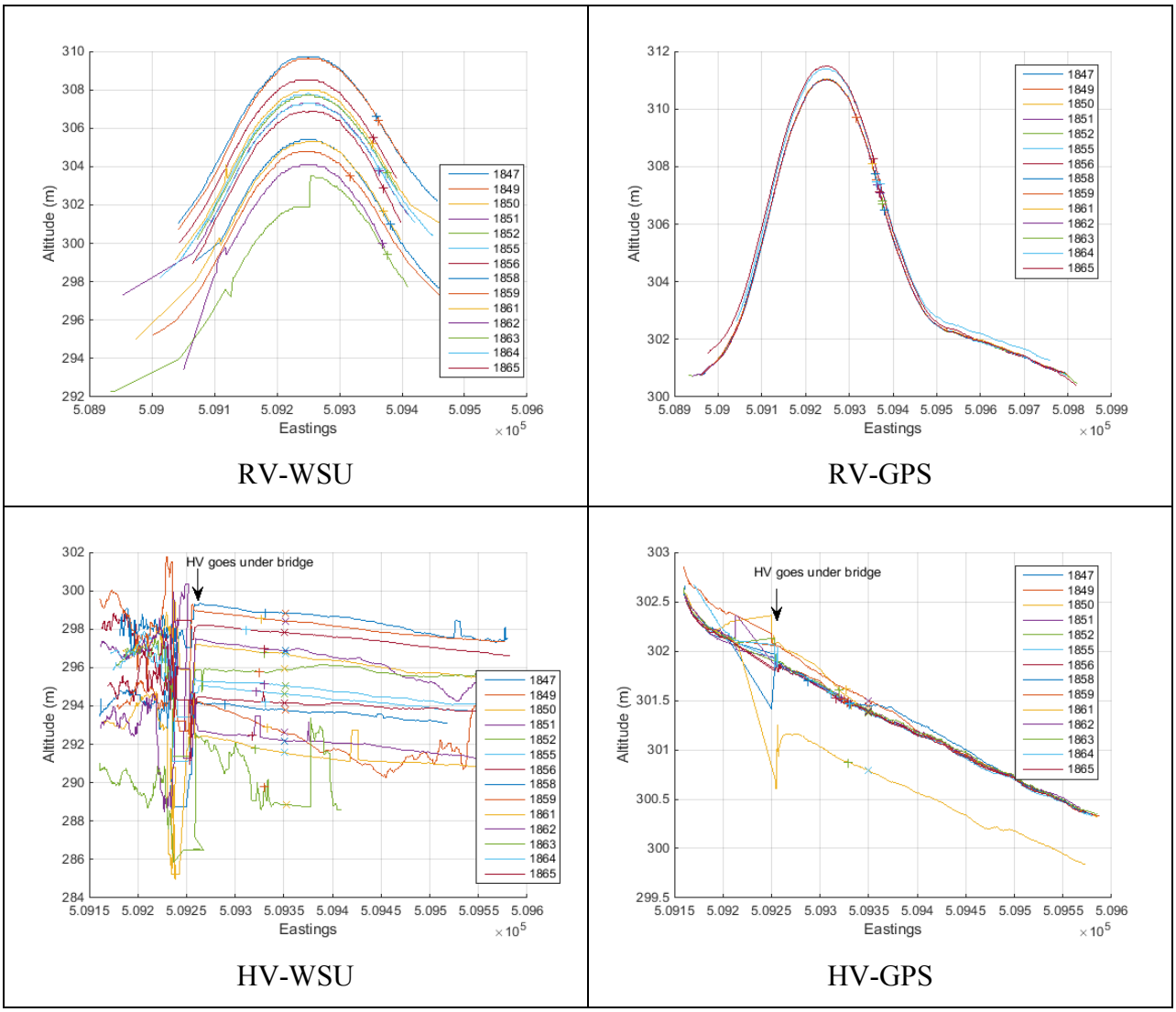


Figure 30: Altitude as a Function of Eastings for RV (Top) and HV (Bottom) for WSU (Left) and GPS (Right) Data

HV and RV altitude values at set locations for the WSU and GPS data are presented in Table 41. For the RV, the peak point on the bridge was the set location. Since the data jumps as the HV goes under the bridge, the selected location for the HV data was arbitrarily chosen at 503950 Eastings. The range of altitude values for the WSU data at the peak of the bridge (RV) ranges from 301.9 to 309.7 meters, a 7.8 meter range (including the trace with the jump in value). The average and standard deviation were 306.7 and 2.2 meters respectively. The RV GPS data have a range of 311.0 to 311.5 meters, a 0.5 meter range (311.1 and 0.2 meter average and standard deviation). Most of the GPS data peaks were very near 311.0 meters with two tests deviating from the narrow range. For the HV WSU data, the altitude ranged from 288.8 to 298.8, a 10 meter range (294.8 and 2.9 meter average and standard deviation). One test contributed 2.5 meters to this range. For the HV GPS data, the altitude ranged from 300.8 to 301.5 meters, a 0.7 meter range (301.4 and 0.2 meter average and standard deviation). One of the tests contributed almost 0.5 meters to this range. The average difference in the HV and RV altitudes for the WSU measured data was 11.9 meters with a 1 meter standard deviation, which was far less than the

individual measurement standard deviations of 2.9 and 2.2 meters for the HV and RV WSU data, respectively. The average difference between the HV and RV GPS measured altitudes was 9.7 meters with a 0.2 meter standard deviation.

Table 41: HV and RV Altitude Measured Values and Differences at Set Locations for WSU and GPS Data

Test No.	WSU Altitude			GPS Altitude		
	HV (m)	RV (m)	Difference (m)	HV (m)	RV (m)	Difference (m)
1847	293.8	305.4	11.6	301.4	311.0	9.6
1849	292.6	304.8	12.2	301.4	311.0	9.6
1850	291.6	305.3	13.7	301.4	311.0	9.6
1851	292.2	304.1	11.9	301.4	311.0	9.6
1852	288.8	301.9	13.1	301.4	311.0	9.7
1855	294.6	307.8	13.2	301.4	311.4	10.0
1856	297.8	308.5	10.7	301.4	311.5	10.1
1858	298.8	309.7	10.9	301.4	311.0	9.6
1859	298.4	309.6	11.2	301.5	311.0	9.5
1861	296.7	308.0	11.3	300.8	311.0	10.2
1862	296.9	307.3	10.4	301.4	311.0	9.6
1863	295.9	307.7	11.8	301.4	311.0	9.6
1864	295.0	307.3	12.3	301.4	311.0	9.6
1865	294.2	306.8	12.6	301.4	311.0	9.6
Mean	294.8	306.7	11.9	301.4	311.1	9.7
Std Dev	2.9	2.2	1.0	0.2	0.2	0.2
C. of V. (%)	1.0	0.7	8.3	0.1	0.0	2.2

7.1.3 HV and RV Reversed Roles

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 42 for the testing with the HV and the RV in reversed roles. Five tests conducted for this condition. RT, GPS, and WSU data for these metrics are given in Appendix B, Section B.14.1. The HV TTC to Intersection at Level 3 alert onset times on average were 7.3 seconds with a standard deviation of 1.1 seconds. One of the tests was an outlier due to the HV arriving at the intersection well before the RV (Test 1868), which had an HV TTC value of 5.6 seconds. The HV and RV Range to Intersection at alert values were fairly different for this test (111 versus 146 meters).

Table 42: IMA-Bridge TTC, Range, and Speed at HV IMA Level 3 Alert Onset (HV and RV Reversed Roles)

Test No.	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1867	8.5	5.4	169.0	108.1	44.7	45.2
1868	5.5	7.3	110.5	146.0	45.0	45.3
1869	8.0	7.1	155.1	141.7	43.3	45.3
1870	7.5	7.3	147.7	146.8	44.3	45.3
1871	7.3	7.4	142.5	149.6	43.4	45.3
Average	7.3	6.9	145.0	138.4	44.1	45.3
Std. Dev.	1.1	0.9	21.7	17.2	0.8	0.0
C. of V. (%)	15.4	12.4	15.0	12.4	1.7	0.1

The timing of the first alert after the HV has found the RV and after the HV has classified the RV as a potential IMA threat are listed in Table 43. The HV was not able to track the RV for very long before issuing an alert for some cases. For the tests where the HV was able to track the RV before a Level 2 Alert, the Level 3 Alert HV TTC times are longer, with Tests 1867 and 1869 having HV TTC values greater than or equal to 8.3 seconds, while the other tests had HV TTC values ranging from 5.6 to 7.8 seconds.

Table 43: IMA-Bridge Timing of First Alert After the HV Has Found the RV and After RV Is IMA Threat (HV and RV Reversed Roles)

Test No.	**First Alert Type**	**Time of Alert After (sec)**	
		RV Found	**IMA Loc.**
1867	Level 2	5.99	1.10
1868	Level 3	3.89	3.69
1869	Level 2	2.00	2.00
1870	Level 3	1.30	1.30
1871	Level 3	2.70	2.70

The vertical distance between the HV and RV as measured with the RT, GPS, and WSU at the Level 3 alert onset are listed in Table 44. The WSU average value was 2.8 meters lower than it was from the RT and GPS data, which were in good agreement with each other on average and for each individual test. The WSU values being lower for the Reversed Role tests is opposite of what was found in the tests where the HV and RV were in the "normal" roles. This suggests that there might be an offset in the height for one or both vehicles. The standard deviation for each measurement type was fairly similar ranging from 1.1 to 1.3 meters.

Table 44: IMA-Bridge Vertical Distance Between HV and RV at Level 3 Alert Onset (HV and RV Reversed Roles)

Test No.	Vertical Dist. RV to HV (m)		
	RT	GPS	WSU
1867	4.4	4.5	0.8
1868	7.2	7.3	4.2
1869	5.0	5.0	2.6
1870	5.4	5.3	2.5
1871	5.6	5.6	3.4
Average	5.5	5.5	2.7
Std. Dev.	1.1	1.1	1.3
C. of V. (%)	19.3	19.0	46.4

The measured altitude for each test is plotted as a function of Eastings position for the RV and the HV in Figure 31. The RV data are plotted in the top row of figures and the HV data are plotted in the bottom row. The WSU data are in the left column and the GPS data are in the right. The HV alert onset is designated with a +. The degree of scatter in the + symbols indicates how variable the alert onset was. The RV goes underneath the bridge at approximately 509250 Eastings, which explains why the HV altitude traces have major jumps in value at this point (the bridge blocks satellites from the GPS antenna, thus reducing the position accuracy). The HV WSU trace for Test 1868 (lower left hand plot) has more noise than the other traces.

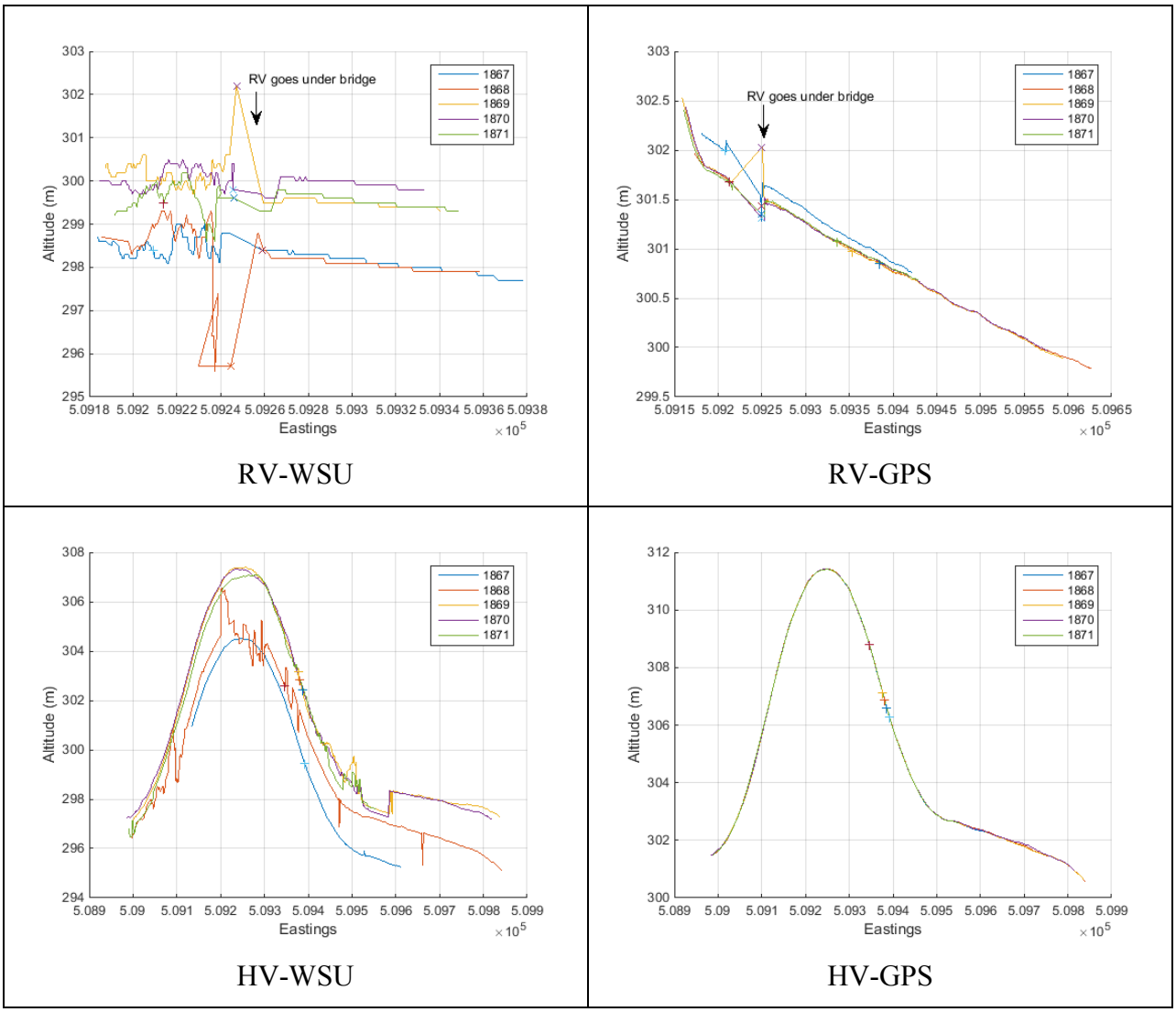


Figure 31: Altitude as a Function of Eastings for RV (Top) and HV (Bottom) for WSU (Left) and GPS (Right) Data

HV and RV altitude values at set locations for the WSU and GPS data are presented in Table 45. For the HV the peak point on the bridge was the set location. Since the data jumps as the RV goes under the bridge, the selected location for the RV data was arbitrarily chosen at 503930 Eastings (slightly later than in the 45/45 tests due to lack of data at 509350 Eastings for some tests). The range of altitude values for the WSU data at the peak of the bridge (HV) ranges from 304.4 to 307.4 meters, a 3.0 meter range. The average and standard deviation values were 306.1 and 1.5 meters respectively. The HV GPS altitude was 311.4 meters for all tests. For the RV WSU data, the altitude ranged from 297.9 to 299.8, a 1.9 meter range (298.9 and 0.9 meter average and standard deviation). For the RV GPS data, the altitude ranged from 301.1 to 301.2 meters, a 0.1 meter range. The average difference in the HV and RV altitudes for the WSU measured data was 7.2 meters with a 0.7 meter standard deviation, which was less than the individual measurement standard deviations of 1.5 and 0.9 meters for the HV and RV WSU data respectively. The average difference between the HV and RV GPS measured altitudes was 10.3 meters with a standard deviation of less than 0.1 meters.

Table 45: HV and RV Altitude Measured Values and Differences at Set Locations for WSU and GPS Data

Test No.	WSU Altitude			GPS Altitude		
	HV (m)	RV (m)	Difference (m)	HV (m)	RV (m)	Difference (m)
1867	304.5	298.0	6.5	311.4	301.2	10.2
1868	304.4	297.9	6.5	311.4	301.1	10.3
1869	307.4	299.4	8.0	311.4	301.1	10.3
1870	307.3	299.8	7.5	311.4	301.1	10.3
1871	307.0	299.4	7.6	311.4	301.1	10.3
Mean	306.1	298.9	7.2	311.4	301.1	10.3
Std Dev	1.5	0.9	0.7	0.0	0.0	0.0
C. of V. (%)	0.5	0.3	9.3	0.0	0.0	0.5

7.2 IMA Bridge Test Results for the RV

As was the case for the HV data, the RV data are grouped by speed combination and HV/RV role.

7.2.1 HV = 40 mph, RV = 45 mph

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 46 for the testing with the HV going 40 mph and the RV going 45 mph. RT, GPS, and WSU data for these metrics are given in Appendix B, Section B.14.2. There were six tests. The average HV TTC was 8.4 seconds with a 0.8 second standard deviation and the average RV TTC was 6.8 seconds with a standard deviation of 0.5 seconds. For Tests 1799 through 1801 the HV arrived at the intersection earlier than the RV.

Table 46: IMA-Bridge TTC, Range, and Speed at RV IMA Level 3 Alert Onset (HV = 40 mph, RV = 45 mph)

Test No.	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1796	8.5	7.4	152	142	40.3	43.0
1797	7.2	7.3	129	144	40.3	44.2
1798	8.4	6.6	148	132	39.6	44.5
1799	8.1	6.3	145	118	40.0	41.6
1800	9.8	7.0	174	134	40.1	42.7
1801	8.3	6.1	147	120	40.1	43.8
Average	8.4	6.8	149	132	40.1	43.3
Std. Dev.	0.8	0.5	14	11	0.3	1.1
C. of V. (%)	9.8	7.9	10	8	0.6	2.6

The timing of the first alert after the RV has found the HV and after the RV has classified the HV as a potential IMA threat are listed in Table 47 for each test. The First Alert Level Type was Level 3 for all tests. For Tests 1799 and 1801 the RV was tracking the HV for a long time prior to issuing the Level 3 Alert. It may not have issued the Level 2 warning because the HV was arriving at the intersection prior to the RV.

Table 47: IMA-Bridge Timing of First Alert After the RV Has Found the HV and After HV Is IMA Threat (HV = 40 mph, RV = 45 mph)

Test No.	First Alert Type	Time of Alert After (sec)	
		HV Found	IMA Loc.
1796	Level 3	0.20	0.10
1797	Level 3	0.20	0.10
1798	Level 3	1.60	1.50
1799	Level 3	14.06	3.39
1800	Level 3	2.50	2.40
1801	Level 3	13.76	3.59

The vertical distance between the HV and RV as measured with the RT and WSU at the Level 3 alert onset are listed in Table 48 (GPS data was not working for these tests). The WSU data have over a 2 meter greater average vertical difference than the RT measured values for this set of tests (8.6 versus 6.2 meters).

Table 48: IMA-Bridge Vertical Distance Between HV and RV at Level 3 Alert Onset (HV = 40 mph, RV = 45 mph)

Test No.	Vertical Dist. RV to HV (m)	
	RT	WSU
1796	5.5	8.4
1797	5.6	8.5
1798	6.4	8.9
1799	7.0	8.5
1800	6.1	8.1
1801	6.8	9.4
Average	6.2	8.6
Std. Dev.	0.6	0.4
C. of V. (%)	9.8	5.2

7.2.2 HV = RV = 45 mph

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 49 for the testing with the HV and the RV going 45 mph. There were fourteen tests that produced a Level 3 alert. RT, GPS, and WSU data for these metrics are given in Appendix B, Section B.14.2. The HV TTC to Intersection at Level 3 alert onset times on average were 6.5 seconds with a standard deviation of 1.7 seconds. The RV TTC times on average were 6.0 seconds with a standard deviation of 1.3 seconds. Two of the tests are outliers (Test 1849 and1860) due to the HV or RV arriving at the intersection well before the RV or HV. Test 1849 had an RV TTC value of 3.0 seconds and Test 1860 had an HV TTC value of 1.6 seconds. The HV and RV Range to Intersection at alert were fairly different for these tests (55 versus 151 meters for Test 1849 and 31 versus 178 meters for Test 1860). These tests would not be considered valid due to the large difference in range. Tests 1858, 1861, and 1862 also had larger differences in HV/RV Range values, but not as different as 1849 and 1860.

Table 49: IMA-Bridge TTC, Range, and Speed at RV IMA Level 3 Alert Onset (HV = RV = 45 mph)

Test No.	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1849	7.4	3.0	151	55	45.8	41.0
1850	6.7	7.3	134	144	45.3	44.4
1851	5.6	5.4	109	109	44.1	45.1
1852	8.9	6.5	182	129	46.1	44.0
1855	5.7	5.6	113	113	44.8	44.4
1856	6.4	6.7	128	131	44.8	43.3
1858	6.3	5.1	127	103	45.1	44.9
1859	7.0	5.7	138	109	44.7	42.9
1860	1.6	8.9	31	178	45.2	45.1
1861	7.3	5.2	147	99	45.1	42.3
1862	7.4	5.4	149	105	45.1	44.0
1863	5.5	6.9	110	137	44.7	44.2
1864	7.3	5.9	145	112	44.9	42.1
1865	7.3	5.8	145	117	45.0	44.9
Average	6.5	6.0	129	117	45.1	43.8
Std. Dev.	1.7	1.3	34	27	0.5	1.3
C. of V. (%)	25.9	22.1	26	23	1.1	2.9

The timing of the first alert after the RV has found the HV and after the RV has classified the HV as a potential IMA threat are listed in Table 50. The RV was not able to track the HV for very long before issuing an alert for some cases. For the one test where the RV was able to track the HV before a Level 2 Alert, the Level 3 Alert RV TTC was 8.1 seconds (Test 1860). All the other tests had RV TTC values ranging from 3.0 to 7.2 seconds. For Tests 1849, 1858, and 1861 the RV was tracking the HV for a long time prior to issuing the Level 3 Alert. It may not have issued the Level 2 warning because the RV was arriving at the intersection prior to the HV.

Table 50: IMA-Bridge Timing of First Alert After the RV Has Found the HV and After HV Is IMA Threat (HV = RV = 45 mph)

Test No.	First Alert Type	Time of Alert After (sec)	
		HV Found	IMA Loc.
1849	Level 3	12.77	4.69
1850	Level 3	1.40	1.40
1851	Level 3	0.00	0.00
1852	Level 3	2.79	2.79
1855	Level 3	0.10	0.10
1856	Level 3	0.10	0.10
1858	Level 3	12.47	3.59
1859	Level 3	3.99	3.49
1860	Level 2	0.20	0.20
1861	Level 3	12.87	3.29
1862	Level 3	3.60	3.60
1863	Level 3	1.30	1.30
1864	Level 3	3.00	3.10
1865	Level 3	2.79	2.79

The vertical distance between the HV and RV as measured with the RT, GPS, and WSU at the Level 3 alert onset are listed in Table 51. The WSU average value was 2.6 meters greater than it was from the RT and GPS data (9.5 versus 6.9 meters). The RT and GPS data were in good agreement with each other on average (although individual tests were up to 0.6 meter different). The standard deviation for each measurement type was fairly similar, ranging from 1.1 to 1.2 meters.

Table 51: IMA-Bridge Vertical Distance Between HV and RV at Level 3 Alert Onset (HV = RV = 45 mph)

Test No.	Vertical Dist. RV to HV (m)		
	RT	GPS	WSU
1849	9.2	9.2	11.5
1850	5.8	5.9	10.3
1851	7.3	7.2	9.5
1852	6.3	6.3	10.5
1855	6.9	6.3	10.7
1856	6.3	6.7	7.6
1858	7.7	7.6	9.1
1859	7.2	7.2	9.2
1860	4.6	4.5	7.0
1861	7.8	8.4	9.7
1862	7.3	7.2	8.3
1863	6.4	6.4	9.2
1864	7.3	7.2	10.2
1865	7.0	7.0	10.2
Average	6.9	6.9	9.5
Std. Dev.	1.1	1.1	1.2
C. of V. (%)	15.3	16.1	13.0

7.2.3 HV and RV Reversed Roles

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table 52 for the testing with the HV and the RV in reversed roles. There were five tests conducted for this condition. RT, GPS, and WSU data for these metrics are given in Appendix B, Section B.14.2. The HV TTC to Intersection at Level 3 alert onset times on average were 6.9 seconds and the RV TTC average value was 6.9 seconds. One of the tests was an outlier due to the RV arriving at the intersection well before the HV (Test 1867), which had an RV TTC value of 4.5 seconds. The HV and RV Range to Intersection at alert were fairly different for these tests (143 versus 91 meters). Test 1896 also had a large difference in HV/RV Range with the RV arriving ahead of the HV. This test was discussed in more detail above in Section 7.1.3.

