U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

NHTSA

DOT HS 812 327 September 2016

Commercial Connected Vehicle Test Procedure Development and Test Results – Emergency Electronic Brake Light

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Suggested APA Format Citation:

Howe, G., Xu, G., Hoover, R., Elsasser, D., & Barickman, F. (2016, September). *Commercial connected-vehicle test procedure development and test results – Emergency electronic brake light* (Report No. DOT HS 812 327.). Washington, DC: National Highway Traffic Safety Administration.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 812 327		

4. Title and Subtitle	5. Report Date
Commercial Connected Vehicle Test Procedure Development and Test Results – Emergency Electronic Brake Light	September 2016
	6. Performing Organization Code 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 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 documenting 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, blind spot warning/lane change warning, forward collision warning, and emergency electronic brake light (EEBL) warning. This report documents the EEBL test procedures and the results of testing commercial vehicles with the developed procedures.

The prototype V2V equipment was capable of tracking potential EEBL threats, but had some issues when vehicles were on curved roadways. The V2V equipment on these trucks did not issue hard braking event flags and was not able to suppress EEBL alerts when the driver applied corrective action under the conditions tested.

17. Key Words:	18. Distribution Statement:
Commercial Connected Vehicles, vehicle-to-vehicle, V2V, vehicle-to-infrastructure, V2I, V2X, emergency electronic brake light, EEBL	This document is available to the public from the National Technical Information Service www.ntis.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	109	

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
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 EEBL test procedures and the results of testing commercial vehicles with prototype V2V equipment with the developed procedures.

The primary test vehicles for the V2V study were two Freightliner Cascadia Class 8 tractors that were 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 Mack CXU612 Class 8 tractor initially used in a retrofit safety device test program was used as an RV. A 2007 Honda Odyssey equipped with a vehicle awareness device was also used as an RV.

In general the V2V equipment was observed to be capable of tracking potential EEBL threats, but had some issues when vehicles were on a curved roadway. The V2V equipment on these trucks did not issue hard braking event flags and were not able to suppress EEBL alerts when the driver applied corrective action under the conditions tested.

For the tests conducted on a curved roadway, the V2V system's error in the estimate of the lateral distance between vehicles for certain scenarios resulted in the generation of a few false FCW alerts and incorrect EEBL alerts. The false FCW alerts were generated in tests where the vehicles were not in the same lane. Both incorrect in-lane and out-of-lane EEBL alerts occurred (in-lane alerts when vehicles were not in-lane with each other and vice versa).

The V2V equipment on the tractors was not observed to broadcast the hard braking event flag in the basic safety message and therefore the EEBL-2: Reversed Role test could not be evaluated with these vehicles.

The V2V equipment did not suppress EEBL alerts when the driver applied the vehicle brakes to avoid the potential threat of a hard braking vehicle. Therefore the equipment did not meet the requirements of the EEBL-7: HV Brakes upon EEBL Alert test.

1 Introduction

This report documents the 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 EEBL testing.

2 Test Vehicles

Figure 1: Freightliner Cascadia and Mack CXU612

The primary test vehicles for the V2V study were two Freightliner Cascadia Class 8 tractors, and one Mack CXU612 Class 8 tractor (Examples shown in Figure 1). One Freightliner was a mid-roof sleeper and the other two tractors were day cabs. 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. The Mack was initially used in a RSD test program at NHTSA's Vehicle Research and Test Center. A summary of the Freightliner vehicle builds 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].

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 and Mack Vehicle Data

Tractor/Cab Configuration	VIN	Color	Build Date	GVWR (lbs)	GAWR (lbs)			Tire Size
					Front	1st	Rear	
Freightliner /Mid-Roof Sleeper	1FUJGHDV0CLBP8896	Red	12/11	52,000	12,000	20,000	20,000	295/75R22.5
Freightliner/Day Cab	1FUJGBDV8CLBP8898	Blue	12/11	52,000	12,000	20,000	20,000	295/75R22.5
Mack/Day Cab	1M1AW01Y7BM002685	White	08/10	34,700	12,000	DNA	22,700	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 was performed with a pair (primary and secondary) of Denso dedicated short-range communication radio/computer platform called mini wireless safety unit model 1.5, each of which has a single board computer and 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.