Table 52: IMA-Bridge TTC, Range, and Speed at RV IMA Level 3 Alert Onset (HV and RV Reversed Roles)

Test No.	TTC HV to Intersection (sec)	TTC RV to Intersection (sec)	Range HV to Intersection (m)	Range RV to Intersection (m)	Speed RT (mph)	
					HV	RV
1867	7.2	4.5	143	91	44.5	45.3
1868	6.4	8.5	130	171	45.1	45.4
1869	7.1	6.6	138	132	43.6	45.2
1870	7.1	7.2	140	145	44.2	45.3
1871	6.8	7.6	131	153	43.4	45.3
Average	6.9	6.9	136	139	44.2	45.3
Std. Dev.	0.3	1.5	5	30	0.7	0.1
C. of V. (%)	4.3	21.7	4	22	1.6	0.1

The timing of the first alert after the RV has found the HV and after the RV has classified the HV as a potential IMA threat are listed in Table 53. For the one test where the RV was able to track the HV before a Level 2 Alert (Test 1868), the Level 3 Alert RV TTC time was 8.5 seconds while the other tests had RV TTC values ranging from 4.5 to 7.6 seconds.

Table 53: IMA-Bridge Timing of First Alert After the RV Has Found the HV and After HV Is IMA Threat (HV and RV Reversed Roles)

Test No.	First Alert Type	Time of Alert After (sec)	
		HV Found	IMA Loc.
1867	Level 3	7.18	3.99
1868	Level 2	10.57	1.90
1869	Level 3	7.28	3.20
1870	Level 3	6.58	2.79
1871	Level 3	5.89	2.60

The vertical distance between the HV and RV as measured with the RT, GPS, and WSU at the Level 3 alert onset are listed in Table 54. The WSU average value was 2.7 meters lower than it was for the RT data (2.9 versus 5.6 meters). The RT and GPS data were in good agreement with each other on average and for each individual test. The WSU values being lower for the Reversed Role tests is opposite of what was found in the tests where the HV and RV were in the "normal" roles. This suggests that there might be an offset in the height for one or both vehicles. The standard deviation for the RT and GPS data were lower than that for the WSU data (0.4 versus 0.9 meters).

Table 54: IMA-Bridge Vertical Distance Between HV and RV at Level 3 Alert Onset (HV and RV Reversed Roles)

Test No.	Vertical Dist. RV to HV (m)		
	RT	GPS	WSU
1867	5.2	5.3	1.6
1868	6.3	6.3	4.1
1869	5.6	5.6	3.1
1870	5.5	5.5	2.7
1871	5.6	5.6	3.3
Average	5.6	5.7	2.9
Std. Dev.	0.4	0.4	0.9
C. of V. (%)	6.8	6.5	31.5

8 IMA On-Ramp Maneuver

The IMA On-Ramp Maneuver test was also developed after reviewing *Integrated Light Vehicle Model Deployment Research Project Update* [6], which also showed that HV V2V-equipped vehicles would get false positive IMA warnings from RVs on an on-ramp and vice-versa. An on-ramp maneuver is simulated on the test track by having the HV driven along a constant radius curve while the RV is driven along a straight line that is a lane width or two outside of the radius. The situation is depicted in Figure 32. As the HV traverses the constant radius, it eventually has a heading angle that will intersect the RV straight line path. The intersection of the two heading angles is termed a dynamic intersection. As the HV travels around the radius, the dynamic intersection moves from right to left along the RV straight line path (towards the RV). The timing of the vehicle should be such that when the HV is at the right-most point of the circle in Figure 32, the RV is on the straight line path at a point directly above the top-most point of the circle.

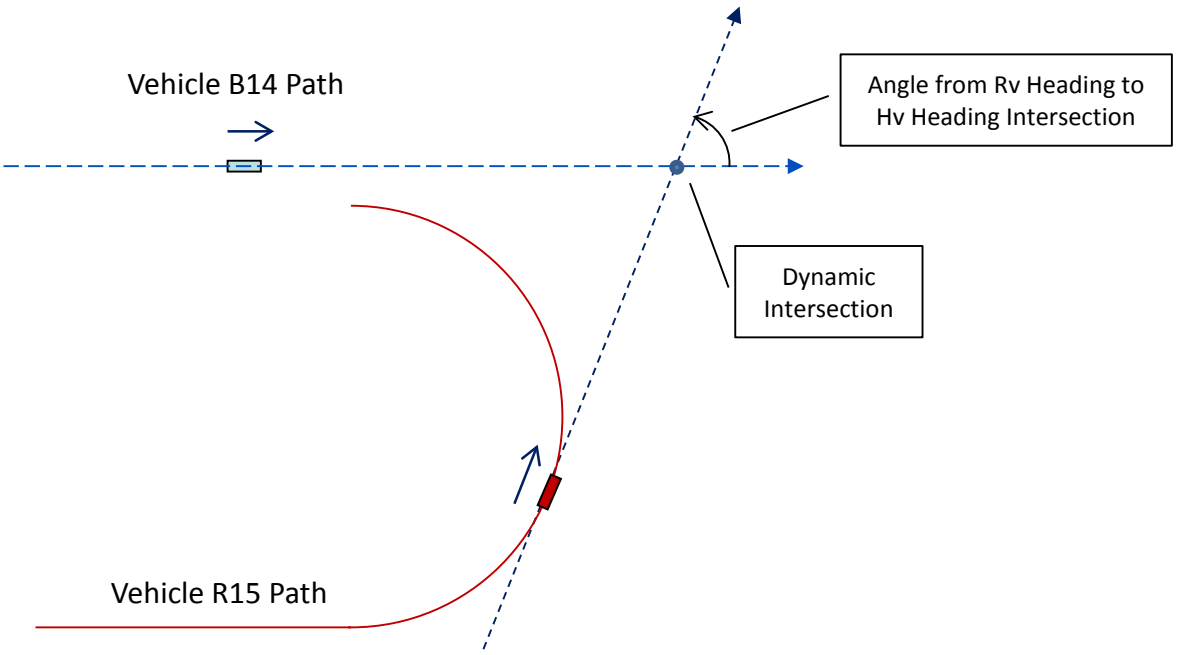


Figure 32: Dynamic Intersection

Tests were conducted on a 150-foot and 300-foot constant radius circle. The HV and RV speeds were varied from approximately 20 mph to speeds that were deemed reasonable for the size of the radius.

This test procedure should result in no alerts being issued by either the HV or the RV.

The test vehicles for all of the IMA On-Ramp maneuvers:

- HV = Red Freightliner Cascadia with WSU
- RV = Blue Freightliner Cascadia with WSU

For all the tests conducted there were no alerts issued. The WSUs did broadcast data that showed that the HV and RV were tracking each other as potential IMA threats (IMA_C channel changes from 0 to 1). Data were collected from both the HV and the RV and are presented below.

8.1 IMA On-Ramp Test Results for the HV

Data presented in the tables below are from the HV WSU and indicate when the HV has located the RV as a potential IMA threat.

The ranges of the HV and RV to the dynamic intersection at the HV IMA Located RV Onset and Offset are listed in Table 55 for the 150-foot radius tests. The HV speed varied from approximately 20 to 25 mph and the RV speed varied from 12 to 26 mph. The 12 mph test (1820) would not be considered a valid test. The HV Range to the dynamic intersection at both IMA Located Onset and Offset are fairly consistent across the range of speeds evaluated (97 m and 42 m for onset and offset on average), which means the HV tracked the RV as a potential threat over a consistent range. The RV range values were less consistent, which means that the timing of the HV along the radius and the RV along the straight line path had some variability.

Table 55: IMA On-Ramp HV and RV Range to Dynamic Intersection at HV IMA Located RV Onset and Offset for 150-Foot Radius Tests

Test	Speed (mph)		Range HV at IMA Located Onset (m)	Range RV at IMA Located Onset (m)	Range HV at IMA Located Offset (m)	Range RV at IMA Located Offset (m)
	HV	RV				
1820	20.9	12.0	98.9	139.4	40.3	22.0
1821	24.2	20.4	95.1	158.6	40.2	46.0
1822	20.9	18.8	97.1	112.7	41.0	3.1
1823	21.9	23.0	98.6	127.0	41.3	6.6
1824	23.1	22.5	95.6	97.6	47.4	4.7
1825	22.2	23.0	96.2	133.0	41.3	17.4
1826	24.3	26.4	95.5	130.3	41.0	6.6
1827	24.4	25.6	97.2	153.9	40.9	33.5
1828	24.7	25.3	97.4	138.4	41.1	19.8
1829	23.4	25.0	99.0	144.7	40.9	20.3
1830	22.7	24.9	96.6	120.1	43.3	4.7
		Ave.	97.0	132.3	41.7	16.8
		Std.	1.4	17.8	2.1	13.7
		C. of V. (%)	1.4	13.4	4.9	81.4

The angle between the RV and HV heading angles at the HV IMA Located RV onset and offset times for the 150-foot radius tests are listed in Table 56. The average onset value was approximately 57 degrees with a standard deviation of 1 degree and the average offset value was approximately 115 degrees with a standard deviation of 4 degrees.

Table 56: IMA On-Ramp Angle Between RV Heading and HV Heading at HV IMA Located RV Onset and Offset for 150-Foot Radius Tests

Test	Angle RV Hdg. to HV Hdg. at IMA Located Onset (deg)	Angle RV Hdg. to HV Hdg. at IMA Located Offset (deg)
1820	54.3	116.7
1821	57.5	118.1
1822	57.0	118.2
1823	56.0	117.5
1824	57.8	103.8
1825	57.4	116.6
1826	57.2	117.0
1827	57.4	116.9
1828	57.1	116.5
1829	56.0	117.3
1830	57.4	111.7
Ave.	56.8	115.5
Std.	1.0	4.2
C. of V. (%)	1.8	3.7

Example traces of the vehicle paths are shown in Figure 33. The vehicle positions when the HV initially starts to track the RV as a potential IMA threat are shown in the plot on the left and the last point before the HV stops to track the RV as a potential IMA threat is shown in the plot on the right.

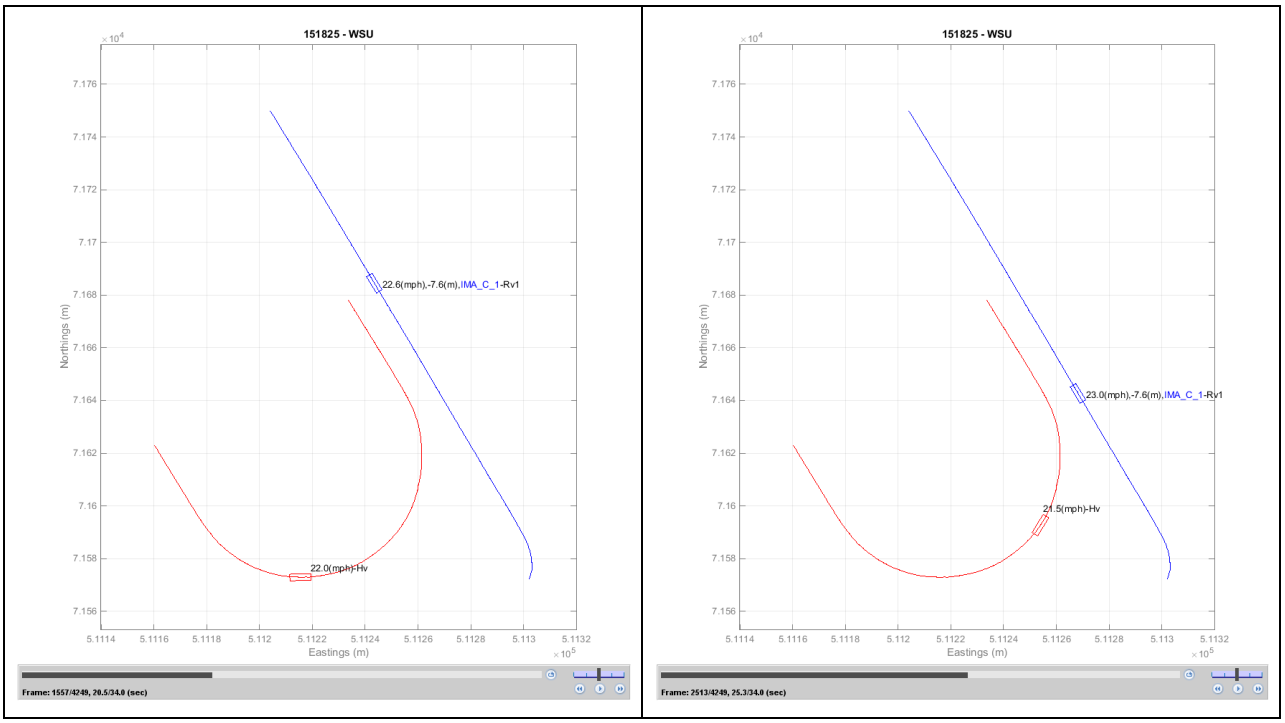


Figure 33: Example Positions of HV and RV at IMA Threat Located – Test 1825

The ranges of the HV and RV to the dynamic intersection at the HV IMA Located RV Onset and Offset are listed in Table 57 for the 300-foot radius tests. The HV and RV speeds were varied from approximately 25 to 42 mph. The HV Range to the dynamic intersection at both IMA Located Onset and Offset are fairly consistent across the range of speeds evaluated (170 m and 70 m for onset and offset on average), which means the HV tracked the RV as a potential threat over a consistent range. The RV range values were less consistent (but better than the 150-foot radius test results), which means that the timing of the HV along the radius and the RV along the straight line path had some variability.

Table 57: IMA On-Ramp HV and RV Range to Dynamic Intersection at HV IMA Located RV Onset and Offset for 300-Foot Radius Tests

Test	Speed (mph)		Range HV at IMA Located Onset (m)	Range RV at IMA Located Onset (m)	Range HV at IMA Located Offset (m)	Range RV at IMA Located Offset (m)
	HV	RV				
1832	25.5	24.9	169.2	202.4	68.4	3.1
1833	25.2	25.6	167.7	201.3	68.9	3.3
1834	25.1	25.2	171.0	197.8	72.1	2.5
1835	26.6	26.9	170.6	191.1	73.1	3.4
1836	28.9	29.1	174.0	205.5	70.5	4.3
1837	30.4	30.5	170.4	193.2	71.7	4.0
1838	32.6	32.3	169.2	191.4	72.0	3.9
1839	34.5	34.7	168.5	208.8	65.8	5.2
1840	36.7	36.1	171.3	191.1	73.7	2.3
1841	38.2	38.0	171.4	193.5	73.4	4.8
1842	40.0	39.8	171.1	214.5	65.8	5.3
1843	42.0	42.1	170.5	190.2	73.4	3.3
1844	39.9	40.2	170.6	220.2	66.2	10.6
		Ave.	170.4	200.1	70.4	4.3
		Std.	1.6	9.8	3.0	2.1
		C. of V. (%)	0.9	4.9	4.3	49.0

The angle between the RV and HV heading angles at the HV IMA Located RV onset and offset times for the 300-foot radius tests are listed in Table 58. The average onset value was approximately 59 degrees with a standard deviation less than 1 degree and the average offset value was approximately 114 degrees with a standard deviation of 3 degrees. These values are consistent with what was found for the 150-foot radius test (57 and 115 degrees on average).

Table 58: IMA On-Ramp Angle Between RV Heading and HV Heading at HV IMA Located RV Onset and Offset for 300-Foot Radius Tests

Test	Angle RV Hdg. to HV Hdg. at IMA Located Onset (deg)	Angle RV Hdg. to HV Hdg. at IMA Located Offset (deg)
1832	59.4	116.3
1833	60.2	115.6
1834	59.3	112.4
1835	59.5	111.4
1836	58.5	113.9
1837	59.6	112.0
1838	59.1	110.8
1839	59.7	117.2
1840	59.2	111.3
1841	59.3	110.7
1842	59.3	118.3
1843	59.3	111.0
1844	59.9	119.0
Ave.	59.4	113.8
Std.	0.4	3.0
C. of V. (%)	0.7	2.7

8.2 IMA On-Ramp Test Results for the RV

Data presented in the tables below are from the RV WSU and indicate when the RV has located the HV as a potential IMA threat.

The ranges of the HV and RV to the dynamic intersection at the RV IMA Located HV Onset and Offset are listed in Table 59 for the 150-foot radius tests. The HV speed varied from approximately 20 to 25 mph and the RV speed varied from 12 to 26 mph. The 12 mph test (1820) would not be considered a valid test. The HV Range to the dynamic intersection at both IMA Located Onset and Offset are fairly consistent across the range of speeds evaluated (95 m and 41 m for onset and offset on average), which means the RV tracked the HV as a potential threat over a consistent range for the HV. The RV range values were less consistent, which means that the timing of the HV along the radius and the RV along the straight line path had some variability.

Table 59: IMA On-Ramp HV and RV Range to Dynamic Intersection at RV IMA Located HV Onset and Offset for 150-Foot Radius Tests

Test No.	Speed (mph)		Range HV at IMA Located Onset (m)	Range RV at IMA Located Onset (m)	Range HV at IMA Located Offset (m)	Range RV at IMA Located Offset (m)
	HV	RV				
1820	20.9	11.9	97.2	137.6	39.7	20.5
1821	24.1	20.4	93.9	155.6	39.5	45.0
1822	20.9	18.8	97.6	112.9	41.0	3.1
1823	21.9	23.0	95.4	122.3	40.8	4.6
1824	23.0	22.5	93.1	94.2	46.6	2.9
1825	22.2	23.0	96.0	132.7	40.7	15.4
1826	24.2	26.5	92.9	126.1	40.4	4.5
1827	24.2	25.7	95.6	150.8	40.2	31.5
1828	24.6	25.3	93.8	133.9	40.7	17.5
1829	23.3	25.0	94.5	138.9	40.6	17.9
1830	22.6	25.0	94.4	117.0	42.8	2.5
Average			95.0	129.3	41.2	15.0
Std. Dev.			1.6	17.5	2.0	13.7
C. of V. (%)			1.7	13.5	4.8	91.3

The angle between the RV and HV heading angles at the RV IMA Located HV onset and offset times for the 150-foot radius tests are listed in Table 60. The average onset value was approximately 58 degrees with a standard deviation of 1 degree and the average offset value was approximately 116 degrees with a standard deviation of 4 degrees. These values are very consistent with what was found for the HV WSU values for the HV IMA Located RV onset and offset times (57 and 115 degrees on average).

Table 60: IMA On-Ramp Angle Between RV Heading and HV Heading at RV IMA Located HV Onset and Offset for 150-Foot Radius Tests

Test	Angle RV Hdg. to HV Hdg. at IMA Located Onset (deg)	Angle RV Hdg. to HV Hdg. at IMA Located Offset (deg)
1820	54.7	117.2
1821	58.5	118.1
1822	56.8	118.4
1823	57.8	118.3
1824	59.1	104.9
1825	57.6	118.1
1826	58.7	118.4
1827	58.3	118.4
1828	58.9	117.9
1829	58.4	118.2
1830	58.5	113.5
Ave	57.9	116.5
Std.	1.2	4.1
C. of V. (%)	2.2	3.5

No data was collected from the RV for the 300-foot radius tests.

8.3 IMA Threat Location Determination for On-Ramp Maneuver

The location classification channels collected from the HV and RV are shown in Figure 34 for Test 1820. The red trace is for the HV and the blue trace is for the RV. The value of 17 on the HV red trace (a little past 21 seconds to a little past 26 seconds) is when the HV has classified the RV as an IMA threat coming from the right. The value of 16 on the RV blue trace is when the RV has classified the HV as an IMA threat coming from the left. The IMA threat detection is only slightly delayed between the two vehicles.

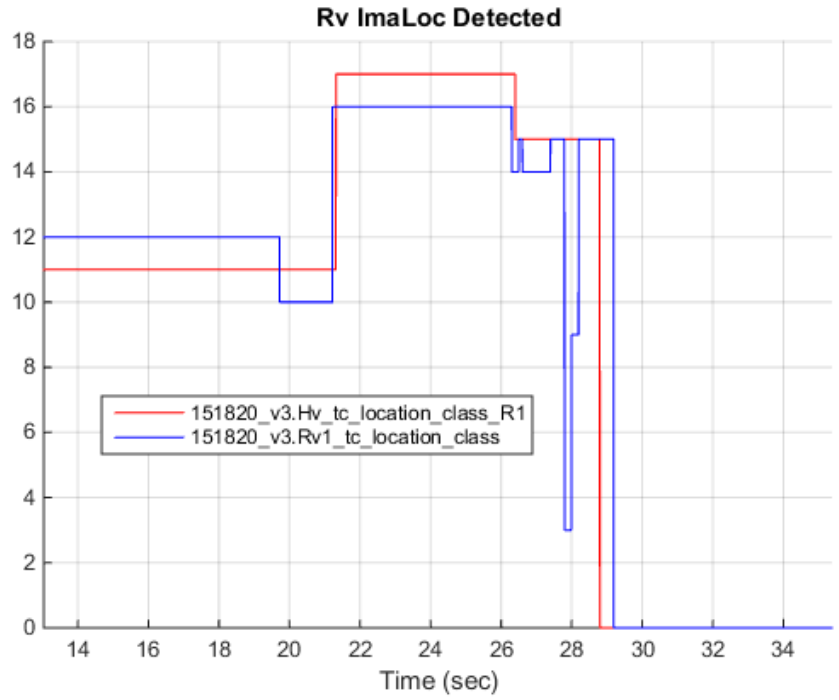


Figure 34: Example Location Classification Traces for HV and RV (Test 1820)

The HV classified the RV as a potential IMA threat at a consistent range to the dynamic intersection. This value did change with the size of the radius. The RV range to the dynamic intersection for when the RV classified the HV as a potential IMA threat was considerably more variable. However, the angle between the HV and RV at the IMA located onsets and offsets was very consistent for both the HV and RV. The average angle between the HV and RV heading angles are summarized in Table 61. The average values did not change very much with radius size or with the classifying vehicle combination.

Table 61: Average Angle Between HV and RV Heading Angles at IMA Classification for Each Classifying Vehicle Combination and On-Ramp Radius

Classifying Vehicle Combination	Radius	Average Angle Between HV and RV Heading at IMA Classification	
		Onset	Offset
HV Locating RV	150’	56.8	115.5
	300’	59.4	113.8
RV Locating HV	150’	57.9	116.5

9 Conclusions and Recommendations

A series of ICA and IMA test procedures were developed and/or evaluated using the class 8 trucks from the model deployment study conducted for NHTSA. In general, the prototype V2V equipment was observed to be capable of tracking potential IMA threats, but the IMA warnings and alerts issued from the V2V equipment on these trucks occurred very early especially for

lower speed tests. As an example, the HV WSU would issue warnings prior to when a driver would normally begin to slow down for a stop or turn at the intersection. The alerts also did not extinguish after the driver had taken corrective action and had slowed the vehicle enough that the collision threat had been diminished. The alerts also did not extinguish promptly if the Remote Vehicle was slowing down for the intersection.

The IMA bridge test procedure was the one scenario where the V2V equipment did not track an IMA threat. This was due to the V2V equipment failing to recognize that the vehicles were not on a collision course due to fact that the vehicles were at different elevations (one on the bridge and the other going beneath the bridge).

Due to the early warnings it was not possible to conduct several of the test procedures, especially the false positive tests that were designed to determine if the V2V equipment could suppress warnings/alerts. Future testing with commercial vehicles equipped with V2V technology that has advanced with respect to warning/alert timing and alert suppression will be required to fully develop the IMA objective test track procedures and performance metrics.

References

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Appendix A IMA Test Procedures

A.1 Introduction

Test procedures for Commercial Connected Vehicle systems have been developed for the following conditions: intersection movement assist (6 procedures), forward collision warning (9 procedures), electronic emergency brake light (8 procedures), and blind spot warning/lane change warning (9 procedures).

This appendix includes a listing of the source documents used to develop the test procedures, definitions for the various systems, and the intersection movement assist procedures.

A.2 Source Documents

The following is a list of documents that were used as source material for the preparation of the test procedures described in this document.

[1] U.S. Department of Transportation. National Highway Traffic Safety Administration, Office of Vehicle Safety, Office of Crash Avoidance Standards. (2013, February). "Forward Collision Warning System Confirmation Test." Available at http://www.safercar.gov/staticfiles/safercar/NCAP/FCW_NCAP_Test_Procedure_2-7-2013.pdf

[2] European Union. (2012, April 16). *Commission Regulation (EU) No 347/2012 of 16 April 2012 implementing Regulation (EC) No 661/2009 of the European Parliament and of the Council with respect to type-approval requirement for certain categories of motor vehicles with regard to advance emergency braking systems*. Official Journal of the European Union, Report Vol. L 109/1. Available at http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32012R0347

[3] Society of Automotive Engineers. (2009, November 19). SAE J2735, "Dedicated Short Range Communication (DSRC) Message Set Dictionary." Warrendale, PA: Author. Avalable at http://standards.sae.org/j2735_200911/

[4] Institute of Electrical and Electronics Engineers. (2010, April). IEEE Standard P802.11p/D11.0, IEEE Draft Standard for Amendment to Standard [for] Information Technology-Telecommunications and information exchange between systems-Local and Metropolitan networks-Specific requirements-Part II: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications-Amendment 6: Wireless Access in Vehicular Environments (Lower layers of DSRC protocol stack) Piscataway, NJ: Author. Available at http://ieeexplore.ieee.org/xpl/mostRecentIssue.jsp?reload=true&punumber=5491848

[5] Institute of Electrical and Electronics Engineers. (2012, Se ptember 21).IEEE 1609.12-2012, IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Identifier Allocations (Upper layers of DSRC protocol stack). Piscataway, NJ: Author. Available at *http://standards.ieee.org/findstds/standard/1609.12-2012.html- 26.1KB*

A.3 Definitions

A.3.1 On-Board Equipment

On-board equipment (OBE) packages are the vehicle platform-mounted elements of V2V-based collision avoidance systems. Variants of V2V-based OBE are the integrated safety system (ISS),

the retrofit safety device (RSD), the aftermarket safety device (ASD), and the vehicle awareness device (VAD).

A.3.2 Integrated Safety System

An integrated safety system (ISS) is a V2V-based collision warning system that is an integral element of a V2V-equipped production vehicle. An ISS both transmits and receives collision avoidance information to and from the OBEs of nearby V2V-equipped vehicles.

A.3.3 Retrofit Safety Device

A retrofit safety device (RSD) is a V2V-based collision warning system that is designed for use in commercial vehicles. It is retrofitted to a finished production vehicle. A RSD both transmits and receives collision avoidance information to and from the OBEs of nearby V2V-equipped vehicles.

A.3.4 Aftermarket Safety Device

An aftermarket safety device (ASD) is a V2V-based collision warning system that is designed for use in light vehicles. It is retrofitted to a finished production vehicle. An ASD both transmits and receives collision avoidance information to and from the OBEs of nearby V2V-equipped vehicles.

A.3.5 Vehicle Awareness Device

A vehicle awareness device (VAD) is a V2V-based system that transmits collision avoidance information to nearby V2V-equipped vehicles. It does not receive collision avoidance information or provide collision warnings to the driver of the vehicle in which it is installed. It is designed to make a vehicle that is otherwise not equipped with V2V technology visible to the OBEs of nearby V2V-equipped vehicles.

A.4 Vehicle Platforms

A.4.1 Host Vehicle

A host vehicle (HV) is a vehicle that carries the ISS or RSD that is the test subject.

A.4.2 Remote Vehicle

A remote vehicle (RV) is a vehicle that carries an ISS, RSD, ASD, or VAD, and represents a collision threat to the HV.

A.5 Vehicle and V2V System Roles

A.5.1 Host Vehicle and On-Board Equipment

The HV/OBE combination is a tractor, with or without a trailer, or a single-unit truck equipped with an ISS or RSD whose FCW safety application is to be evaluated.

A.5.2 Remote Vehicle and On-Board Equipment

The RV/OBE combination is a light, medium, or heavy vehicle equipped with an ISS, RSD, ASD, or VAD that conforms to the standards of documents listed as 8, 9, and 10 in the Source Documents section of this procedure. The RV's ISS, RSD, ASD, or VAD will be a standard, stable system that broadcasts consistent and reliable crash avoidance information.

A.6 General Procedures

A.6.1 Ambient Conditions

Developmental draft note: The following ambient condition requirements are those of [1], and appear to be appropriate for both sensor-based and V2V tests. The visibility requirement has been modified to address visibility for test vehicle operators when the sun is close to the forward horizon.

- The ambient temperature shall be between 0° C (32° F) and 38° C (100° F).
- The maximum wind speed shall be no greater than 10 m/s (22 mph).
- Tests should not be performed during periods of inclement weather. This includes, but is not limited to, rain, snow, hail, fog, smoke, or ash.
- Unless specified otherwise, the tests shall be conducted during daylight hours with good atmospheric visibility (defined as an absence of fog and the ability to see clearly for more than 5,000 meters). The test shall not be conducted with the vehicle oriented into the sun during very low sun angle conditions, (the sun is oriented 15 degrees or less from horizontal) where low sun angles degrade forward visibility for the test vehicle operators.
- Unless stated otherwise, all tests shall be conducted such that there are no overhead signs, bridges, or other significant structures over, or near, the testing site. Each trial shall be conducted with no vehicles, obstructions, or stationary objects within one lane width of either side the vehicle path.

A.6.2 Personnel

A test execution team would include an experimenter, a host vehicle driver, and remote vehicle drivers. The team would typically use person-to-person radios for communication.

The experimenter observes and directs the execution of each test trial, and would typically be located in the HV as the test is executed. The experimenter would also be familiar with the OBE test subject (ISS or RSD) such that he or she could confirm its operation during each test. The experimenter records test conditions and test trial notes, and judges apparent test trial validity. The experimenter might also operate the data acquisition system and other test equipment.

The HV driver would be skilled in the operation of the HV. The HV driver would also be familiar with the operation of the collision warning system's driver-vehicle interface (DVI) such that he or she can differentiate among various alerts that the might be provided by the collision avoidance system via the DVI.

The RV drivers would be skilled in the operation of the remote vehicles. The RV drivers would also be familiar with the OBE (ISS, RSD, ASD, or VAD) used in the RV such that he or she could confirm its operation during each test.

A.6.3 Zero Position Measurement

The in-lane longitudinal position of the HV at the point of impact with the RV—the zero position—is required to determine the longitudinal position of the HV in relation to the RV during the execution of each trial. The zero position defines the distance between the range measuring instrumentation's reference points for the HV and RV when the front of the HV contacts the rear of the RV.

The zero position measurement is used to confirm or correct the longitudinal headway data produced by the data acquisition system. The headway is the distance between the trailing edge of the RV and the leading edge of the HV. The zero position measurement is taken before and after each set of trials.

1. On the test facility, select a driving lane in which to measure the zero position.
2. Along the edge of the driving lane, establish a reference point at which the zero position will be measured. Place a traffic cone or other suitable marker over the reference point.
3. Select a convenient length—say 1 m—for gauging the distance between the trailing edge of the RV and the leading edge of the HV.
4. Along the edge of the driving lane that is common with the reference point, establish a gauging point at a distance from the reference point equal to the selected gauging length. Place a traffic cone or other suitable marker over the gauging point.
5. Drive the RV forward along the lane such that it passes the gauging point before it arrives at the reference point.
6. Drive the leading edge of the RV forward past the reference point and stop the RV, without reversing, such that its trailing edge is even with the reference point. Apply the RV's parking brake.
7. In the same direction as the RV was driven, drive the HV forward along the lane and toward the gauging point. Stop the HV, without reversing, such that its leading edge is even with the gauging point. Apply the HV's parking brake.
8. Confirm the distance between the trailing edge of the RV and the leading edge of the HV with a tape measure, a dedicated gauge, or an equivalent linear measurement tool. Record the measurement as the gauge distance.
9. Record the distance displayed by the DME as the raw headway value. Subtract the gauge distance from the raw headway value and record the result as the zero position correction value.

A.6.4 Path History (Breadcrumbs or Breadcrumb Trail)

For test scenarios in which an RV or HV is stopped, V2V-based applications may require that the RV/HV's OBE broadcast the RV/HV's path history. Test procedures that feature a stopped RV include a step to establish a path history by driving the RV/HV for a specified distance along the test course before stopping. The RV is driven along the test course from the course entrance to a location sufficiently downrange to include the full length of the test course. Once the RV/HV is stopped and parked, the RV/HV's OBE must remain on. Test procedure trials may typically be repeated without moving the RV/HV to re-establish a path history as long as the RV/HV's OBE continues to broadcast the RV/HV's path history from the initial trial and the quality of the broadcast path history does not deteriorate.

A.7 Test Facility

For IMA tests, the test facility includes two straight, flat, and level intersecting roadways (90 degrees) whose surface is constructed of asphalt or concrete; and whose driving lanes are at least 12 feet wide and delineated by lane markings or pavement seams visible to the vehicle operators. One of the two intersecting roadways will be the primary test roadway on which the HV will be driven. The other intersecting roadway will be used by the RV.

A.8 IMA-1 - RV Brakes to Stop at Intersection, HV Passes Through

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific IMA pre-crash scenario. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to alert commercial vehicle drivers of possible collisions with other V2V-equipped vehicles.

A.8.1 Pre-Crash Scenario

Two vehicles travel along perpendicular roadways approaching an intersection. The host vehicle is a commercial truck equipped with a V2V system that features an IMA application. The remote vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The host and remote vehicle are moving at the same speed on a collision course towards an intersection. The remote vehicle brakes to come to a stop at the intersection and the host vehicle passes through the intersection.

A.8.2 Test Subject and Purpose

The subject of this test is the V2V-based IMA system of the HV. The test determines the ability of the HV's OBE system to identify the RV in the IMA path (perpendicular roadway) and alert the HV's driver of the threat in a timely manner as well as extinguish the alert when the threat has passed (the RV has slowed enough to no longer be a threat or the HV has passed through the intersection).

A.8.3 Initial Condition

A.8.3.1 Test Velocities

For this test of the V2V-based IMA systems, the velocities of the HV and RV are specified for each trial or set of trials. The velocity of the RV is equal to the specified velocity until braking is initiated. A minimum test velocity may be specified above which the HV's OBE will broadcast the HV's location, velocity, and direction of travel, and above which the RV's ISS, RSD, or ASD would issue an alert to produce a successful trial. A single, standard test velocity—not necessarily a minimum velocity—may be specified. A range of test velocities may be specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress IMA event broadcasts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.8.4 Execution of Procedure

If unexpected events are encountered during any trial, the HV/RV drivers should brake and/or control the HV/RV as needed for safety and abort the trial.

The test procedure is depicted in Figure A-1 and Figure A-2.

1. The vehicles get into position with the HV on one road at a distance far enough from the intersection to get up to the specified test speed and allow enough time at that speed to track the RV. The RV is on a perpendicular road traveling towards the same intersection as the HV. It should be start at a similar distance from the intersection as the HV.
2. The vehicles accelerate to their respective test speeds at a similar acceleration level to ensure the HV and RV would meet at the intersection at a similar time if no braking action is taken by either vehicle.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds until the RV reaches a pre-set (marked with a cone) distance to begin braking before the intersection. The braking level should be below 0.3 g.
5. Even though the HV may receive IMA warnings/alerts, the HV driver should continue driving at the test speed until the HV passes through the intersection (unless unexpected events are encountered, then as stated previously the HV/RV drivers should brake and/or control the HV/RV as needed for safety and abort the trial).
6. Each trial ends after the HV has passed through the intersection.

A.8.5 Trial Validity

An individual trial is valid if during the course of the trial:

1. The HV's and RV's velocities did not deviate from the specified velocities by more than ±1.0 mph.
2. The HV and RV did not deviate from the center of their respective lanes by a distance of more than ±2.0 ft.
3. The yaw rate of the HV and RV did not exceed ±1 degree/second.

Working draft note: Other trial validity elements might include GPS coverage requirements and packet error rate of DRSC message exchange between HV and RV OBEs.

A.8.6 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful if the HV OBE initiates an IMA alert when the RV's speed/distance is above a pre-determined TTCmin (TTC that would allow the HV driver to brake in time to avoid a crash) and extinguishes that alert once the HV is clear of the intersection or when the RV has slowed enough that a collision is no longer possible (RV is braking such that it will not enter intersection). A trial is unsuccessful if the HV OBE does not initiate an IMA alert prior to TTCmin, or the alert persists after the HV has cleared the intersection or the RV has slowed enough that it will not reach the intersection.

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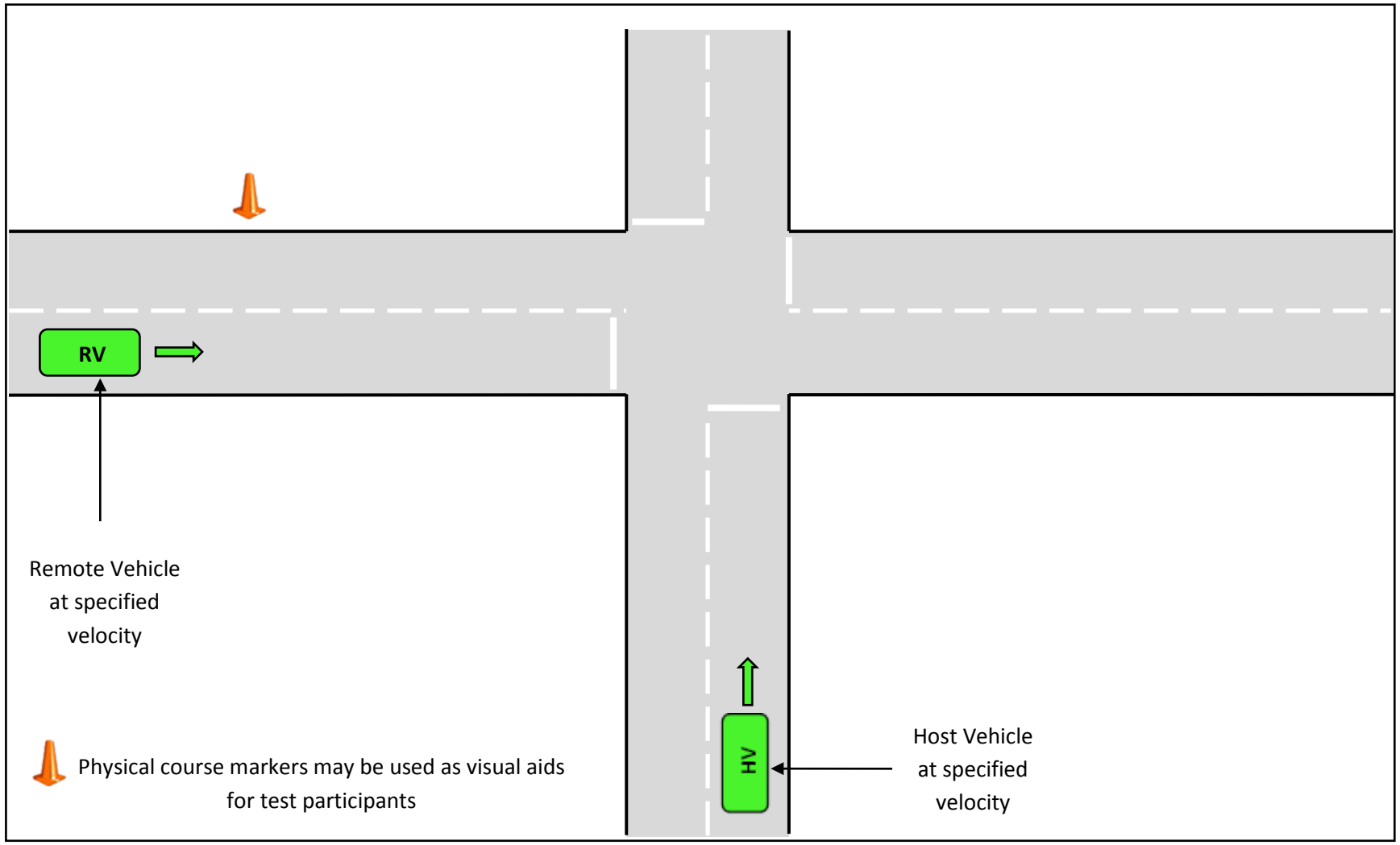

Figure A-1 - IMA-1 Test Course Graphic, Initial Conditions [not to scale]

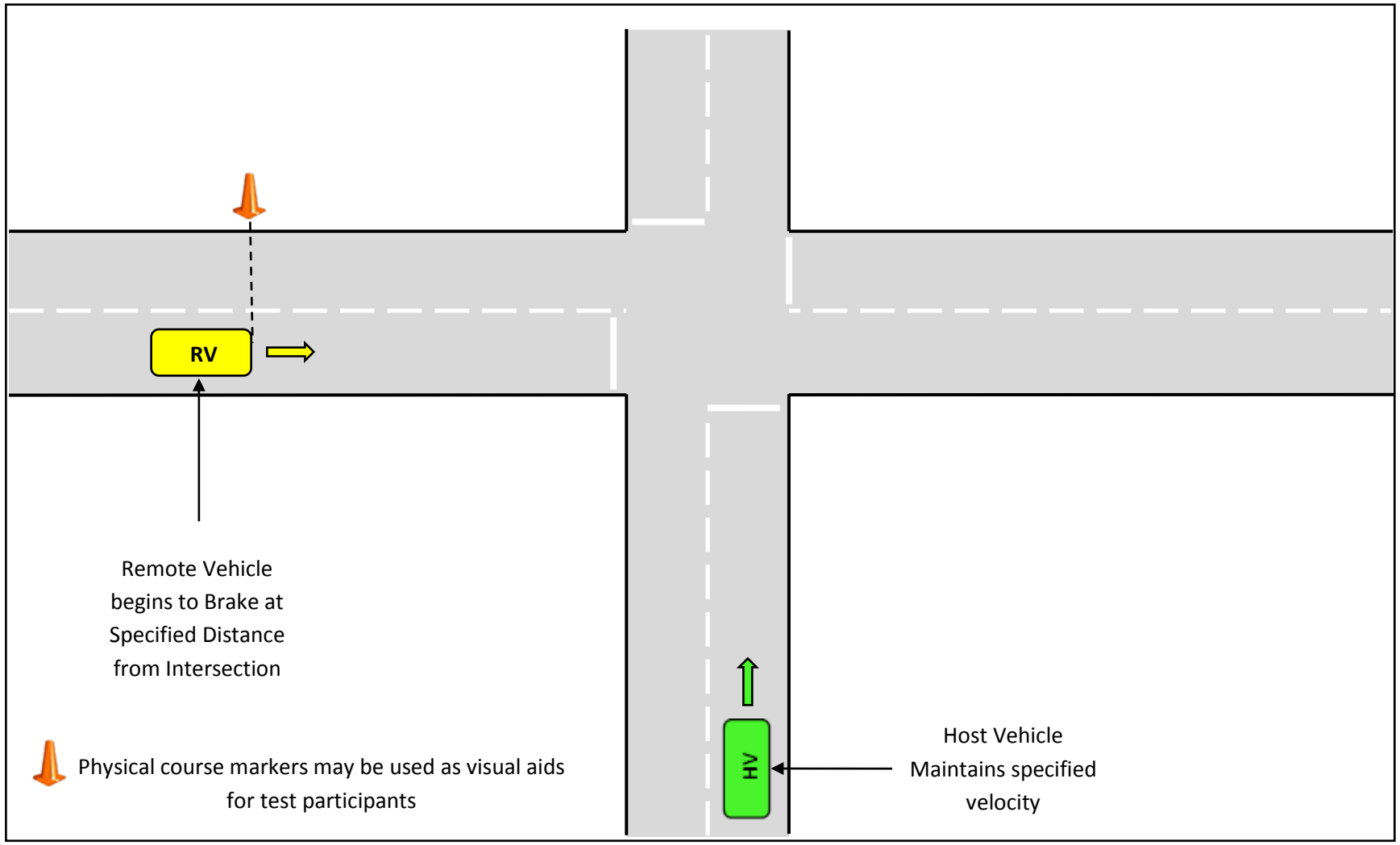

Figure A-2 - IMA-1 Test Course Graphic, Braking Event [not to scale]

A.9 IMA-2 - HV Moves toward Intersection from Stop

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific IMA pre-crash scenario. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to alert commercial vehicle drivers of possible collisions with other V2V-equipped vehicles.

A.9.1 Pre-Crash Scenario

The host vehicle is stopped at an intersection and the remote vehicle travels along the perpendicular roadway approaching the intersection. The host vehicle is a commercial truck equipped with a V2V system that features an IMA application. The remote vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The remote vehicle is moving at a specified speed. When the host vehicle OBE issues an IMA warning, the host vehicle starts to move toward the intersection. The host vehicle brakes to a stop when the OBE issues an IMA alert or to guarantee that the host vehicle does not cross the path of the remote vehicle. The remote vehicle maintains the specified speed until it passes through the intersection.

A.9.2 Test Subject and Purpose

The subject of this test is the V2V-based IMA system of the HV. The test determines the ability of the HV's OBE system to identify the RV in the IMA path (perpendicular roadway) by issuing a warning and alert the HV's driver of the threat in a timely manner when the HV driver starts to move toward the intersection, as well as extinguish the alert when the threat has passed (the RV has passed through the intersection or the HV has stopped).

A.9.3 Initial Condition

A.9.3.1 Test Velocities

For this test of the V2V-based IMA systems, the velocity for the RV is specified for each trial or set of trials. The HV is sitting still and far enough back from the intersection that the short movement required to produce the IMA alert will not cause the vehicle to be in the pathway of the approaching RV. A minimum test velocity may be specified above which the RV's ISS, RSD, or ASD would issue an alert to produce a successful trial. A single, standard test velocity—not necessarily a minimum velocity—may be specified. A range of test velocities may be specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress IMA event broadcasts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.9.4 Execution of Procedure

If unexpected events are encountered during any trial, the HV/RV drivers should brake and/or control the HV/RV as needed for safety and abort the trial.

The test procedure is depicted in Figure A-3, Figure A-4, and Figure A-5.

1. The vehicles get into position with the HV on one roadway stopped near the intersection but far enough back from the intersection to allow enough movement of the HV to

produce an IMA alert without entering the pathway of the RV. The RV is on a perpendicular road traveling towards the intersection.
2. The RV accelerates to the specified test speed. As the RV starts to move the experimenter arms the data acquisition system. The RV maintains the specified speed until after clearing the intersection.
3. As the RV approaches the intersection, the HV OBE should issue an IMA warning. At the onset of this warning, the HV driver should start to move the HV towards the intersection.
4. The HV OBE should then issue an IMA alert at which point the HV driver should stop the HV (apply the HV brakes). If no IMA alert is issued, the HV driver shall stop the HV prior to reaching the pathway of the RV.
5. Each trial ends after the RV has passed through the intersection.

A.9.5 Trial Validity

An individual trial is valid if during the course of the trial:

1. The RV velocity did not deviate from the specified velocity by more than ±1.0 mph.
2. The RV did not deviate from the center of the lane by a distance of more than ±2.0 ft.
3. The yaw rate of the RV did not exceed ±1 degree/second.

Working draft note: Other trial validity elements might include GPS coverage requirements and packet error rate of DRSC message exchange between HV and RV OBEs.

A.9.6 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful if the HV OBE initiates an IMA warning as the RV approaches the intersection and when the RV's speed/distance is above a pre-determined TTCmin (TTC that would allow the HV driver to brake in time to avoid a crash), issues an IMA alert as the HV starts to move toward the intersection, and extinguishes that alert once the RV is clear of the intersection or when the HV has stopped such that a collision is no longer possible. A trial is unsuccessful if the HV OBE does not initiate an IMA warning prior to TTCmin, an IMA alert as the HV moves toward the intersection, or the alert persists after the RV has cleared the intersection or the HV has stopped such that a collision is no longer possible.

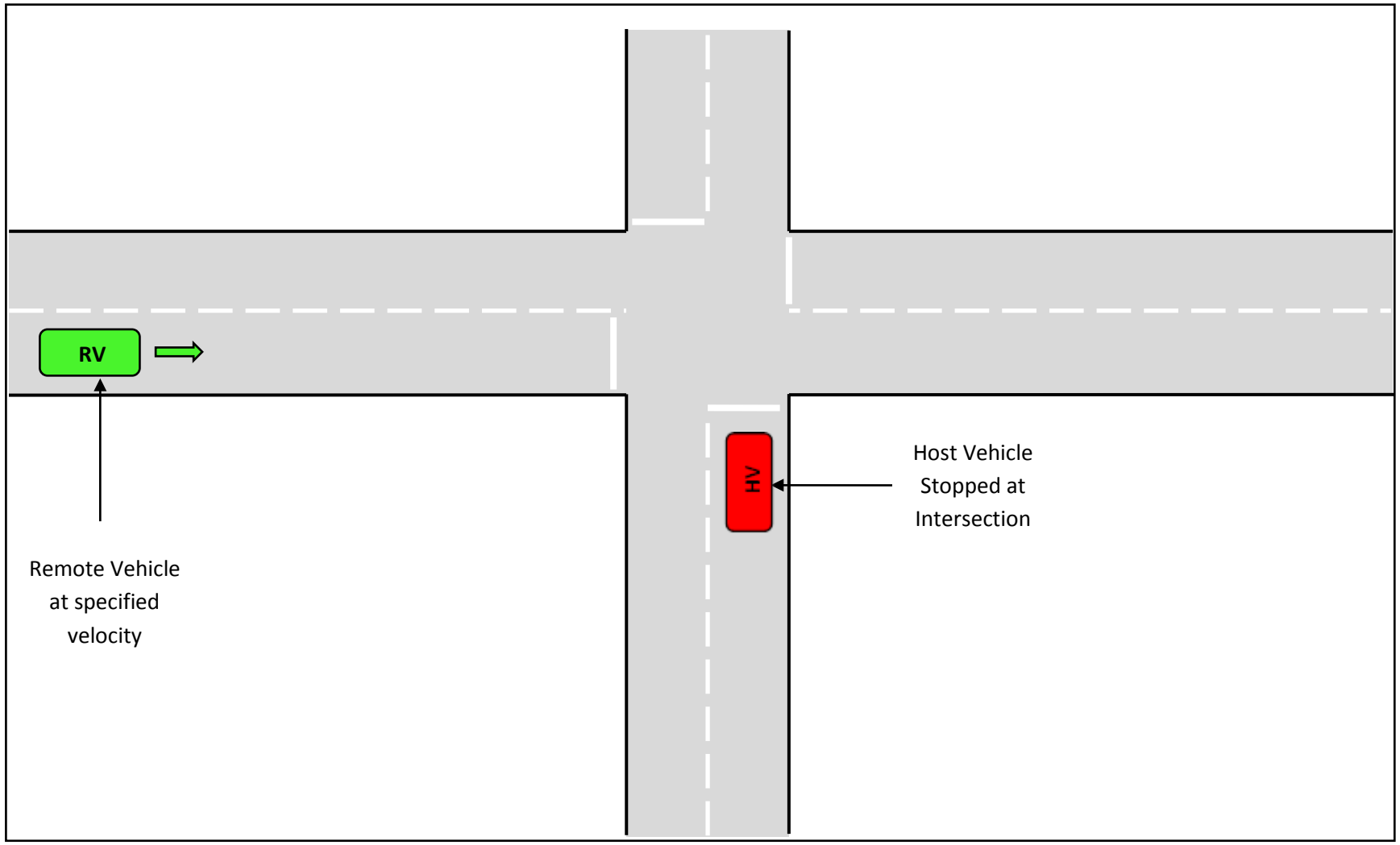

Figure A-3 - IMA-2 Test Course Graphic, Initial Conditions [not to scale]

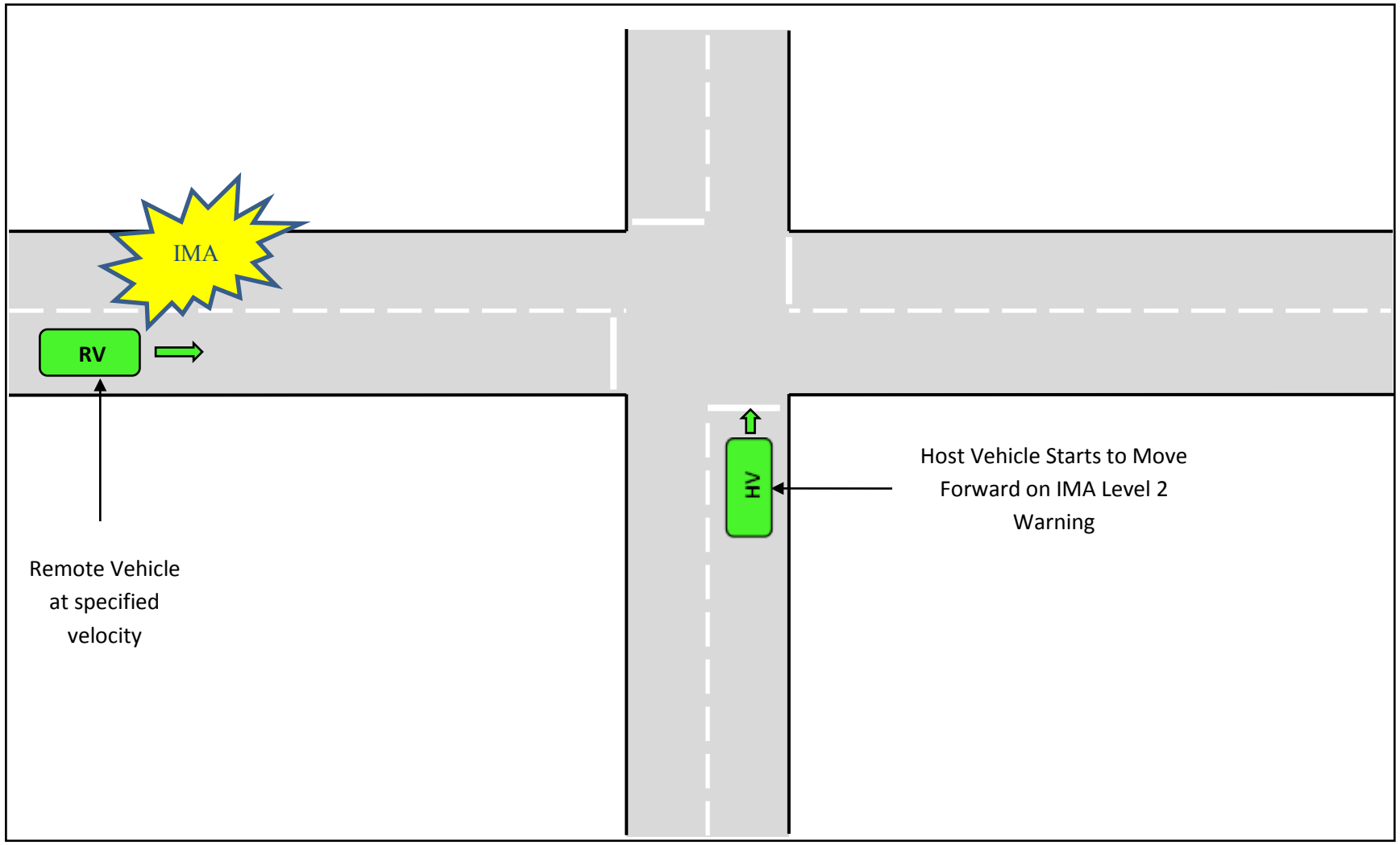

Figure A-4 - IMA-2 Test Course Graphic, HV Starts to Move [not to scale]

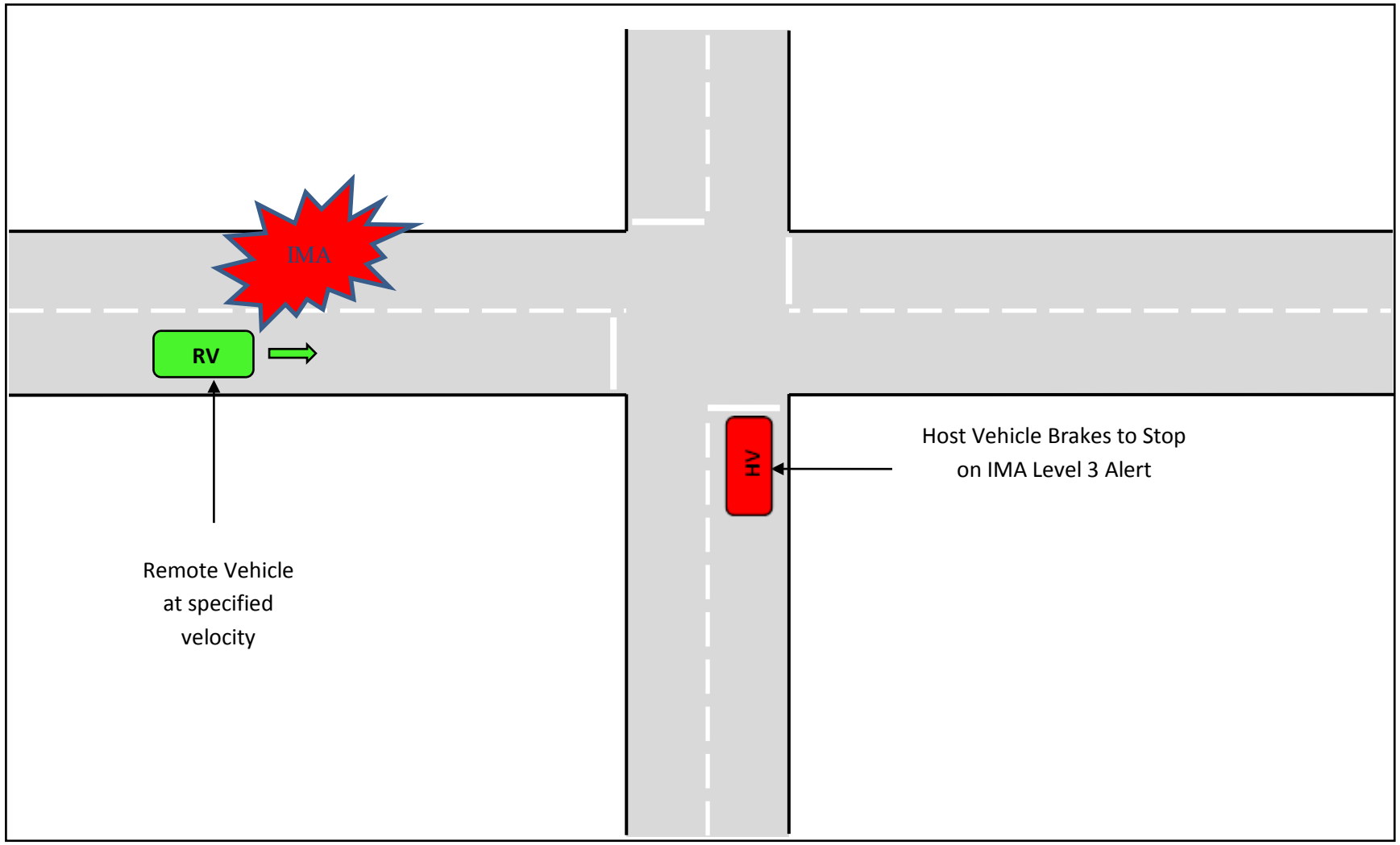

Figure A-5 - IMA-2 Test Course Graphic, HV Brakes [not to scale]

A.10 IMA-3 - RV at Rest at Intersection, HV Passes Through

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific IMA pre-crash scenario. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to alert commercial vehicle drivers of possible collisions with other V2V-equipped vehicles.

A.10.1 Pre-Crash Scenario

The host vehicle travels toward an intersection at a specified speed and a remote vehicle is stopped at the intersection on the perpendicular roadway. The host vehicle is a commercial truck equipped with a V2V system that features an IMA application. The remote vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. Since the remote vehicle is stopped, no IMA alert/warning should be issued as the HV moves toward and passes through the intersection.

A.10.2 Test Subject and Purpose

The subject of this test is the V2V-based IMA system of the HV. The test determines the ability of the HV's OBE system to suppress any potential warning/alert due to the RV stopped at the intersection.

A.10.3 Initial Condition

A.10.3.1 Test Velocities

For this test of the V2V-based IMA systems, the velocity for the HV is specified for each trial or set of trials. The RV is sitting still at the intersection.

A.10.4 Execution of Procedure

If unexpected events are encountered during any trial, the HV/RV drivers should brake and/or control the HV/RV as needed for safety and abort the trial.

The test procedure is depicted in Figure A-6 and Figure A-7.

1. The vehicles get into position with the HV traveling on one roadway and the RV is on the perpendicular road stopped at the intersection.
2. The HV accelerates to the specified test speed and maintains the specified speed until after clearing the intersection.
3. As the HV approaches the intersection, the HV OBE should NOT issue an IMA warning/alert.
4. Each trial ends after the HV has passed through the intersection.

A.10.5 Trial Validity

An individual trial is valid if during the course of the trial:

1. The HV velocity did not deviate from the specified velocity by more than ±1.0 mph.
2. The HV did not deviate from the center of the lane by a distance of more than ±2.0 ft.
3. The yaw rate of the HV did not exceed ±1 degree/second.

Working draft note: Other trial validity elements might include GPS coverage requirements and packet error rate of DRSC message exchange between HV and RV OBEs.

A.10.6 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful if the HV OBE does not initiate an IMA warning/alert as the HV approaches and passes through the intersection.

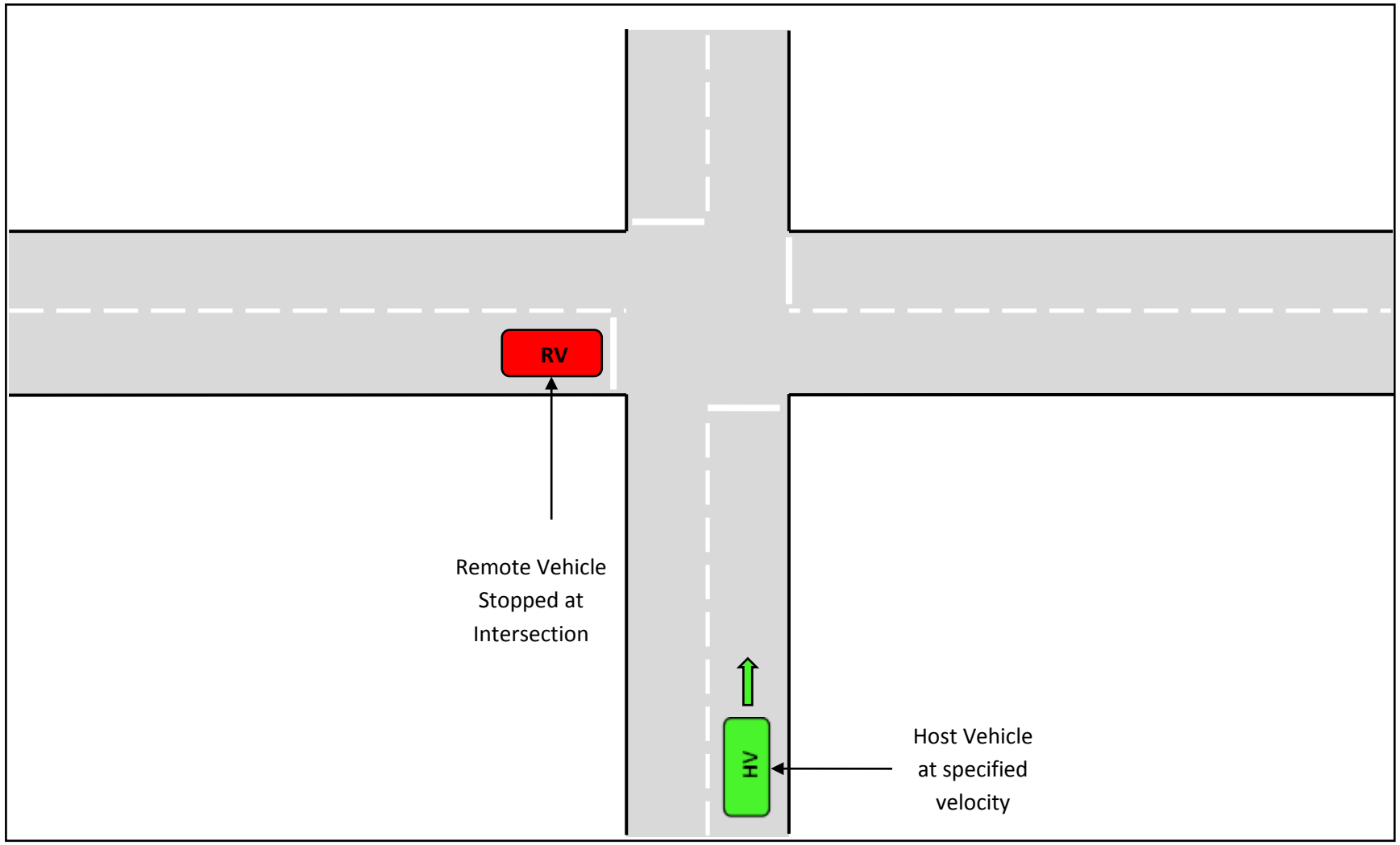

Figure A-6 - IMA-3 Test Course Graphic, Initial Conditions [not to scale]

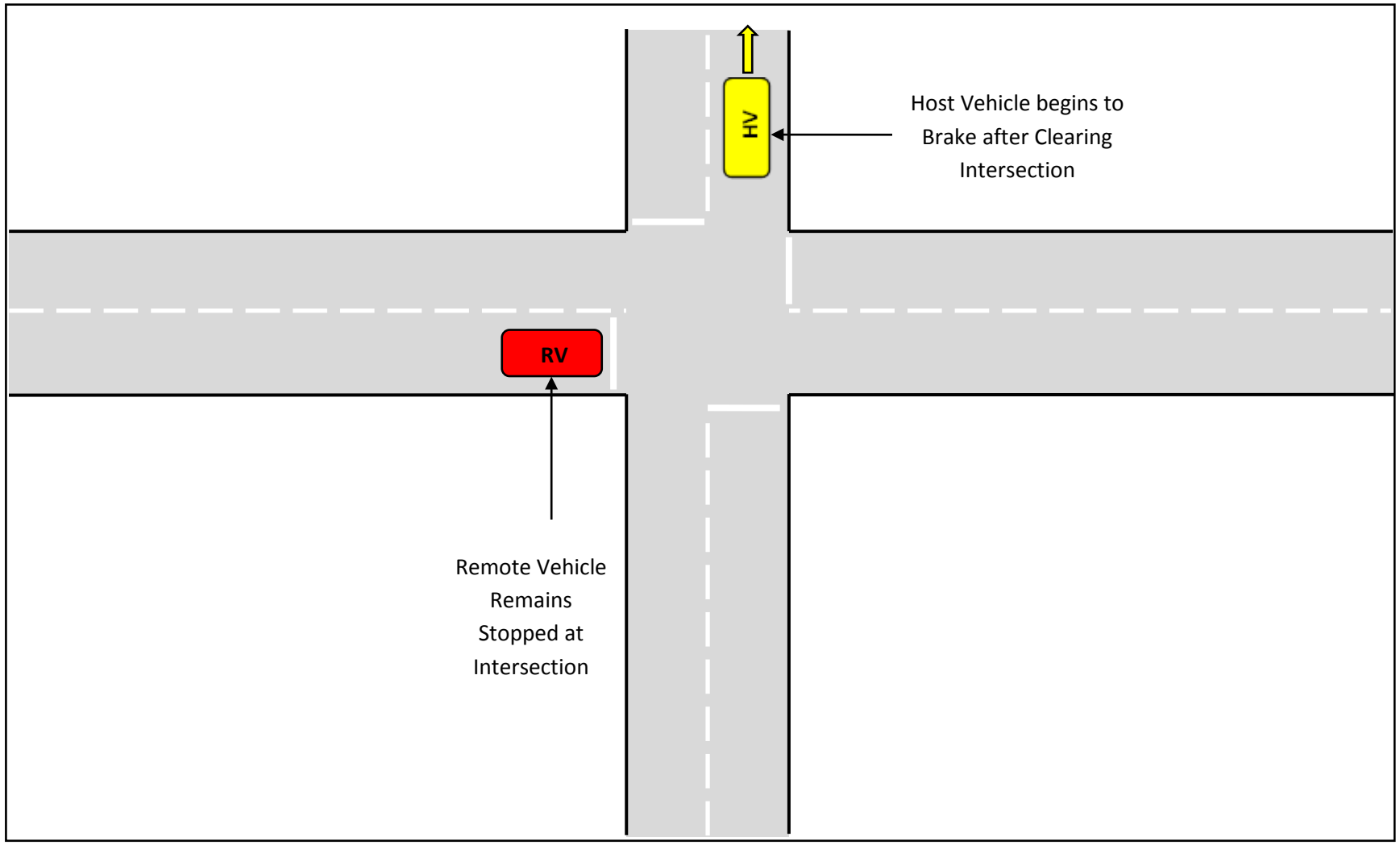

Figure A-7 - IMA-3 Test Course Graphic, End of Trial [not to scale]

A.11 IMA-4 - RV Moves Slowly Toward Intersection, HV Passes Through

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific IMA pre-crash scenario. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to alert commercial vehicle drivers of possible collisions with other V2V-equipped vehicles.

A.11.1 Pre-Crash Scenario

Two vehicles travel along perpendicular roadways approaching an intersection. The host vehicle is a commercial truck equipped with a V2V system that features an IMA application. The remote vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The host travels at a higher rate of speed (high enough to ensure broadcast of IMA warnings/alerts) and the remote vehicle is at a speeds below or close to where it would issue an alert. The remote vehicle brakes to come to a stop at the intersection and the host vehicle passes through the intersection at the specified speed.

A.11.2 Test Subject and Purpose

The subject of this test is the V2V-based IMA system of the HV. The test determines the ability of the HV's OBE system to identify the RV in the IMA path (perpendicular roadway) and at what speed the RV will cause the HV's OBE system to start to warn/alert the HV's driver of the threat.

A.11.3 Initial Condition

A.11.3.1 Test Velocities

For this test of the V2V-based IMA systems, the velocities of the HV and RV are specified for each trial or set of trials. The initial velocity of the RV is generally increased for successive runs up to the point that the HV OBE starts to issue alerts. The starting distance for each test is adjusted such that the RV can get up to the correct speed and time the arrival at the intersection to be near or coincide with that of the HV arrival. In general a range of test velocities will be specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress IMA event broadcasts. Test speed sequences can also be used to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.11.4 Execution of Procedure

If unexpected events are encountered during any trial, the HV/RV drivers should brake and/or control the HV/RV as needed for safety and abort the trial.

The test procedure is depicted in Figure A-8 and Figure A-9.

1. The vehicles get into position with the HV on one road at a distance far enough from the intersection to get up to the specified test speed and allow enough time at that speed to track the RV. The RV is on a perpendicular road traveling towards the same intersection as the HV. The RV starting position will change (get further) with each successively higher RV speed.

2. The vehicles accelerate to their respective test speeds at a similar acceleration level to ensure the HV and RV would meet at the intersection at a similar time if no braking action is taken by either vehicle.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds until the RV reaches a pre-set (marked with a cone) distance to begin braking before the intersection. The braking level should be below 0.3 g. The braking distance point will increase with successively higher speed runs.
5. Even though the HV may receive IMA warnings/alerts, the HV driver should continue driving at the test speed until the HV passes through the intersection (unless unexpected events are encountered, then as stated previously the HV/RV drivers should brake and/or control the HV/RV as needed for safety and abort the trial).
6. Each trial ends after the HV has passed through the intersection.

A.11.5 Trial Validity

An individual trial is valid if during the course of the trial:

1. The HV's and RV's velocities did not deviate from the specified velocities by more than ±1.0 mph.
2. The HV and RV did not deviate from the center of their respective lanes by a distance of more than ±2.0 ft.
3. The yaw rate of the HV and RV did not exceed ±1 degree/second.

Working draft note: Other trial validity elements might include GPS coverage requirements and packet error rate of DRSC message exchange between HV and RV OBEs.

A.11.6 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

The test sequences are specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress IMA event broadcasts. A trial with RV speeds above the threshold value will be successful if the HV OBE initiates an IMA alert when the RV's speed/distance is above a pre-determined TTCmin (TTC that would allow the HV driver to brake in time to avoid a crash) and extinguishes that alert once the HV is clear of the intersection or when the RV has slowed enough that a collision is no longer possible (RV is braking such that it will not enter intersection). Trials with RV speeds below the threshold value will be successful if the HV OBE does not issue an IMA warning/alert.

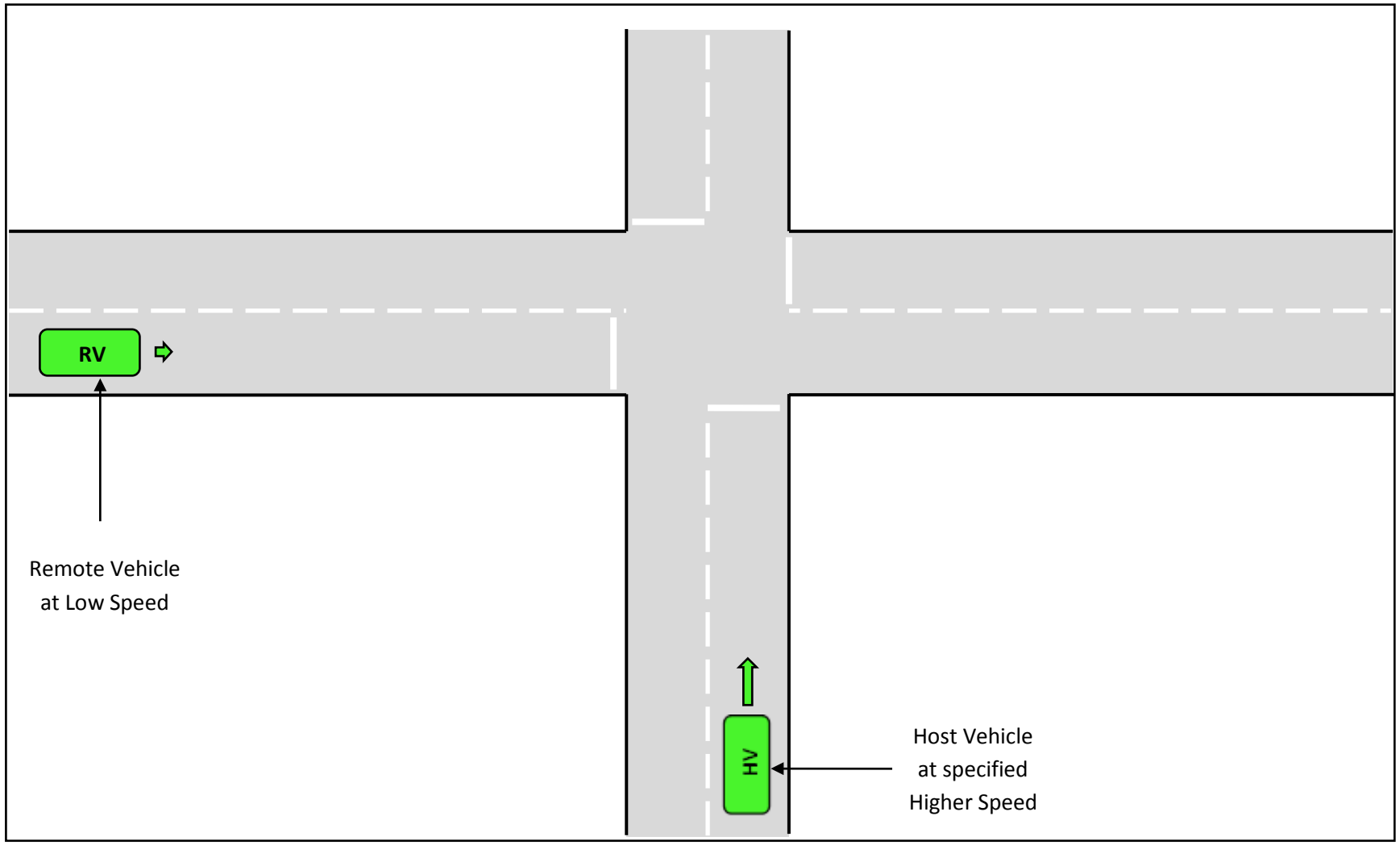

Figure A-8 - IMA-4 Test Course Graphic, Initial Conditions [not to scale]

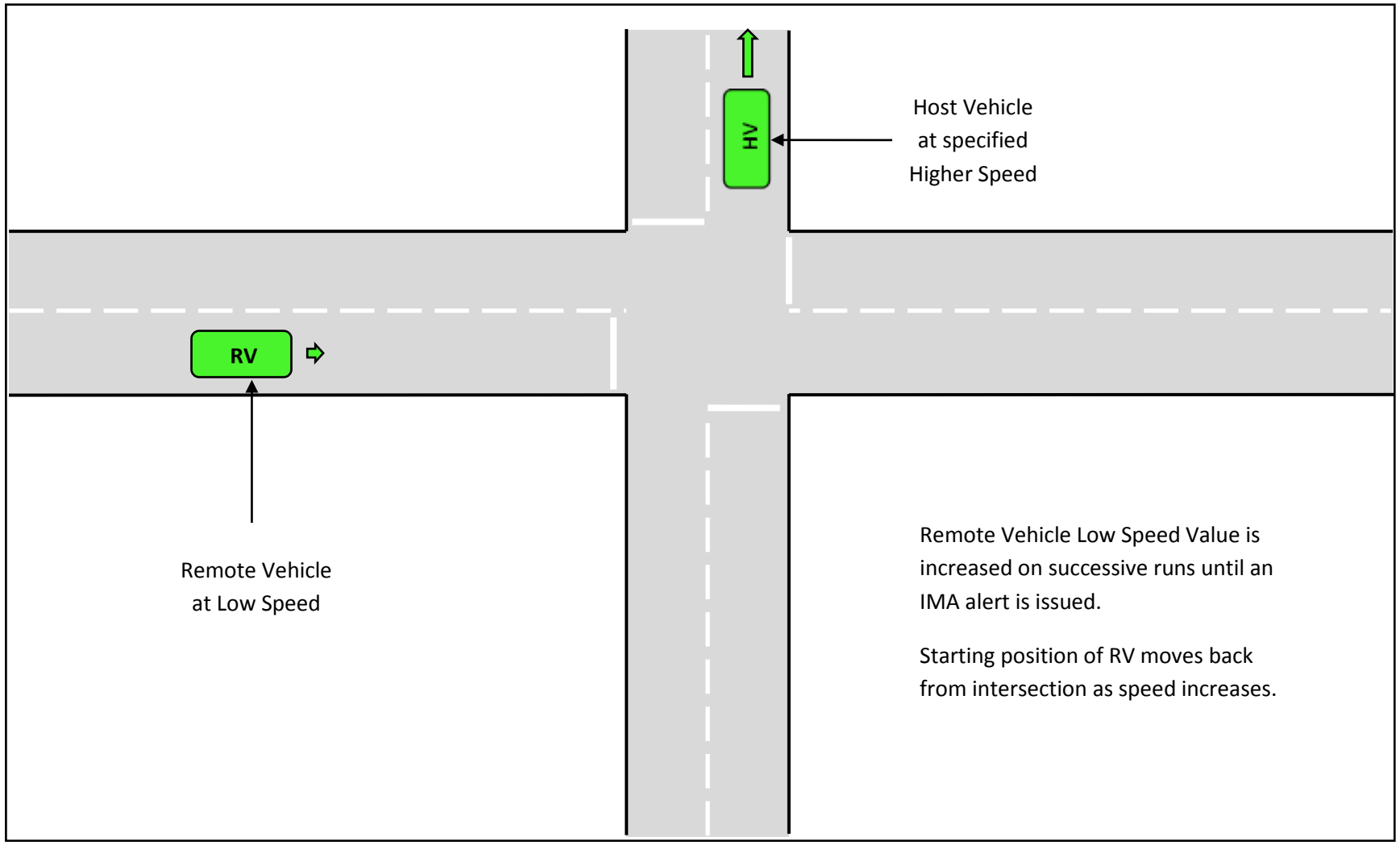

Figure A-9 - IMA-4 Test Course Graphic, End of Trial [not to scale]

A.12 IMA-5 - HV Brakes to Avoid Intersection Collision, RV Passes Through

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific IMA pre-crash scenario. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to alert commercial vehicle drivers of possible collisions with other V2V-equipped vehicles.

A.12.1 Pre-Crash Scenario

Two vehicles travel along perpendicular roadways approaching an intersection. The host vehicle is a commercial truck equipped with a V2V system that features an IMA application. The remote vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The host and remote vehicle are moving at the same speed on a collision course towards an intersection. After an IMA alert has been issued by the host vehicle OBE, the host vehicle brakes to come to a stop at the intersection and the remote vehicle passes through the intersection.

A.12.2 Test Subject and Purpose

The subject of this test is the V2V-based IMA system of the HV. The test determines the ability of the HV's OBE system to identify the RV in the IMA path (perpendicular roadway) and alert the HV's driver of the threat in a timely manner as well as extinguish the alert when the threat has passed (the HV has slowed enough that it will not reach the intersection or the RV has passed through the intersection).

A.12.3 Initial Condition

A.12.3.1 Test Velocities

For this test of the V2V-based IMA systems, the velocities of the HV and RV are specified for each trial or set of trials. The velocity of the RV is equal to the specified velocity until braking is initiated. A minimum test velocity may be specified above which the HV's OBE will broadcast the HV's location, velocity, and direction of travel, and above which the RV's ISS, RSD, or ASD would issue an alert to produce a successful trial. A single, standard test velocity—not necessarily a minimum velocity—may be specified. A range of test velocities may be specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress IMA event broadcasts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.12.4 Execution of Procedure

If unexpected events are encountered during any trial, the HV/RV drivers should brake and/or control the HV/RV as needed for safety and abort the trial.

The test procedure is depicted in Figure A-10 and Figure A-11.

1. The vehicles get into position with the HV on one road at a distance far enough from the intersection to get up to the specified test speed and allow enough time at that speed to track the RV. The RV is on a perpendicular road traveling towards the same intersection as the HV. It should be start at a similar distance from the intersection as the HV.

2. The vehicles accelerate to their respective test speeds at a similar acceleration level to ensure the HV and RV would meet at the intersection at a similar time if no braking action is taken by either vehicle.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds until the HV OBE system has issued an IMA alert at which point the HV driver begins to brake to avoid the intersection incursion. If the HV reaches a pre-determined safe stopping distance (marked with a cone) before an IMA alert is issued, the HV driver should begin to brake at the safe stopping distance cone. The braking level should be below 0.3 g.
5. Each trial ends after the RV has passed through the intersection.

A.12.5 Trial Validity

An individual trial is valid if during the course of the trial:

1. The HV's and RV's velocities did not deviate from the specified velocities by more than ±1.0 mph (up to the point of braking for the HV).
2. The HV and RV did not deviate from the center of their respective lanes by a distance of more than ±2.0 ft.
3. The yaw rate of the HV and RV did not exceed ±1 degree/second.

Working draft note: Other trial validity elements might include GPS coverage requirements and packet error rate of DRSC message exchange between HV and RV OBEs.

A.12.6 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful if the HV OBE initiates an IMA alert when the RV's speed/distance is above a pre-determined TTCmin (TTC that would allow the HV driver to brake in time to avoid a crash) and extinguishes that alert once the HV is clear of the intersection or when the HV has slowed enough that a collision is no longer possible (HV is braking such that it will not enter intersection). A trial is unsuccessful if the HV OBE does not initiate an IMA alert prior to TTCmin, or the alert persists after the RV has cleared the intersection or the HV has slowed enough that it will not reach the intersection.

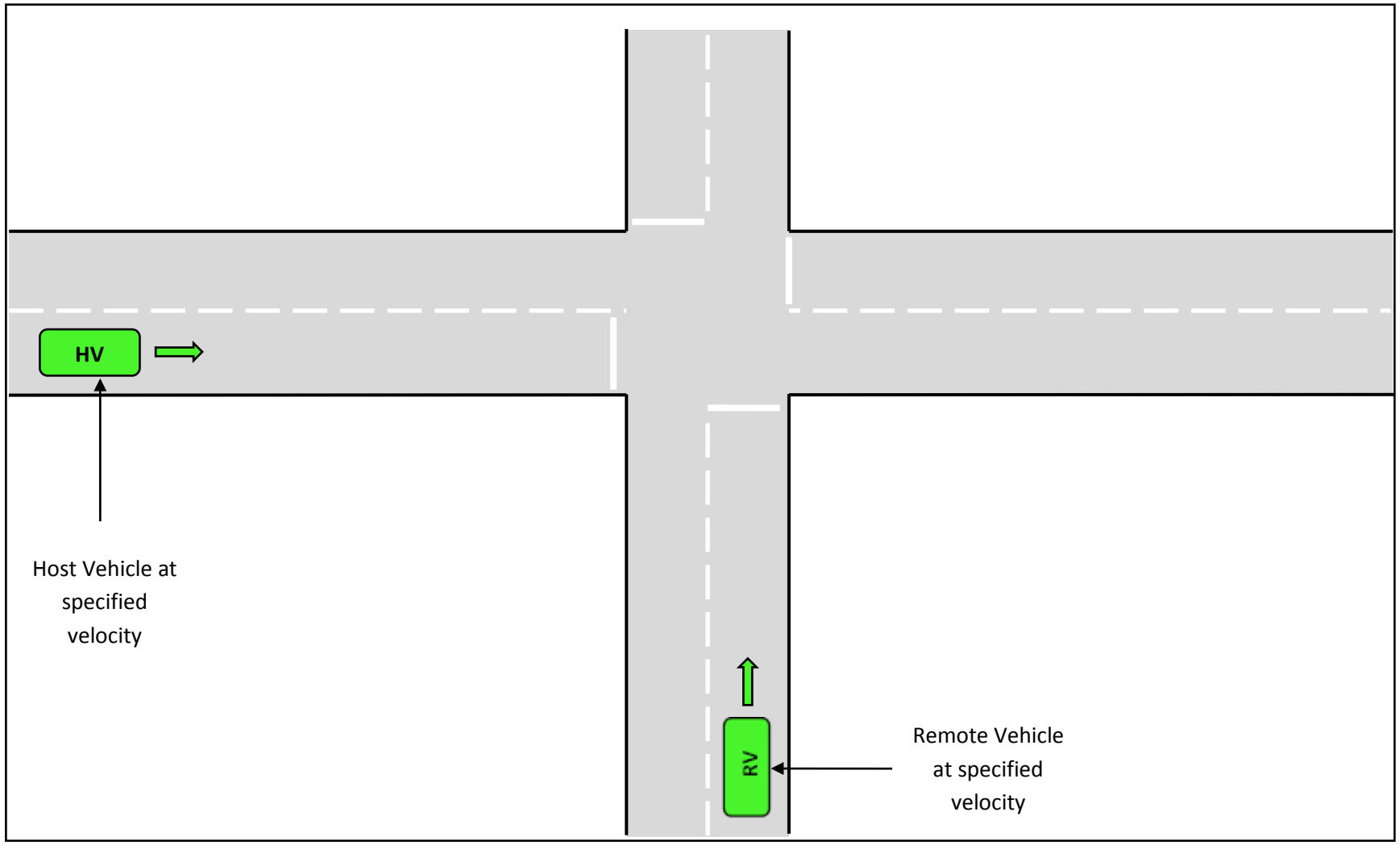

Figure A-10 - IMA-5 Test Course Graphic, Initial Conditions [not to scale]

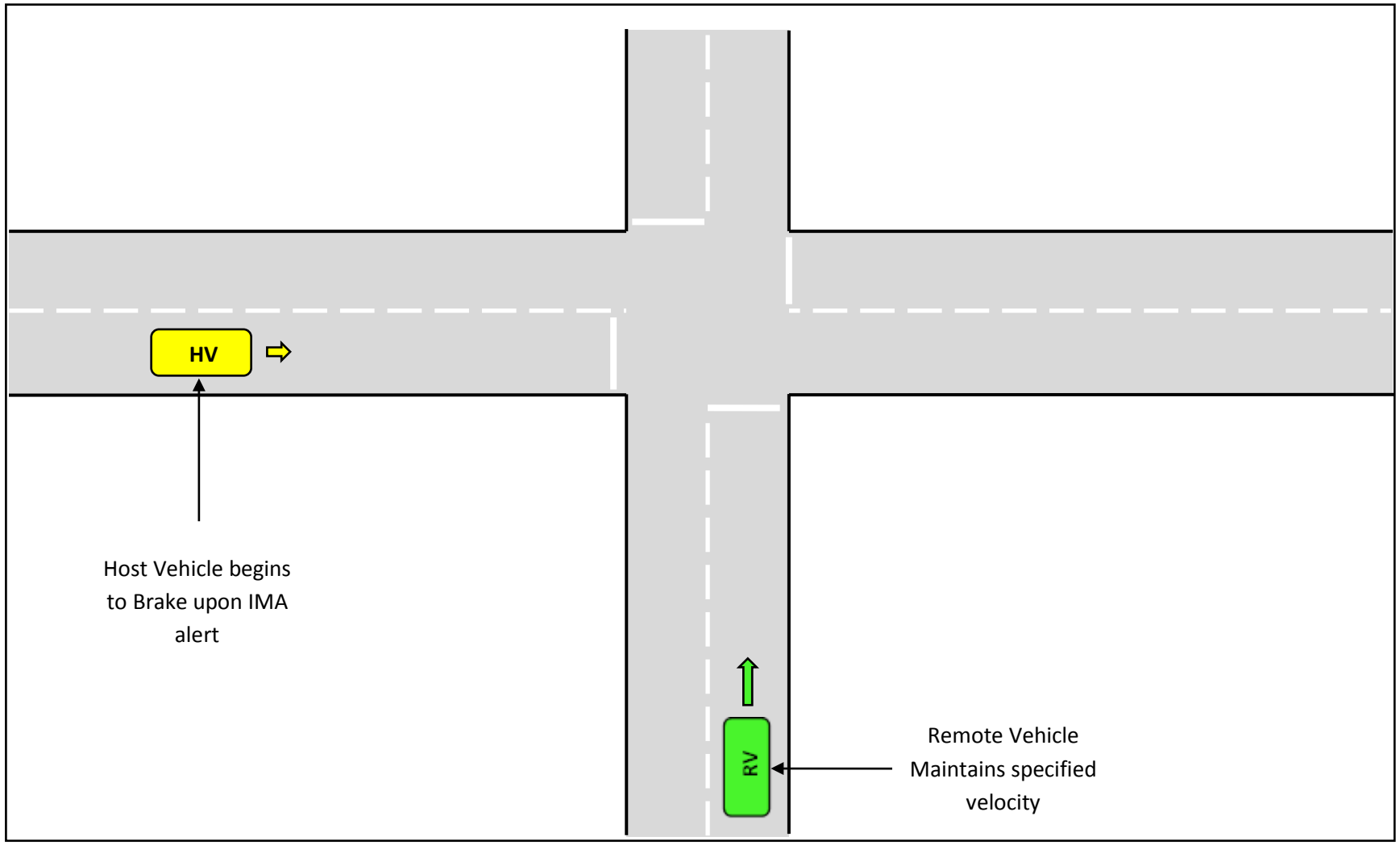

Figure A-11 - IMA-5 Test Course Graphic, Braking Event [not to scale]

A.13 IMA-6 - HV and RV Move Slowly Toward Intersection

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific IMA pre-crash scenario. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to alert commercial vehicle drivers of possible collisions with other V2V-equipped vehicles.

A.13.1 Pre-Crash Scenario

Two vehicles travel along perpendicular roadways approaching an intersection. The host vehicle is a commercial truck equipped with a V2V system that features an IMA application. The remote vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The host and remote vehicles travels at successively higher speeds (same speed for both vehicles) until the speeds are high enough to produce the broadcast of an IMA warnings/alert from the host vehicle OBE. The host vehicle brakes to come to a stop at the intersection or upon the IMA warning and the remote vehicle passes through the intersection at the specified speed.

A.13.2 Test Subject and Purpose

The subject of this test is the V2V-based IMA system of the HV. The test determines the ability of the HV's OBE system to identify the RV in the IMA path (perpendicular roadway) and at what speed the RV will cause the HV's OBE system to start to warn/alert the HV's driver of the threat.

A.13.3 Initial Condition

A.13.3.1 Test Velocities

For this test of the V2V-based IMA systems, the velocities of the HV and RV are specified for each trial or set of trials. The initial velocity of the HV and RV are generally increased for successive runs up to the point that the HV ODE start to issue alerts. The starting distance for each test is adjusted such that the HV and RV can get up to the correct speed and time the arrival at the intersection to be near or coincide with each other (a collision occur without braking by the HV or RV). In general a range of test velocities will be specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress IMA event broadcasts. Test speed sequences can also be used to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.13.4 Execution of Procedure

If unexpected events are encountered during any trial, the HV/RV drivers should brake and/or control the HV/RV as needed for safety and abort the trial.

The test procedure is depicted in Figure A-12 and Figure A-13.

1. The vehicles get into position with the HV on one road at a distance far enough from the intersection to get up to the specified test speed and allow enough time at that speed to track the RV. The RV is on a perpendicular road traveling towards the same intersection as the HV. The RV starting distance from the intersection will be similar to that for the HV.

2. The vehicles accelerate to the trial test speed at a similar acceleration level to ensure the HV and RV would meet at the intersection at a similar time if no braking action is taken by either vehicle.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds until the HV reaches a pre-determined (marked with a cone) stopping distance to begin braking before the intersection. If an IMA warning/alert is issued before the pre-determined safe stopping distance cone, the HV driver should brake upon hearing/seeing the IMA warning/alert. The braking level should be below 0.3 g. The safe braking distance point will increase with successively higher speed runs.
5. Each trial ends after the HV has come to a stop and the RV has passed through the intersection.

A.13.5 Trial Validity

An individual trial is valid if during the course of the trial:

1. The HV's and RV's velocities did not deviate from the specified velocities by more than ±1.0 mph.
2. The HV and RV did not deviate from the center of their respective lanes by a distance of more than ±2.0 ft.
3. The yaw rate of the HV and RV did not exceed ±1 degree/second.

Working draft note: Other trial validity elements might include GPS coverage requirements and packet error rate of DRSC message exchange between HV and RV OBEs.

A.13.6 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

The test sequences are specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress IMA event broadcasts. A trial with HV/RV speeds above the threshold value will be successful if the HV OBE initiates an IMA alert when the RV's speed/distance is above a pre-determined TTCmin (TTC that would allow the HV driver to brake in time to avoid a crash) and extinguishes that alert once the HV is clear of the intersection or when the RV has slowed enough that a collision is no longer possible (RV is braking such that it will not enter intersection). Trials with HV/RV speeds below the threshold value will be successful if the HV OBE does not issue an IMA warning/alert.

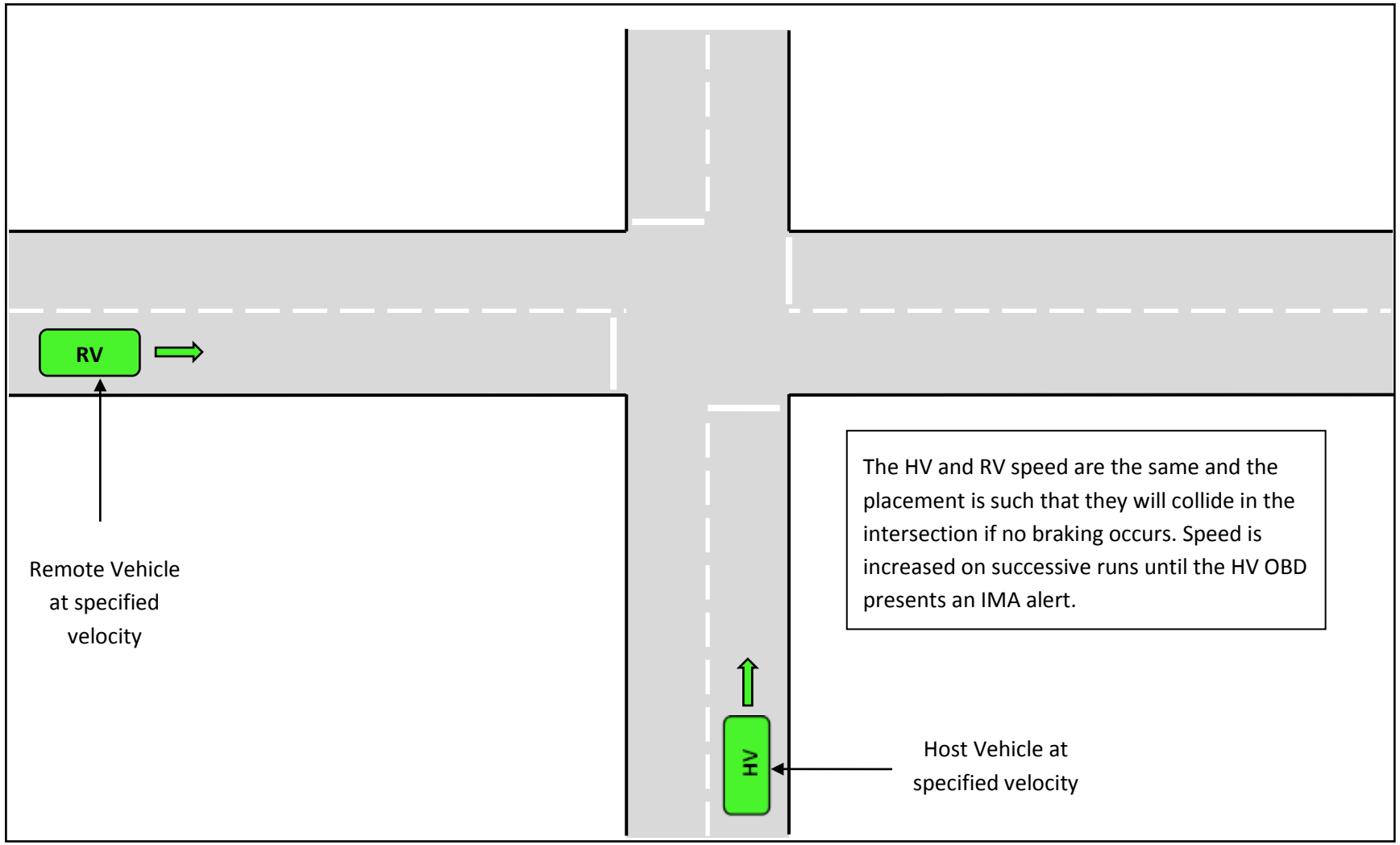

Figure A-12 - IMA-6 Test Course Graphic, Initial Conditions [not to scale]

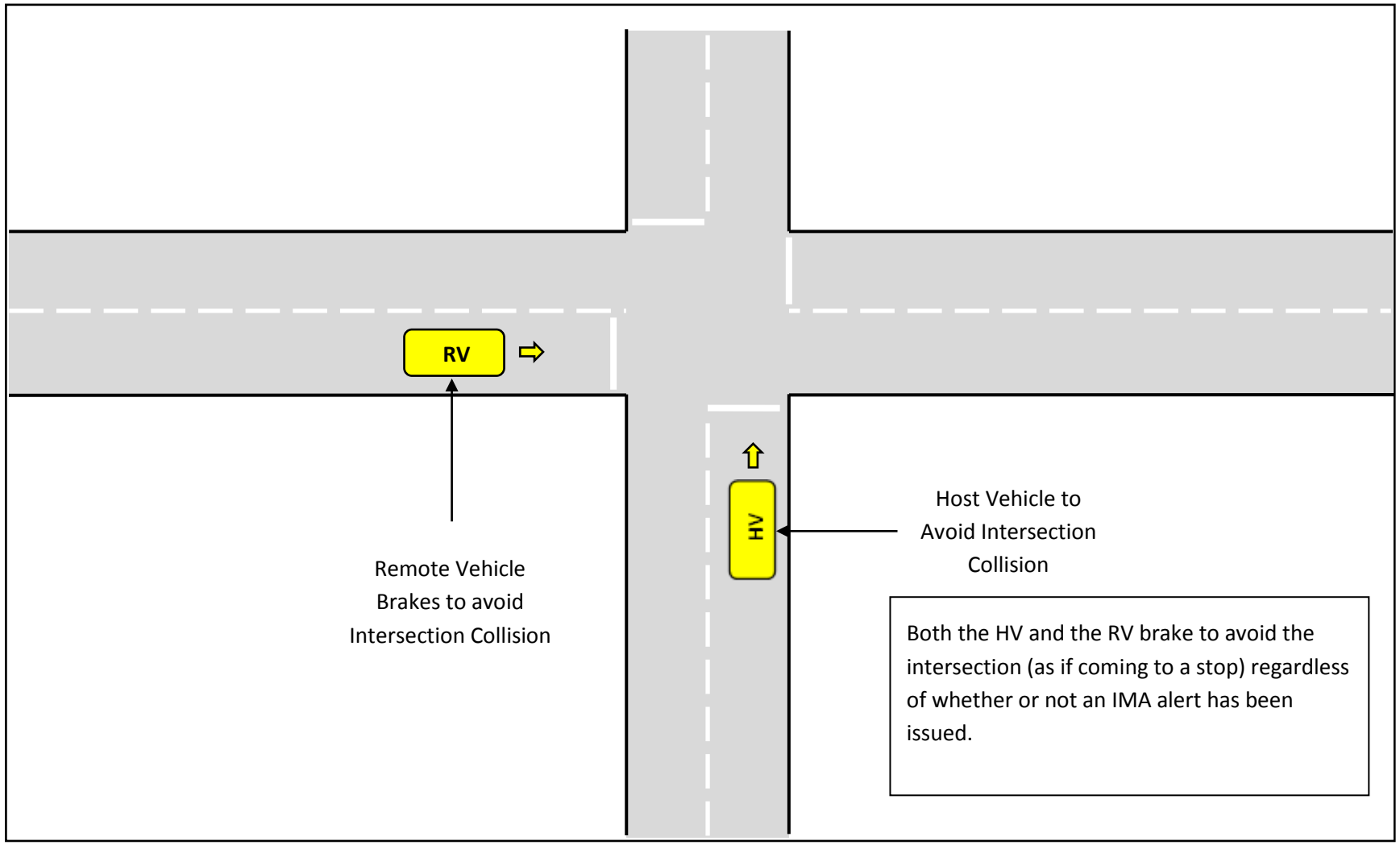

Figure A-13 - IMA-6 Test Course Graphic, Braking Event [not to scale]

Appendix B - Tabulated Test Results

B.1 ICA-1 Tabulated Test Results

There were three ICA-1A tests. The tabulated results for each test are presented in the following sections.

B.1.1 ICA-1A Test 1: V_{HV}=25, V_{RV}=25

The HV and RV TTC to Intersection and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-1. Four tests were conducted for ICA-1A Test 1. Since the HV and RV speeds are the same (25 mph), the range to intersection values at alert onset should be fairly similar if the vehicles were to arrive at the intersection at the same time. This was generally the case except for Test 1272 where the RV Range to Intersection is much lower than the HV range (87 versus 107 meters). Despite the earlier RV arrival, the HV alert occurred in the same range of values for HV TTC and Range to Intersection for this test as it did for the others. The HV TTC was very consistent with an average value of 9.6 seconds with a 0.1 second standard deviation giving a coefficient of variation of 0.5%.

Table B-1: ICA-1A Test 1 TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1271	9.6	9.6	9.7	10.0	10.0	9.8	107	108	108	111	111	108	25.0	24.7
1272	9.5	9.5	9.6	7.9	7.9	7.6	107	107	107	87	87	83	25.1	24.6
1273	9.5	9.5	9.7	9.6	9.6	9.4	107	107	107	107	106	103	25.0	24.7
1274	9.6	9.6	9.7	10.1	10.1	9.8	106	106	106	111	111	108	24.7	24.6
Ave.	9.6	9.6	9.7	9.4	9.4	9.1	107	107	107	104	104	101	25.0	24.7
Std.	0.1	0.1	0.0	1.1	1.0	1.0	1	1	1	12	12	12	0.2	0.1
C. of V. (%)	0.5	0.6	0.4	11.2	11.1	11.4	1	1	1	11	11	12	0.7	0.3

The same metrics for the Level 3 alert onset are listed in Table B-2. The TTC for the HV to Intersection was again very consistent with an average value of 7.3 seconds and a standard deviation less than 0.1 seconds, giving a coefficient of variation of 0.5 percent.

Table B-2: ICA-1A Test 1 TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1271	7.3	7.4	7.4	7.8	7.8	7.6	82	82	82	86	86	82	25.0	24.6
1272	7.3	7.3	7.4	5.5	5.5	5.2	81	81	81	61	61	58	25.0	25.0
1273	7.2	7.3	7.3	7.1	7.1	6.8	80	80	81	80	80	76	24.7	25.1
1274	7.3	7.3	7.4	7.9	7.9	7.7	81	81	82	87	87	84	25.0	24.6
Ave.	7.3	7.3	7.4	7.1	7.1	6.8	81	81	81	78	78	75	24.9	24.8
Std.	0.0	0.0	0.0	1.1	1.1	1.2	1	1	1	12	12	12	0.2	0.3
C. of V. (%)	0.5	0.5	0.5	16.1	16.0	16.9	1	1	1	15	15	16	0.6	1.1

TTC_{NA} and HV and RV speed values at the Level 3 alert offset are given in Table B-3. TTC_{NA} values are listed instead of TTC because the TTC values are generally infinite (HV will not reach intersection) at alert offset. The HV had no intervention capabilities and the HV driver applied the brakes after the Level 3 alert occurred. The HV speed at offset was greatly reduced by the time the Level 3 alert extinguished (down in the 10 to 13 mph range), well after a collision would be possible as noted by the large difference between the HV and RV TTC_{NA} values.

Table B-3: ICA-1A Test 1 TTC_{NA} and Speed at IMA Level 3 Alert Offset

Test No.	IMA Level 3 Offset							
	TTC_{NA} HV to Intersection (sec)			TTC_{NA} RV to Intersection (sec)			Speed WSU (mph)	
	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1271	6.9	6.8	7.4	3.1	3.1	2.9	11.9	24.6
1272	6.1	6.1	6.5	0.6	0.6	0.4	12.7	24.7
1273	6.3	6.3	6.9	1.5	1.5	1.3	10.0	24.6
1274	6.9	6.8	7.3	2.4	2.4	2.2	10.0	24.6
Ave.	6.6	6.5	7.0	1.9	1.9	1.7	11.1	24.6
Std.	0.4	0.4	0.4	1.1	1.1	1.1	1.3	0.0
C. of V. (%)	5.7	5.7	6.0	57.0	56.7	63.4	12.0	0.2

For most of the tests, the IMA Level 3 offset was the end of the warning, but Test 1271 briefly went from Level 3 to Level 2 before extinguishing completely. The TTC_{NA} values for the Level 2 offset are listed in Table B-4.

Table B-4: ICA-1A Test 1 TTC_{NA} and Speed at IMA Level 2 Alert Offset

Test No.	IMA Level 2 Offset							
	TTC_{NA} HV to Intersection (sec)			TTC_{NA} RV to Intersection (sec)			Speed WSU (mph)	
	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1271	7.9	7.8	8.4	2.6	2.6	2.4	9.9	24.6

B.1.2 ICA-1A Test 2: V_{HV}=45, V_{RV}=45

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-5. Five tests were conducted for ICA-1A Test 2, but Test 1280 did not have a Level 2 alert. Since the HV and RV speeds were supposed to be the same (45 mph), the Range to Intersection values at alert onset should be fairly similar if the vehicles were to arrive at the intersection at the same time. The RV Range to Intersection was generally lower than the HV range for this set of tests (177 versus 152 meters on average), but the average TTC were fairly similar (7.5 versus 7.6 seconds). This happens in part due to the alert occurring so early that that HV (Red Cascadia) is still not up to the test speed of 45 mph and is therefore still accelerating that reduces the HV TTC value. It also increases the variability of the HV TTC.

Table B-5: ICA-1A Test 2 TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1276	8.0	8.8	8.4	7.6	7.6	7.5	188	188	188	152	152	149	41.7	44.9
1277	7.1	7.2	7.2	7.7	7.7	7.6	167	168	167	153	153	150	43.3	44.6
1278	7.4	7.4	7.4	7.6	7.6	7.5	173	173	173	152	151	149	43.4	44.6
1279	7.7	7.9	7.5	7.7	7.7	7.6	181	181	181	153	153	151	42.1	44.7
Ave.	7.5	7.8	7.6	7.6	7.6	7.5	177	177	177	152	152	150	42.6	44.7
Std.	0.4	0.7	0.5	0.0	0.0	0.1	9	9	9	1	1	1	0.9	0.1
C. of V.(%)	5.1	9.2	6.8	0.6	0.6	0.7	5	5	5	0	1	1	2.0	0.3

The same metrics for the Level 3 alert are listed in Table B-6. Again the average TTC values for the HV and RV are fairly similar (7.1 versus 7.3 seconds on average), even though the average Range to Intersection values are relatively different (163 versus 145 meters).

Table B-6: ICA-1A Test 2 TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1276	7.2	7.2	7.2	6.7	6.7	6.6	171	171	171	134	134	131	43.9	44.8
1277	7.3	7.1	6.9	7.6	7.6	7.5	165	166	165	151	151	148	43.6	44.5
1278	7.0	7.1	7.1	7.4	7.4	7.3	169	169	169	148	147	145	43.9	44.5
1279	7.2	7.3	7.0	7.0	7.0	6.9	167	168	167	139	139	137	43.8	44.6
1280	7.0	7.4	7.1	7.7	7.7	7.6	141	141	141	154	154	151	44.9	44.6
Ave.	7.1	7.2	7.1	7.3	7.3	7.2	163	163	163	145	145	142	44.0	44.6
Std.	0.1	0.1	0.1	0.4	0.4	0.4	12	12	12	8	8	8	0.5	0.1
C. of V. (%)	1.7	1.9	1.3	5.9	6.0	5.8	8	7	8	6	6	6	1.1	0.2

The TTC_{NA} and vehicle speeds at the Level 3 Alert offset are given in Table B-7. Some RV values are blank because the RV has passed through intersection by the time the alert has extinguished. The HV has slowed considerably before the alert has extinguished and well after any possibility of collision between the vehicles.

Table B-7: ICA-1A Test 2 TTC_{NA} and Speed at IMA Level 3 Alert Offset

Test No.	IMA Level 3 Offset							
	TTC_{NA} HV to Intersection (sec)			TTC_{NA} RV to Intersection (sec)			Speed WSU (mph)	
	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1276	4.6	4.6	4.8				25.0	44.2
1277	4.1	4.1	4.4				20.7	44.6
1278	5.2	5.2	5.5	0.3	0.3	0.2	20.6	43.9
1279	5.0	5.0	5.4	0.1	0.2	0.1	22.5	43.8
1280	5.1	5.1	5.4	0.0	0.0		12.9	42.7
Ave.	4.8	4.8	5.1	0.1	0.2	0.2	20.3	43.8
Std.	0.4	0.4	0.5	0.1	0.1	0.1	4.5	0.7
C. of V. (%)	9.2	9.1	9.7	83.5	70.9	45.5	22.2	1.6

B.1.3 ICA-1A Test 2: V_{HV}=25, V_{RV}=45

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-8. Five tests were conducted for ICA-1A Test 3, but Test 1286 did not have a Level 2 alert. Similar values for the Level 3 alert onset are listed in Table B-9. Except for Test 1285, the TTC values for both the Level 2 and Level 3 alerts are fairly similar for the HV and RV, which suggests that the vehicles would arrive at the intersection at approximately the same time if the speeds for both vehicles were kept constant. Both the HV and RV were near the test conditions of 25 and 45 mph for all tests. The Level 2 alert was generally

very short prior to switching to a Level 3 alert (average of 7.8 seconds HV TTC for Level 2 and 7.3 seconds for Level 3).

Table B-8: ICA-1A Test 3 TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1282	7.7	7.7	7.8	7.6	7.6	7.4	86	87	87	151	152	148	25.2	44.6
1283	7.3	7.4	7.4	7.7	7.7	7.5	84	85	85	154	154	150	25.7	44.8
1284	7.5	7.5	7.6	7.6	7.7	7.5	84	85	85	152	153	148	25.1	44.6
1285	8.5	8.6	8.6	7.7	7.8	7.5	96	96	96	154	154	150	25.2	44.5
Ave.	7.8	7.8	7.9	7.7	7.7	7.5	88	88	88	153	153	149	25.3	44.6
Std.	0.5	0.5	0.5	0.1	0.1	0.1	5	6	5	1	1	1	0.3	0.1
Cos.(%)	6.6	6.8	6.6	0.8	0.8	0.7	6	6	6	1	1	1	1.2	0.3

Table B-9: ICA-1A Test 3 TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1282	7.3	7.3	7.4	7.2	7.2	7.0	82	82	83	143	144	140	25.2	44.5
1283	7.3	7.3	7.3	7.6	7.6	7.4	83	84	84	152	152	148	25.7	44.8
1284	7.3	7.3	7.4	7.5	7.5	7.3	82	82	83	149	149	144	25.1	44.5
1285	7.3	7.3	7.4	6.6	6.6	6.4	82	83	83	130	130	126	25.3	44.3
1286	7.3	7.3	7.4	7.6	7.7	7.5	83	84	84	152	153	148	25.5	44.6
Ave.	7.3	7.3	7.4	7.3	7.3	7.1	83	83	83	145	146	141	25.4	44.5
Std.	0.0	0.0	0.0	0.4	0.4	0.5	1	1	1	9	9	9	0.3	0.2
C. of V. (%)	0.4	0.4	0.6	6.0	5.9	6.4	1	1	1	6	6	7	1.0	0.4

The TTC_{NA} and vehicle speeds at the Level 3 Alert offset are given in Table B-10. The HV has slowed considerably before the alert has extinguished and well after any possibility of collision between the vehicles, as noted by the large difference in the TTC_{NA} values between the HV and the RV.

Table B-10: ICA-1A Test 3 TTC_{NA} and Speed at IMA Level 3 Alert Offset

Test No.	IMA Level 3 Offset							
	TTC_{NA} HV to Intersection (sec)			TTC_{NA} RV to Intersection (sec)			Speed WSU (mph)	
	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1282	7.4	7.2	7.8	1.6	1.7	1.6	9.6	44.2
1283	7.0	6.9	7.4	2.2	2.2	2.1	9.7	44.2
1284	7.2	7.0	7.5	2.2	2.2	2.1	10.0	44.3
1285	6.2	6.2	6.9	1.5	1.5	1.4	10.9	44.1
1286	6.8	6.8	7.1	4.0	4.0	3.9	14.9	44.2
Ave.	6.9	6.8	7.3	2.3	2.3	2.2	11.0	44.2
Std.	0.5	0.4	0.3	1.0	1.0	1.0	2.2	0.1
C. of V. (%)	6.6	5.5	4.6	43.4	42.5	45.5	20.3	0.2

B.2 ICA-2 Tabulated Test Results

The ICA-2A HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-11. The same data for the Level 3 alert onset are listed in Table B-12. There were five tests conducted. The first test (1290) did not have a Level 2 alert. It had a fairly large difference in HV and RV TTC for the Level 3 Alert onset, which means the vehicles would not have arrived at the intersection at the same time and therefore would not have been considered a valid test.

Table B-11: ICA-2A TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1291	9.4	9.4	9.4	8.9	9.0	8.9	93	93	92	135	135	134	22.1	33.7
1292	9.3	9.3	9.5	9.8	9.9	9.8	93	93	93	148	148	146	22.3	33.6
1293	9.3	9.3	9.4	8.7	8.7	8.6	92	92	92	131	132	130	22.2	33.7
1294	8.5	8.6	8.6	10.1	10.1	10.0	84	84	84	152	153	151	22.1	33.8
Ave.	9.1	9.1	9.2	9.4	9.4	9.3	90	91	90	142	142	140	22.2	33.7
Std.	0.4	0.4	0.4	0.7	0.7	0.7	4	4	4	10	10	10	0.1	0.1
C. of V. (%)	4.5	4.2	4.3	7.1	7.1	7.1	5	5	4	7	7	7	0.5	0.3

Table B-12: ICA-2A TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1290	6.8	6.9	6.7	10.0	10.1	9.9	66	67	66	151	152	150	21.9	33.8
1291	7.2	7.2	7.2	6.7	6.7	6.6	72	72	71	103	103	102	22.5	34.5
1292	7.1	7.1	7.1	7.5	7.6	7.5	71	71	71	115	115	113	22.4	34.0
1293	7.2	7.2	7.2	6.5	6.6	6.4	71	72	71	100	100	98	22.3	34.1
1294	7.1	7.2	7.2	8.6	8.6	8.5	69	70	70	130	130	128	21.7	33.9
Ave.	7.1	7.1	7.1	7.9	7.9	7.8	70	70	70	119	120	118	22.2	34.1
Std.	0.2	0.1	0.2	1.4	1.5	1.4	2	2	2	21	22	21	0.3	0.2
C. of V. (%)	2.2	1.6	2.9	18.2	18.5	18.6	3	3	3	18	18	18	1.4	0.7

B.3 ICA-3 Tabulated Test Results

The ICA-3A HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-13. The same data for the Level 3 alert onset are listed in Table B-14. There were five tests conducted.

Table B-13: ICA-3A TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1296	9.2	9.2	9.5	9.6	9.6	9.5	88	88	89	151	151	149	21.5	35.3
1297	9.6	9.5	9.9	9.6	9.6	9.5	98	99	99	150	150	148	23.1	35.0
1298	9.0	9.0	9.2	9.6	9.6	9.5	90	90	91	151	151	149	22.5	35.1
1299	9.0	9.1	9.3	9.7	9.7	9.6	92	93	93	151	151	150	22.9	35.0
1300	9.0	9.0	9.1	9.6	9.6	9.5	94	94	94	149	149	148	23.3	34.9
Ave.	9.2	9.2	9.4	9.6	9.6	9.5	93	93	93	150	150	149	22.6	35.1
Std.	0.2	0.2	0.3	0.0	0.0	0.1	4	4	4	1	1	1	0.7	0.2
C. of V. (%)	2.6	2.4	3.3	0.4	0.5	0.6	4	4	4	1	1	1	3.1	0.5

Table B-14: ICA-3A TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1296	7.0	7.0	7.1	7.3	7.3	7.2	66	66	67	114	113	112	21.0	34.8
1297	7.0	7.0	7.1	6.8	6.8	6.7	69	70	70	105	105	103	22.1	34.5
1298	7.2	7.3	7.4	7.9	8.0	7.8	72	73	73	123	123	121	22.3	34.5
1299	7.1	7.1	7.2	7.7	7.7	7.6	71	71	72	118	119	118	22.5	34.6
1300	7.2	7.2	7.1	7.5	7.5	7.5	72	72	72	117	117	115	22.4	34.5
Ave.	7.1	7.1	7.2	7.5	7.5	7.4	70	70	71	115	115	114	22.1	34.6
Std.	0.1	0.1	0.1	0.4	0.4	0.4	3	3	3	7	7	7	0.6	0.1
C. of V. (%)	1.5	1.5	1.4	5.8	5.8	6.0	4	4	4	6	6	6	2.9	0.3

B.4 ICA-4 Tabulated Test Results

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-15. The same data for the Level 3 alert onset are listed in Table B-16. There were five tests conducted. There was a drop out in the RT data for the final test (Test 1305).

Table B-15: ICA-4A TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1301	9.4	9.5	9.6	9.1	9.1	9.0	98	98	96	140	141	139	23.2	34.5
1302	8.5	8.6	8.4	9.8	9.9	9.8	87	87	86	151	151	149	22.8	34.3
1303	9.0	9.0	9.1	9.8	9.8	9.8	91	91	90	151	151	150	22.6	34.4
1304	9.0	9.0	9.0	9.7	9.8	9.6	92	92	92	150	150	148	22.9	34.4
1305		9.3	9.5		9.3	9.3		94	94		143	143	22.1	34.3
Ave.	9.0	9.0	9.1	9.6	9.6	9.5	92	92	92	148	147	146	22.9	34.4
Std.	0.4	0.4	0.5	0.4	0.3	0.3	4	4	4	5	5	5	0.2	0.1
C. of V. (%)	4.1	4.3	5.1	3.8	3.6	3.4	5	5	4	3	3	3	1.0	0.3

Table B-16: ICA-4A TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1301	9.0	9.3	8.8	6.3	6.3	6.1	70	70	68	97	97	94	21.4	34.7
1302	7.2	7.3	7.2	8.5	8.5	8.4	74	74	73	131	131	129	22.9	34.5
1303	7.3	7.4	7.3	8.1	8.1	8.0	73	73	72	123	124	122	22.3	34.2
1304	7.3	7.3	7.3	8.1	8.1	8.0	75	76	75	125	126	124	23.2	34.7
1305		7.1	7.3		6.9	6.9		71	71		108	107	21.8	34.8
Ave.	7.7	7.6	7.6	7.7	7.6	7.5	73	72	72	119	117	115	22.4	34.5
Std.	0.8	0.9	0.7	1.0	0.9	1.0	2	2	2	15	14	14	0.8	0.2
C. of V. (%)	10.9	12.0	8.7	12.9	12.4	12.8	3	3	3	13	12	12	3.4	0.6

B.5 ICA-6 Tabulated Test Results

The HV Range to the Intersection at RV Brake Onset, HV Range to Intersection when RV Stopped, RV Braking Distance, and Average RV Brake Deceleration are listed in Table B-17.

Table B-17: ICA-6A HV Range to the Intersection at RV Brake Onset, HV Range to Intersection When RV Stopped, RV Braking Distance, and Average RV Brake Deceleration

Test No.	Brake Conditions											
	HV Range to Intersection at RV Brake Onset (m)			HV Range to Intersection at RV Stopped (m)			RV Brake Distance (m)			Ave. of RV Brake Deceleration (mpss)		
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU
1310	87.2	88.0	80.4	16.9	16.9	15.6	70.2	71.1	64.8	1.7	1.7	1.7
1311	100.5	101.9	95.3	47.9	47.8	47.5	52.7	54.1	47.8	2.0	2.0	2.0
1312	110.8	112.5	104.4	59.2	59.1	59.0	51.6	53.4	45.5	2.0	2.0	2.1
1313	119.6	120.8	112.2	69.0	68.9	69.0	50.6	51.9	43.3	2.2	2.2	2.3
1314	131.8	133.2	126.6	78.2	78.1	79.1	53.6	55.1	47.5	2.2	2.1	2.3
1315	142.3	143.9	136.9	98.1	98.0	98.9	44.2	45.9	38.0	2.5	2.4	2.5
1316	152.4	153.7	146.8	98.7	98.6	99.1	53.7	55.1	47.7	2.2	2.2	2.3

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-18. The same data for the Level 3 alert onset are listed in Table B-19.

Table B-18: ICA-6A TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1310	10.6	10.6	10.5	9.7	9.8	9.7	166	166	163	149	149	147	34.9	34.2
1311	10.6	10.7	10.7	9.7	9.8	9.7	167	167	166	148	149	147	35.1	34.2
1312	10.0	10.1	10.1	10.2	10.2	10.1	157	157	156	152	153	151	34.9	33.4
1313	10.6	10.6	10.6	9.6	9.6	9.6	167	167	166	146	147	146	35.3	34.2
1314	10.6	10.6	10.6			8.6	166	166	164	128	128	128	35.0	33.2
1315	10.4	10.5	10.5	9.7	9.7	9.7	164	165	164	149	149	149	35.2	34.5
1316	10.4	10.4	10.5			9.9	165	166	164	150	150	150	35.4	33.9

Table B-19: ICA-6A TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1310	8.0	8.0	7.9	7.1	7.1	7.0	127	127	123	110	111	108	35.5	34.7
1311	8.0	8.0	8.0	6.9	7.0	6.8	125	125	123	107	108	105	35.1	34.6
1312	8.0	8.0	8.0	8.5	8.5	8.4	127	127	126	124	125	123	35.5	32.7
1313	8.0	8.0	7.9				125	125	123	106	106	105	35.0	29.7
1314	8.0	8.1	8.0				125	126	124	97	97	97	34.8	20.7
1315	7.9	7.9	7.9				122	123	122	114	114	115	34.7	20.5
1316	7.9	7.9	7.9				124	125	123	118	118	117	35.1	21.0

Due to the RV to Intersection TTC going to infinity, TTC_{NA} data (TTC with no acceleration) are presented in Table B-20 with Range and Speed data being repeated from Table B-19.

Table B-20: ICA-6A TTC_{NA}, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC_{NA} HV to Intersection (sec)			TTC_{NA} RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1310	8.0	8.0	7.9	7.1	7.1	7.0	127	127	123	110	111	108	35.5	34.7
1311	8.0	8.0	8.0	6.9	7.0	6.8	125	125	123	107	108	105	35.1	34.6
1312	8.0	8.0	8.0	8.5	8.5	8.4	127	127	126	124	125	123	35.5	32.7
1313	8.0	8.0	7.9	8.0	8.0	8.0	125	125	123	106	106	105	35.0	29.7
1314	8.0	8.1	8.0	10.4	10.6	10.7	125	126	124	97	97	97	34.8	20.7
1315	7.9	7.9	7.9	12.5	12.4	12.5	122	123	122	114	114	115	34.7	20.5
1316	7.9	7.9	7.9	12.6	12.6	12.9	124	125	123	118	118	117	35.1	21.0

B.6 ICA-7 Tabulated Test Results

six tests ICA-7 were conducted, but the first test had the HV arriving at the intersection too early and therefore it is not included in the tabulated data. The HV Range to the Intersection at HV Brake Onset, HV Range to Intersection when HV Stopped, RV Braking Distance, and Average RV Brake Deceleration are listed in Table B-21.

Table B-21: ICA-7A Range to Intersection at HV Brake Onset and HV Stopped and HV Braking Distance and Average Deceleration

Test No.	Brake Conditions											
	HV Range to Intersection at HV Brake Onset (m)			HV Range to Intersection at HV Stopped (m)			HV Brake Distance (m)			Ave. HV Brake Deceleration (mpss)		
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU
1318	72.6	73.0	71.8	16.3	16.1	15.6	56.3	56.9	56.2	1.7	1.7	1.7
1319	91.0	91.6	89.7	23.7	23.7	22.6	67.3	67.9	67.1	1.7	1.7	1.7
1320	102.6	102.8	101.1	44.2	43.8	42.9	58.5	59.0	58.2	2.0	2.0	1.9
1321	117.0	117.4	116.6	44.7	44.6	43.9	72.3	72.8	72.7	1.6	1.6	1.6
1322	125.1	125.3	126.0	59.0	58.7	59.6	66.1	66.6	66.4	1.7	1.7	1.7

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-22. The same data for the Level 3 alert onset are listed in Table B-23.

Table B-22: ICA-7A TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	Level 2 Alert Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1318	9.0	9.0	9.0	9.8	9.8	9.8	141	141	139	150	150	149	35.1	34.2
1319	9.4	9.5	9.4	9.8	9.8	9.7	146	146	144	151	151	150	34.7	34.5
1320	9.7	9.7	9.6	9.8	9.8	9.8	146	146	144	150	150	149	33.8	34.3
1321	8.3	8.8	7.8	9.7	9.8	9.7	166	166	164	149	149	148	35.3	34.3
1322	9.8	10.0	9.0	10.0	10.1	9.9	137	137	137	153	153	151	34.5	34.0

Table B-23: ICA-7A TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	Level 3 Alert Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1318	7.9	7.9	7.9	8.5	8.5	8.5	122	123	121	131	131	131	34.7	34.5
1319	8.0	8.0	7.9	8.3	8.4	8.3	124	125	122	129	130	128	34.7	34.7
1320	8.1	8.1	7.9	8.3	8.4	8.3	123	123	121	127	127	127	34.2	34.2
1321	8.0	8.0	7.9	7.3	7.3	7.2	128	128	126	112	113	111	35.8	34.5

B.7 ICA-9 Tabulated Test Results

The ICA-9 HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-24. The same data for the Level 3 alert onset are listed in Table B-25.

Table B-24: ICA-9A TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	Level 2 Alert Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1328	9.6	9.6	9.6	12.7	12.7	12.5	108	108	107	141	141	139	25.1	24.9
1329	9.7	9.8	9.7	10.1	10.1	10.0	109	109	109	117	118	116	25.1	26.1
1330	9.6	9.6	9.7	11.1	11.1	10.9	107	107	107	128	129	127	24.9	26.0
1331	9.5	9.6	9.6	12.0	12.0	11.9	107	107	107	136	137	135	25.2	25.5
1332	9.6	9.7	9.7	12.9	12.9	12.7	109	109	108	142	142	139	25.3	24.6
Ave.	9.6	9.6	9.7	11.7	11.7	11.6	108	108	108	133	133	131	25.1	25.4
Std.	0.1	0.1	0.0	1.2	1.2	1.1	1	1	1	10	10	10	0.1	0.7
C. of V. (%)	0.7	0.8	0.5	10.0	10.0	9.8	1	1	1	8	8	7	0.5	2.6

Table B-25: ICA-9A TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	Level 3 Alert Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1328	7.3	7.3	7.4	10.6	10.6	10.5	82	82	81	115	116	114	25.0	24.3
1329	7.4	7.5	7.5	7.9	8.0	7.7	85	86	85	93	93	90	25.7	26.2
1330	7.3	7.3	7.4	8.7	8.7	8.4	81	81	81	102	102	99	24.9	26.2
1331	7.5	7.5	7.5	9.8	9.8	9.7	84	84	83	112	113	111	25.0	25.7
1332	7.4	7.4	7.4	10.5	10.5	10.4	83	83	82	116	117	115	25.1	24.9
Ave.	7.4	7.4	7.4	9.5	9.5	9.3	83	83	83	108	108	106	25.1	25.5
Std.	0.1	0.1	0.1	1.2	1.2	1.2	2	2	2	10	10	11	0.3	0.8
C. of V. (%)	1.2	1.3	1.1	12.2	12.2	13.1	2	2	2	9	9	10	1.2	3.3

B.8 ICA-10 Tabulated Test Results

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-26. The same data for the Level 3 alert onset are listed in Table B-27. For Test 1337 there was no Level 2 alert prior to the Level 3 alert.

Table B-26: ICA-10A TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	Level 2 Alert Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1334	9.6	9.7	9.8	7.7	7.7	7.6	111	111	112	119	119	117	25.7	34.7
1335	8.5	8.6	8.7	9.7	9.8	9.6	95	95	96	153	153	150	24.9	35.1
1336	8.0	8.0	8.1	10.0	10.0	9.8	90	91	91	155	155	151	25.2	34.7
Ave.	8.7	8.8	8.9	9.1	9.1	9.0	99	99	99	142	142	139	25.3	34.8
Std.	0.8	0.8	0.8	1.3	1.3	1.2	11	11	11	20	20	19	0.4	0.2
C. of V. (%)	9.4	9.4	9.5	14.0	14.0	13.6	11	11	11	14	14	14	1.7	0.6

Table B-27: ICA-10A TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	Level 3 Alert Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT(mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1334	7.4	7.4	7.5	5.5	5.5	5.4	85	86	86	85	85	83	25.8	34.6
1335	7.2	7.2	7.3	8.3	8.3	8.2	78	79	79	129	130	127	24.4	34.7
1336	7.2	7.3	7.3	9.2	9.2	9.1	81	82	82	142	143	140	25.2	34.7
1337	6.8	6.8	6.8	9.5	9.5	9.4	74	74	74	148	148	146	24.5	35.0
Ave.	7.1	7.2	7.2	8.1	8.1	8.0	80	80	80	126	126	124	25.0	34.8
Std.	0.3	0.3	0.3	1.8	1.8	1.8	5	5	5	29	29	29	0.7	0.2
C. of V. (%)	3.8	3.8	4.2	22.5	22.5	22.8	6	6	6	23	23	23	2.6	0.5

B.9 IMA-1 Tabulated Test Results

The RV Range to the Intersection at RV Brake Onset, RV Range to Intersection when RV Stopped, RV Braking Distance, and Average RV Brake Deceleration are listed in Table B-28. Four tests were conducted.

Table B-28: IMA-1 RV Range to Intersection at RV Brake Onset and RV Stopped and RV Braking Distance and Average Deceleration

Test No.	Brake Conditions											
	RV Range to Intersection at Brake Onset (m)			RV Range to Intersection at Stopped (m)			RV Brake Distance (m)			Ave. of RV Brake Decel. (m/s/s)		
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU
1124	90.7	92.5	84.1	13.7	13.7	13.4	76.9	78.8	70.7	2.3	2.2	2.3
1125	91.0	92.4	82.0	13.5	13.5	13.2	77.5	79.0	68.7	2.1	2.1	2.2
1126	93.4	94.0	84.4	12.7	12.7	12.3	80.7	81.3	72.2	2.4	2.4	2.5
1127	98.5	99.6	92.8	11.9	11.9	11.6	86.5	87.7	81.2	2.2	2.2	2.2
Ave.	93.4	94.6	85.8	13.0	12.9	12.6	80.4	81.7	73.2	2.2	2.2	2.3
Std.	3.6	3.4	4.8	0.8	0.8	0.8	4.4	4.2	5.5	0.1	0.1	0.1
C. of V. (%)	3.9	3.6	5.5	6.2	6.4	6.7	5.5	5.1	7.5	4.8	4.9	5.3

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-29. The same data for the Level 3 alert onset are listed in Table B-30.

Table B-29: IMA-1 TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1124	9.0	9.0	9.0				165	166	162	61	62	60	41.1	34.3
1125	7.0	7.2	6.9			5.4	167	168	164	76	77	75	39.7	39.5
1126	8.0	7.9	7.8	5.7	5.7	5.6	167	168	166	111	112	110	34.8	43.8
1127	7.9	7.9	7.9	5.7	5.8	5.6	167	167	166	112	112	110	34.6	43.8
Ave.	7.9	8.0	7.9	5.7	5.7	5.5	166	167	165	90	91	89	37.6	40.3
Std.	0.8	0.7	0.8	0.0	0.0	0.2	1	1	2	25	25	25	3.4	4.5
C. of V. (%)	10.2	9.1	10.8	0.3	0.4	2.9	1	1	1	28	28	28	9.0	11.2

Table B-30: IMA-1 TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1124	7.2	7.4	7.5				152	153	150	51	52	49	41.3	30.1
1125	8.3	7.7	7.5				154	155	152	64	66	63	41.4	35.4
1126	6.2	6.4	6.2	5.8	5.8	4.6	146	146	144	86	87	84	39.5	42.6
1127	6.7	6.3	6.2	6.4	6.6	5.1	146	146	144	87	87	85	39.3	41.8
Ave.	7.1	7.0	6.8	6.1	6.2	4.9	149	150	147	72	73	70	40.4	37.5
Std.	0.9	0.7	0.7	0.4	0.6	0.4	4	5	4	17	17	18	1.1	5.9
C. of V. (%)	12.6	10.1	10.8	7.1	8.9	7.2	3	3	2	24	24	25	2.7	15.7

B.10 IMA-2 Tabulated Test Results

The RV TTC to Intersection, Range to Intersection, and Speed at Level 3 alert onset and offset are given, respectively, in Table B-31 and Table B-32.

Table B-31: IMA-2 TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset							
	TTC RV to Intersection (sec)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1111	6.2	6.2	6.1	124	125	123	0.0	45.0
1112	6.2	6.1	6.1	123	123	121	0.0	44.6
1113	6.3	6.3	6.1	130	130	126	0.0	46.0
1117	6.3	6.3	6.2	128	129	126	0.0	45.7
1118	6.3	6.3	6.2	129	129	127	0.0	46.0
Ave.	6.2	6.2	6.1	127	127	125	0.0	45.5
Std.	0.1	0.1	0.0	3	3	2	0.0	0.6
C. of V. (%)	1.2	1.2	0.7	2	3	2		1.4

Table B-32: IMA-2 Range and Speed at IMA Level 3 Alert Offset

Test No.	IMA Level 3 Offset				
	Range RV to Intersection (m)			Speed WSU (mph)	
	RT	GPS	WSU	HV	RV
1111	-2.6	-1.6	-1.8	0.3	45.1
1112	-2.4	-1.9	-1.8	0.0	45.0
1113	-1.9	-1.1	-1.8	2.2	44.9
1117	-3.4	-2.7	-3.8	0.0	44.7
1118	-3.2	-2.3	-2.9	0.0	43.5
Ave.	-2.7	-1.9	-2.4	0.5	44.6
Std.	0.6	0.6	0.9	1.0	0.6
C. of V. (%)	22.5	31.8	38.4	194.6	1.4

B.11 IMA-3 Tabulated Test Results

No alerts were issued for any of the tests and therefore the WSU passed this test procedure. There is an IMA location classification channel available in the data broadcast by the WSU. The HV Range to the Intersection for when the RV is classified as a potential IMA threat is given in Table B-33 and Table B-34 for the two sets of test data (different days). Ten tests were conducted (two sets of five).

Table B-33: IMA-3 (9/04/15) HV Range, and Speed at Classification as Potential IMA Threat

Test No.	IMA Location Classified				
	Range HV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	HV	RV
1119	302	302	300	40.9	0.0
1120	302	302	299	44.4	0.0
1121	303	304	299	43.4	0.0
1122	303	303	300	41.1	0.0
1123	301	302	300	43.7	0.0
Ave.	302	303	300	42.7	0.0
Std.	1	1	1	1.6	0.0
C. of V. (%)	0	0	0	3.8	

Table B-34: IMA-3 (9/16/15) HV Range and Speed at Classification as Potential IMA Threat

Test No.	IMA Location Classified				
	Range HV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	HV	RV
1340	301	301	300	42.9	0.0
1341	302	302	299	40.0	0.0
1342	301	301	298	43.2	0.0
1343	301	301	299	44.9	0.0
1344	302	302	299	45.3	0.0
Ave.	301	301	299	43.2	0.0
Std.	1	1	1	2.1	0.0
C. of V. (%)	0	0	0	4.8	

B.12 IMA-4 Tabulated Test Results

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-35. The same data for the Level 3 alert onset are listed in Table B-36.

Table B-35: IMA-4 TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1348	11.7	11.7	11.8	6.9	6.9	6.5	233	233	233	73	73	72	44.5	18.7
1349	9.7	9.7	9.9	7.0	6.9	6.8	197	197	199	74	74	73	45.5	16.4
1350	8.7	8.7	8.8	7.5	7.6	7.0	175	175	175	66	66	65	45.1	16.0
Ave.	10.0	10.0	10.2	7.1	7.2	6.8	202	202	202	71	71	70	45.0	17.0
Std.	1.5	1.5	1.5	0.3	0.4	0.2	29	29	29	4	4	4	0.5	1.5
C. of V. (%)	15.5	15.3	15.0	4.3	5.4	3.3	15	15	14	6	6	6	1.1	8.6

Table B-36: IMA-4 TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1347	8.5	8.5	8.7	5.7	5.6	5.5	170	170	172	49	49	48	44.7	19.4
1348	8.7	8.7	8.8	5.3	5.3	5.2	177	177	176	48	48	47	45.6	20.3
1349	8.5	8.5	8.7	8.1	8.1	6.6	173	173	175	65	65	64	45.3	17.9
1350	8.6	8.6	8.7	7.5	7.6	6.9	173	173	173	65	65	65	45.1	16.1
Ave.	8.6	8.6	8.7	6.6	6.7	6.1	173	173	174	57	57	56	45.2	18.4
Std.	0.1	0.1	0.0	1.4	1.4	0.8	3	3	2	9	10	10	0.4	1.9
C. of V. (%)	0.8	0.9	0.5	20.6	20.9	13.8	2	2	1	17	17	18	0.8	10.1

B.13 IMA-6 Tabulated Test Results

Five tests were conducted. Only one test did not produce alerts (Test 1352). The HV maximum speed for this test was 10.6 mph and the RV maximum speed was 11.3 mph. The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-37. The same data for the Level 3 alert onset are listed in Table B-38.

Table B-37: IMA-6 TTC, Range, and Speed at IMA Level 2 Alert Onset

Test No.	IMA Level 2 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1353	7.3	7.3	7.6	7.3	7.3	7.3	49	49	51	51	51	51	15.1	15.7
1354	7.9	7.8	7.8	8.3	8.2	8.2	60	60	61	59	59	58	17.0	16.0
Ave.	7.6	7.6	7.7	7.8	7.8	7.7	55	55	56	55	55	54	16.1	15.9
Std.	0.4	0.3	0.1	0.7	0.7	0.6	7	7	7	6	6	5	1.3	0.2
C. of V. (%)	5.3	4.5	1.4	8.9	9.0	8.3	13	13	13	10	10	10	8.1	1.3

Table B-38: IMA-6 TTC, Range, and Speed at IMA Level 3 Alert Onset

Test No.	IMA Level 3 Onset													
	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1353	6.9	6.9	7.1	6.5	6.5	6.5	44	44	46	46	46	45	14.3	15.6
1354	6.8	6.8	7.1	7.1	7.1	7.0	51	51	53	51	51	50	16.8	16.2
1355	6.8	6.9	7.0	7.6	7.5	7.5	50	50	50	54	54	53	16.2	15.9
1356	7.1	7.0	7.1	5.8	5.8	5.7	46	46	47	40	39	39	14.5	15.3
Ave.	6.9	6.9	7.1	6.8	6.7	6.7	48	48	49	48	47	47	15.5	15.7
Std.	0.1	0.1	0.0	0.8	0.8	0.7	3	3	3	6	6	6	1.2	0.4
C. of V. (%)	1.6	1.3	0.4	11.3	11.3	11.2	7	7	7	13	13	13	8.1	2.4

B.14 IMA-Bridge Tabulated Test Results

Data were collected from both the HV and the RV. The data for the alerts on the HV are presented first, followed by the data for the RV.

B.14.1 HV Alert Data

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-39 for the testing with the HV going 40 mph and the RV going 45 mph. There were six tests conducted on this date and the first two (1796 and 1797) did not produce Level 2 alerts. Similar data for the Level 3 alert onset are listed in Table B-40.

Table B-39: IMA-Bridge TTC, Range, and Speed at HV IMA Level 2 Alert Onset (HV = 40 mph, RV = 45 mph)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1798	9.2		9.3	7.1		7.1	163		164	144		143	39.6	45.0
1799	9.9		9.9	7.5		7.5	177		176	141		142	40.0	42.3
1800	9.0		9.0	7.6		7.6	161		160	145		145	40.1	42.8
1801	9.7		9.9	7.6		7.3	174		176	145		140	40.1	42.8
Average	9.4		9.5	7.4		7.4	168		169	144		142	40.0	43.2
Std. Dev.	0.4		0.5	0.2		0.2	8		8	2		2	0.2	1.2
C. of V. (%)	4.5		4.8	2.7		2.9	5		5	1		2	0.6	2.8

Table B-40: IMA-Bridge TTC, Range, and Speed at HV IMA Level 3 Alert Onset (HV = 40 mph, RV = 45 mph)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1796	7.8		8.1	7.5		6.8	140		145	144		131	40.3	43.0
1797	7.0		7.0	6.8		6.7	126		125	134		132	40.3	43.9
1798	8.2		8.3	6.3		6.3	145		146	124		123	39.6	44.3
1799	8.2		8.2	5.9		5.9	146		146	110		110	40.0	41.6
1800	8.3		8.3	6.9		6.9	148		148	132		132	40.1	42.7
1801	8.2		8.4	5.8		5.6	147		150	115		110	40.1	44.2
Average	7.9		8.1	6.5		6.4	142		143	126		123	40.1	43.3
Std. Dev.	0.5		0.5	0.6		0.5	9		9	13		10	0.3	1.0
C. of V. (%)	6.4		6.5	9.8		8.6	6		6	10		8	0.6	2.4

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-41 for the testing with the HV and the RV going 45 mph. Fourteen tests produced Level 3 alerts, but only 7 tests produced Level 2 alerts. Similar data for the Level 3 alert onset are listed in Table B-42.

Table B-41: IMA-Bridge TTC, Range, and Speed at HV IMA Level 2 Alert Onset (HV = RV = 45 mph)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1849	11.6	11.6	11.7	7.2	7.2	7.2	235.1	236.0	234.9	140.2	140.9	140.1	45.4	43.6
1858	9.8	9.9	9.9	8.6	8.7	7.5	197.4	198.6	197.7	171.4	172.6	149.6	44.9	44.4
1859	9.1	10.8	9.1	8.0	8.1	7.9	181.4	215.2	181.7	155.0	158.4	153.4	44.7	43.4
1861	9.8	9.8	9.9	7.9	7.9	7.8	196.4	197.2	196.8	151.9	152.6	149.9	44.8	43.2
1862	9.0	10.5	9.0	7.6	7.7	7.5	179.7	210.9	179.7	151.7	154.6	149.1	44.9	44.8
1864	9.2	9.2	9.2	8.0	8.0	7.9	184.2	185.3	184.1	153.0	153.8	151.3	44.9	42.7
1865	8.8	8.9	8.8	7.7	7.7	7.6	176.8	178.2	175.9	153.3	154.0	151.3	45.0	44.6
Average	9.6	10.1	9.7	7.9	7.9	7.6	193.0	203.0	192.9	153.8	155.3	149.2	44.9	43.8
Std. Dev.	1.0	0.9	1.0	0.4	0.5	0.3	20.2	19.5	20.3	9.2	9.4	4.3	0.2	0.8
C. of V. (%)	10.1	9.4	10.1	5.6	5.8	3.4	10.5	9.6	10.5	6.0	6.0	2.9	0.5	1.8

Table B-42: IMA-Bridge TTC, Range, and Speed at HV IMA Level 3 Alert Onset (HV = RV = 45 mph)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1847	4.0	4.0	4.1	8.0	8.0	7.7	80.5	81.5	81.6	158.9	159.9	152.2	45.1	44.6
1849	8.6	8.7	8.7	4.6	4.6	4.6	176.1	177.1	176.0	85.1	85.8	85.0	45.7	41.6
1850	7.6	7.6	7.6	7.6	7.6	7.5	153.4	154.6	153.3	150.4	151.3	147.7	45.3	44.4
1851	7.3	7.4	7.3	7.2	7.3	7.0	142.8	143.9	141.8	147.9	149.1	143.3	43.6	45.9
1852	8.1	8.1	8.2	7.6	7.6	7.6	168.0	168.3	167.4	149.5	149.7	148.2	46.3	43.9
1855	7.6	7.7	7.7	7.8	7.6	7.7	153.3	154.5	154.3	152.9	149.0	151.2	45.0	43.7
1856	6.6	6.7	6.6	6.7	6.8	6.6	133.0	133.9	132.5	130.4	132.1	128.9	44.8	43.4
1858	8.5	8.6	8.6	7.3	7.4	6.2	171.4	172.8	171.5	145.6	146.9	123.8	45.0	44.4
1859	8.5	10.2	8.5	7.4	7.6	7.3	169.6	203.3	169.6	143.6	147.1	141.8	44.7	43.3
1861	8.4	8.4	8.4	6.5	6.5	6.4	168.2	169.1	168.7	124.8	125.6	122.9	45.0	42.7
1862	8.4	10.0	8.5	7.1	7.3	7.0	169.4	200.8	169.6	141.5	144.8	139.2	44.9	44.4
1863	7.9	8.0	7.9	8.0	8.1	7.8	158.7	160.1	158.4	155.4	156.6	153.3	44.9	43.5
1864	8.5	8.5	8.5	7.4	7.4	7.3	170.2	171.3	170.0	139.7	140.6	138.1	44.9	42.5
1865	8.5	8.6	8.5	7.4	7.4	7.3	170.8	172.1	169.8	147.1	148.0	145.3	45.0	44.7
Average	7.8	8.0	7.8	7.2	7.2	7.0	156.1	161.7	156.0	140.9	141.9	137.2	45.0	43.8
Std. Dev.	1.2	1.5	1.2	0.9	0.9	0.8	25.0	29.8	24.8	18.5	18.4	18.0	0.6	1.1
C. of V. (%)	15.8	18.4	15.7	12.0	11.8	12.1	16.0	18.4	15.9	13.1	13.0	13.1	1.3	2.5

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-43 for the testing with the HV and the RV in reversed roles. Five tests were conducted for this condition, but only two tests produced a Level 2 alert. Similar data for the Level 3 alert onset are listed in Table B-44.

Table B-43: IMA-Bridge TTC, Range, and Speed at HV IMA Level 2 Alert Onset (HV and RV Reversed Roles)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1867	10.4	10.9	10.5	7.4	7.4	7.4	207.8	217.2	209.0	149.5	148.8	148.6	44.5	45.3
1869	8.6	9.1	8.3	7.3	8.9	7.3	166.4	176.9	160.8	147.6	179.8	147.7	43.3	45.3
Average	9.5	10.0	9.4	7.3	8.1	7.4	187.1	197.1	184.9	148.6	164.3	148.1	43.9	45.3
Std. Dev.	1.3	1.3	1.6	0.1	1.1	0.0	29.3	28.5	34.1	1.3	21.9	0.6	0.9	0.0
C. of V. (%)	13.7	12.5	16.6	0.9	13.3	0.5	15.6	14.5	18.4	0.9	13.3	0.4	1.9	0.0

Table B-44: IMA-Bridge TTC, Range, and Speed at HV IMA Level 3 Alert Onset (HV and RV Reversed Roles)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1867	8.4	8.9	8.5	5.4	5.4	5.4	167.9	177.4	169.0	108.9	108.5	108.1	44.7	45.2
1868	5.6	6.1	5.5	7.2	7.3	7.3	113.2	122.3	110.5	146.0	147.1	146.0	45.0	45.3
1869	8.3	8.8	8.0	7.0	8.6	7.1	160.6	171.2	155.1	141.3	173.8	141.7	43.3	45.3
1870	7.8	8.2	7.5	7.3	7.3	7.3	153.5	163.0	147.7	147.0	147.8	146.8	44.3	45.3
1871	7.8	8.0	7.3	7.4	7.5	7.4	150.4	154.9	142.5	150.0	151.0	149.6	43.4	45.3
Average	7.6	8.0	7.3	6.8	7.2	6.9	149.1	157.8	145.0	138.6	145.6	138.4	44.1	45.3
Std. Dev.	1.1	1.2	1.1	0.8	1.2	0.9	21.2	21.6	21.7	16.9	23.5	17.2	0.8	0.0
C. of V. (%)	14.9	14.4	15.4	12.2	16.1	12.4	14.2	13.7	15.0	12.2	16.1	12.4	1.7	0.1

B.14.2 RV Alert Data

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 3 alert onset are listed in Table B-45 for the testing with the HV going 40 mph and the RV going 45 mph. There were six tests. None of the tests produced a Level 2 alert prior to the Level 3 alert.

Table B-45: IMA-Bridge TTC, Range, and Speed at RV IMA Level 3 Alert Onset (HV = 40 mph, RV = 45 mph)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1796	7.7		8.5	7.7		7.4	139		152	148		142	40.3	43.0
1797	7.3		7.2	7.4		7.3	132		129	146		144	40.3	44.2
1798	8.4		8.4	6.6		6.6	148		148	132		132	39.6	44.5
1799	8.3		8.1	6.3		6.3	149		145	117		118	40.0	41.6
1800	8.3		9.8	7.2		7.0	149		174	138		134	40.1	42.7
1801	8.3		8.3	6.2		6.1	148		147	122		120	40.1	43.8
Average	8.1		8.4	6.9		6.8	144		149	134		132	40.1	43.3
Std. Dev.	0.4		0.8	0.6		0.5	7		14	13		11	0.3	1.1
C. of V. (%)	5.3		9.8	8.8		7.9	5		10	9		8	0.6	2.6

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-46 for the testing with the HV and the RV going 45 mph. Fourteen tests produced Level 3 alerts, but only one test produced a Level 2 alert. Similar data for the Level 3 alert onset are listed in Table B-47.

Table B-46: IMA-Bridge TTC, Range, and Speed at RV IMA Level 2 Alert Onset (HV = RV = 45 mph)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	45.7
1860	4.4	4.5	3.2	9.5	9.5	10.2	90	91	65	194	195	208	45.2	45.3

Table B-47: IMA-Bridge TTC, Range, and Speed at RV IMA Level 3 Alert Onset (HV = RV = 45 mph)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1849	7.4	7.5	7.4	3.0	3.0	3.0	152	153	151	55	56	55	45.8	41.0
1850	7.5	7.5	6.7	7.2	7.2	7.3	152	153	134	143	144	144	45.3	44.4
1851	5.7	5.7	5.6	5.4	5.4	5.4	112	113	109	109	110	109	44.1	45.1
1852	7.4	7.4	8.9	6.7	6.7	6.5	152	152	182	133	133	129	46.1	44.0
1855	6.2	6.2	5.7	5.7	6.7	5.6	124	125	113	117	131	113	44.8	44.4
1856	7.1	7.1	6.4	6.8	6.8	6.7	141	142	128	131	131	131	44.8	43.3
1858	7.3	7.4	6.3	5.2	5.3	5.1	147	149	127	103	106	103	45.1	44.9
1859	7.4	7.5	7.0	5.9	5.9	5.7	148	149	138	114	114	109	44.7	42.9
1860	2.9	3.0	1.6	8.1	8.1	8.9	59	61	31	163	164	178	45.2	45.1
1861	7.3	7.3	7.3	5.2	5.2	5.2	146	147	147	98	99	99	45.1	42.3
1862	7.2	7.3	7.4	5.6	5.7	5.4	146	147	149	111	112	105	45.1	44.0
1863	6.9	7.0	5.5	6.5	6.6	6.9	139	140	110	129	130	137	44.7	44.2
1864	7.4	7.4	7.3	5.9	6.0	5.9	148	149	145	112	113	112	44.9	42.1
1865	7.4	7.5	7.3	5.9	5.9	5.8	149	150	145	118	119	117	45.0	44.9
Average	6.8	6.8	6.5	5.9	6.0	6.0	137	138	129	117	119	117	45.1	43.8
Std. Dev.	1.2	1.2	1.7	1.2	1.2	1.3	25	25	34	25	25	27	0.5	1.3
C. of V. (%)	18.1	17.9	25.9	19.8	19.6	22.1	18	18	26	21	21	23	1.1	2.9

The HV and RV TTC and Range to Intersection values and the HV and RV speeds at the Level 2 alert onset are listed in Table B-48 for the testing with the HV and the RV in reversed roles. Five tests were conducted for this condition, but only one test produced a Level 2 alert. Similar data for the Level 3 alert onset are listed in Table B-49.

Table B-48: IMA-Bridge TTC, Range, and Speed at RV IMA Level 2 Alert Onset (HV and RV Reversed Roles)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	45.7
1868	7.0	7.1	7.0	9.0	9.1	9.1	141	142	141	183	185	183	44.9	45.5

Table B-49: IMA-Bridge TTC, Range, and Speed at RV IMA Level 3 Alert Onset (HV and RV Reversed Roles)

Test No.	TTC HV to Intersection (sec)			TTC RV to Intersection (sec)			Range HV to Intersection (m)			Range RV to Intersection (m)			Speed RT (mph)	
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	HV	RV
1867	7.3	7.3	7.2	4.5	4.5	4.5	146	146	143	91	92	91	44.5	45.3
1868	6.4	6.4	6.4	8.4	8.5	8.5	129	130	130	171	173	171	45.1	45.4
1869	7.3	7.4	7.1	6.5	6.6	6.6	142	143	138	132	134	132	43.6	45.2
1870	7.3	7.3	7.1	7.2	7.3	7.2	144	145	140	145	147	145	44.2	45.3
1871	7.4	7.4	6.8	7.5	7.6	7.6	143	144	131	153	154	153	43.4	45.3
Average	7.1	7.2	6.9	6.8	6.9	6.9	141	142	136	138	140	139	44.2	45.3
Std. Dev.	0.4	0.4	0.3	1.5	1.5	1.5	7	7	5	30	30	30	0.7	0.1
C. of V. (%)	5.9	5.7	4.3	21.5	21.7	21.7	5	5	4	22	22	22	1.6	0.1

B.15 IMA On-Ramp Tabulated Test Results

HV and RV alert data were collected. The HV alert data are presented first followed by the RV alert data.

B.15.1 HV Alert Data

Data presented in the tables below are from the HV WSU and indicate when the HV has located the RV as a potential IMA threat.

The ranges of the HV and RV to the dynamic intersection at the HV IMA Located RV Onset and Offset are listed in Table B-50 for the 150-foot radius tests.

Table B-50: IMA On-Ramp HV and RV Range to Dynamic Intersection at HV IMA Located RV Onset and Offset for 150-Foot Radius Tests

Test	Speed at IMA Located Onset (mph)		Range HV at IMA Located Onset (m)			Range RV at IMA Located Onset (m)			Range HV at IMA Located Offset (m)			Range RV at IMA Located Offset (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1820	20.9	12.0	98.9		98.1	139.4		135.5	40.3	33.2	40.9	22.0	38.8	21.3
1821	24.2	20.4	95.1	86.4	99.5	158.6	152.1	159.9	40.2	43.9	41.6	46.0	44.9	44.1
1822	20.9	18.8	97.1	96.6	97.3	112.7	112.7	112.0	41.0	41.4	41.4	3.1	3.3	2.1
1823	21.9	23.0	98.6	99.5	100.0	127.0	127.4	126.2	41.3	40.7	41.3	6.6	6.6	6.0
1824	23.1	22.5	95.6	106.0	96.8	97.6	103.8	96.7	47.4	47.4	47.2	4.7	4.5	3.3
1825	22.2	23.0	96.2	97.7	96.4	133.0	135.5	132.6	41.3	41.4	41.9	17.4	18.5	17.0
1826	24.3	26.4	95.5	98.5	98.0	130.3	132.1	130.1	41.0	41.3	41.2	6.6	6.0	4.9
1827	24.4	25.6	97.2	98.9	99.0	153.9	156.5	154.5	40.9	40.8	41.1	33.5	33.7	32.2
1828	24.7	25.3	97.4	98.5	98.7	138.4	139.8	138.0	41.1	41.2	41.4	19.8	19.6	18.4
1829	23.4	25.0	99.0	99.4	99.8	144.7	145.0	143.1	40.9	41.3	41.5	20.3	19.9	18.3
1830	22.7	24.9	96.6	99.1	99.2	120.1	122.6	121.5	43.3	43.6	43.8	4.7	4.8	3.3
Ave.			97.0	98.0	98.4	132.3	132.7	131.8	41.7	41.5	42.1	16.8	18.2	15.5
Std.			1.4	4.8	1.2	17.8	16.7	18.0	2.1	3.4	1.9	13.7	15.0	13.5
C. of V. (%)			1.4	4.9	1.3	13.4	12.6	13.7	4.9	8.2	4.4	81.4	82.3	87.0

The angle between the RV and HV heading angles at the HV IMA Located RV onset and offset times for the 150-foot radius tests are listed in Table B-51.

Table B-51: IMA On-Ramp Angle Between RV Heading and HV Heading at HV IMA Located RV Onset and Offset for 150-Foot Radius Tests

Test	Angle RV Hdg. to HV Hdg. at IMA Located Onset (deg)			Angle RV Hdg. to HV Hdg. at IMA Located Offset (deg)		
	WSU	RT	GPS	WSU	RT	GPS
1820	54.3		57.3	116.7	131.2	117.4
1821	57.5	58.9	56.9	118.1	113.0	117.8
1822	57.0	57.2	57.7	118.2	117.1	117.9
1823	56.0	55.8	56.5	117.5	116.1	116.6
1824	57.8	52.8	58.0	103.8	103.3	104.1
1825	57.4	57.2	58.5	116.6	115.6	116.4
1826	57.2	56.4	57.3	117.0	116.3	117.6
1827	57.4	56.6	57.3	116.9	116.4	117.1
1828	57.1	56.7	57.4	116.5	115.8	116.7
1829	56.0	56.1	56.8	117.3	115.6	116.7
1830	57.4	56.5	56.9	111.7	111.0	112.5
Ave.	56.8	56.4	57.3	115.5	115.6	115.5
Std.	1.0	1.5	0.6	4.2	6.5	4.1
C. of V. (%)	1.8	2.7	1.0	3.7	5.6	3.5

The ranges of the HV and RV to the dynamic intersection at the HV IMA Located RV Onset and Offset are listed in Table B-52 for the 300-foot radius tests.

Table B-52: IMA On-Ramp HV and RV Range to Dynamic Intersection at HV IMA Located RV Onset and Offset for 300-Foot Radius Tests

Test	Speed at IMA Located Onset (mph)		Range HV at IMA Located Onset (m)			Range RV at IMA Located Onset (m)			Range HV at IMA Located Offset (m)			Range RV at IMA Located Offset (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1832	25.5	24.9	169.2	170.4	171.7	202.4	204.9	204.1	68.4	67.8	68.3	3.1	4.0	2.9
1833	25.2	25.6	167.7	169.6	170.7	201.3	204.1	202.6	68.9	68.6	69.0	3.3	3.1	2.3
1834	25.1	25.2	171.0	172.8	173.5	197.8	199.2	197.5	72.1	71.4	71.7	2.5	1.8	1.4
1835	26.6	26.9	170.6	173.3	173.5	191.1	194.7	191.4	73.1	72.7	73.3	3.4	3.5	2.5
1836	28.9	29.1	174.0	174.9	175.9	205.5	206.9	204.8	70.5	69.7	69.8	4.3	5.0	4.7
1837	30.4	30.5	170.4	171.1	171.2	193.2	194.8	192.3	71.7	71.6	71.8	4.0	4.3	3.5
1838	32.6	32.3	169.2	171.1	172.5	191.4	193.0	192.5	72.0	71.8	72.0	3.9	4.2	3.7
1839	34.5	34.7	168.5	170.3	170.2	208.8	209.8	207.3	65.8	65.0	65.5	5.2	5.3	3.6
1840	36.7	36.1	171.3	173.2	173.2	191.1	193.2	190.2	73.7	72.7	72.7	2.3	2.9	1.4
1841	38.2	38.0	171.4	173.4	174.0	193.5	196.7	194.4	73.4	72.8	72.9	4.8	5.1	4.1
1842	40.0	39.8	171.1	173.2	174.4	214.5	217.8	216.8	65.8	65.2	65.8	5.3	5.6	4.9
1843	42.0	42.1	170.5	171.4	171.8	190.2	192.3	190.1	73.4	72.9	72.9	3.3	4.3	2.6
1844	39.9	40.2	170.6	173.2	175.3	220.2	223.7	222.7	66.2	65.0	65.9	10.6	10.9	10.9
Ave.			170.4	172.1	172.9	200.1	202.4	200.5	70.4	69.8	70.1	4.3	4.6	3.7
Std.			1.6	1.6	1.8	9.8	10.1	10.5	3.0	3.1	2.9	2.1	2.2	2.4
C. of V. (%)			0.9	0.9	1.0	4.9	5.0	5.2	4.3	4.5	4.2	49.0	47.0	64.9

The angle between the RV and HV heading angles at the HV IMA Located RV onset and offset times for the 300-foot radius tests are listed in Table B-53.

Table B-53: IMA On-Ramp Angle Between RV Heading and HV Heading at HV IMA Located RV Onset and Offset for 300-Foot Radius Tests

Test	Angle RV Hdg. to HV Hdg. at IMA Located Onset (deg)			Angle RV Hdg. to HV Hdg. at IMA Located Offset (deg)		
	WSU	RT	GPS	WSU	RT	GPS
1832	59.4	59.0	59.0	116.3	116.2	116.4
1833	60.2	59.5	59.7	115.6	115.3	115.4
1834	59.3	58.8	59.1	112.4	112.7	112.4
1835	59.5	58.7	59.4	111.4	111.2	111.5
1836	58.5	58.4	58.7	113.9	113.5	113.2
1837	59.6	59.6	60.1	112.0	111.7	111.5
1838	59.1	59.1	59.0	110.8	110.8	110.5
1839	59.7	59.5	60.1	117.2	117.0	117.6
1840	59.2	58.7	59.2	111.3	110.6	110.9
1841	59.3	58.8	59.2	110.7	110.0	110.2
1842	59.3	58.8	59.0	118.3	118.4	118.6
1843	59.3	59.3	59.6	111.0	110.7	111.2
1844	59.9	59.1	59.3	119.0	118.8	118.7
Ave.	59.4	59.0	59.3	113.8	113.6	113.7
Std.	0.4	0.4	0.4	3.0	3.2	3.2
C. of V. (%)	0.7	0.6	0.7	2.7	2.8	2.8

RV Alert Data

Data presented in the tables below are from the RV WSU and indicate when the RV has located the HV as a potential IMA threat.

The ranges of the HV and RV to the dynamic intersection at the RV IMA Located HV Onset and Offset are listed in Table B-54 for the 150-foot radius tests.

Table B-54: IMA On-Ramp HV and RV Range to Dynamic Intersection at RV IMA Located HV Onset and Offset for 150-Foot Radius Tests

Test No.	Speed at IMA Located Onset (mph)		Range HV at IMA Located Onset (m)			Range RV at IMA Located Onset (m)			Range HV at IMA Located Offset (m)			Range RV at IMA Located Offset (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1820	20.9	11.9	97.2		96.1	137.6		133.0	39.7	34.3	40.4	20.5	35.2	19.3
1821	24.1	20.4	93.9	84.1	95.7	155.6	148.8	155.2	39.5	43.0	40.8	45.0	43.2	42.6
1822	20.9	18.8	97.6	96.6	97.3	112.9	112.7	112.0	41.0	41.4	41.4	3.1	3.3	2.1
1823	21.9	23.0	95.4	97.1	97.0	122.3	123.8	122.9	40.8	40.2	40.8	4.6	4.6	4.1
1824	23.0	22.5	93.1	104.3	94.8	94.2	100.5	93.5	46.6	46.7	46.5	2.9	2.5	1.3
1825	22.2	23.0	96.0	97.7	96.4	132.7	135.5	132.6	40.7	41.1	41.4	15.4	16.5	14.9
1826	24.2	26.5	92.9	96.0	95.7	126.1	128.2	125.8	40.4	40.8	40.6	4.5	3.8	2.9
1827	24.2	25.7	95.6	96.4	96.6	150.8	152.6	151.0	40.2	40.2	40.5	31.5	31.4	30.1
1828	24.6	25.3	93.8	95.9	95.4	133.9	135.9	133.7	40.7	40.7	41.0	17.5	17.4	16.0
1829	23.3	25.0	94.5	96.6	96.2	138.9	140.8	138.4	40.6	40.8	41.1	17.9	17.7	15.9
1830	22.6	25.0	94.4	96.6	96.7	117.0	118.9	117.8	42.8	43.0	43.2	2.5	2.6	1.4
Average	22.9	22.5	95.0	96.1	96.2	129.3	129.8	128.7	41.2	41.1	41.6	15.0	16.2	13.7
Std. Dev.	1.3	4.2	1.6	4.9	0.7	17.5	16.3	17.4	2.0	3.0	1.8	13.7	14.7	13.4
C. of V. (%)	5.8	18.7	1.7	5.1	0.8	13.5	12.5	13.5	4.8	7.2	4.3	91.3	90.6	98.0

The angle between the RV and HV heading angles at the RV IMA Located HV onset and offset times for the 150-foot radius tests are listed in Table B-55.

Table B-55: IMA On-Ramp Angle Between RV Heading and HV Heading at RV IMA Located HV Onset and Offset for 150-Foot Radius Tests

Test	Angle RV Hdg. to HV Hdg. at IMA Located Onset (deg)			Angle RV Hdg. to HV Hdg. at IMA Located Offset (deg)		
	WSU	RT	GPS	WSU	RT	GPS
1820	54.7		58.1	117.2	130.7	118.7
1821	58.5	60.3	58.9	118.1	114.4	118.9
1822	56.8	57.2	57.7	118.4	117.1	117.9
1823	57.8	57.1	57.7	118.3	117.4	117.8
1824	59.1	53.5	59.0	104.9	104.6	105.1
1825	57.6	57.2	58.5	118.1	116.9	118.0
1826	58.7	57.8	58.7	118.4	117.6	119.0
1827	58.3	57.9	58.6	118.4	117.7	118.5
1828	58.9	58.1	59.1	117.9	117.2	117.9
1829	58.4	57.6	58.6	118.2	117.0	118.3
1830	58.5	57.8	58.2	113.5	112.3	113.4
Ave	57.9	57.4	58.5	116.5	116.6	116.7
Std.	1.2	1.7	0.5	4.1	6.1	4.1
C. of V. (%)	2.2	2.9	0.8	3.5	5.2	3.5

No data were collected from the RV for the 300-foot radius tests.

DOT HS 812 276
May 2016

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

12245-051316-v2a