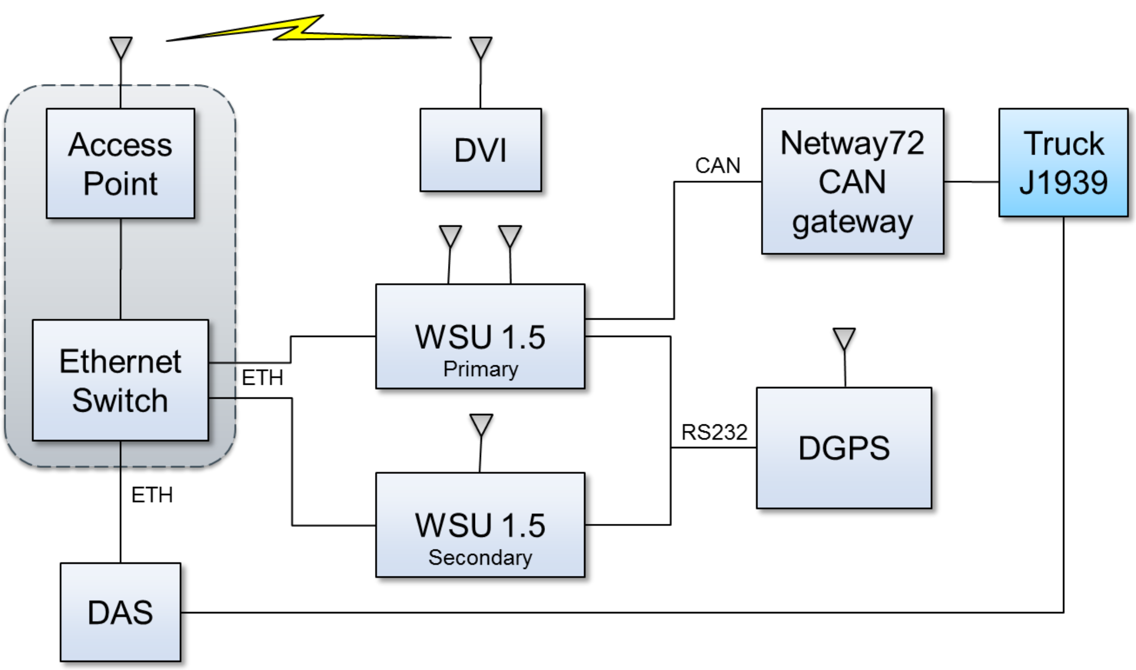


Figure 2: OBE System Architecture

Example EEBL application Level 3 Warning icon that was displayed on the tablet is shown in Figure 3. This icon showed the host vehicle approaching a leading vehicle from the rear while the lead vehicle was performing an emergency braking maneuver. The leading vehicle issues/broadcasts a hard braking event when the deceleration of the vehicle is 0.4 g or greater. This hard braking event is picked up by surrounding vehicles and these vehicles will issue an

EEBL alert based on proximity and relative lane position to the broadcasting vehicle. If the surrounding vehicles are in the lane behind the broadcasting vehicle, a Level 3 warning will be issued. If the surrounding vehicles are behind and in a lane directly next to the broadcasting vehicle, a Level 2 warning will be issued (left or right).

Figure 3: EEBL Warning Level 3 Alert [2]

A fourth 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 and were labelled RT, GPS, and WSU. The following sections briefly described how this data was 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 either Mack tractor or Honda Odyssey), an RT 3000 was connected to an RT Target box, which broadcast its data stream wirelessly for collection 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 was 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 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 Emergency Electronic Brake Light Results

There were eight EEBL test procedures evaluated in this study.

- EEBL-1: Hidden Braking Vehicle Ahead In Same Lane, Straight Road
- EEBL-2: Reverse Roles, Hidden Braking Vehicle Ahead in Same Lane, Straight Road
- EEBL-3: Mildly Braking Vehicle Ahead in Same Lane, Straight Road
- EEBL-4: Braking Vehicle Ahead in Adjacent Lane, Straight Road
- EEBL-5: Braking Vehicle Ahead in Same Lane, Curved Road
- EEBL-6: Braking Vehicle Ahead in Outside Adjacent Lane, Curved Road
- EEBL-7: HV Brakes upon EEBL Alert
- EEBL-8: Slow Moving HV

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

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 these and other V2V system types can be found in Appendix A, Section 0.) that 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. For many of the EEBL tests there is a blocking RV vehicle that is placed between the lead RV vehicle and the HV. The lead RV is called RV2 while the blocking RV vehicle is called RV1. The RV2 conducts a hard braking maneuver that is broadcast to the other vehicles via a hard braking event flag. The HV V2V system features an EEBL application.

The ranges between the HVs and RVs are discussed for the EEBL results presented in the following sections. The HV V2V equipment can track the RV (for the vehicles evaluated in this study) for distances much greater than 300 meters, but it is at this distance that the HV V2V equipment starts to calculate the longitudinal and lateral components of the overall range to the RV. Example traces of the range, longitudinal range, and lateral range for an FCW-1 test (Test 1459) are shown in Figure 4. For an FCW-1 test, the RV is stationary and the HV approaches it from behind. The overall range (red trace) shows that the HV is tracking the RV from over 500 meters away. Once the HV closes to 300 meters (near 11.5 seconds), the HV V2V equipment starts to calculate the longitudinal and lateral ranges to the RV (blue and black traces). If the vehicles are in a curve, the distance where the HV V2V equipment starts to calculate lateral and longitudinal ranges is somewhat reduced (closer to 250 meters). Examples of range in a curve traces will be presented below for the EEBL tests that are conducted in a curve.

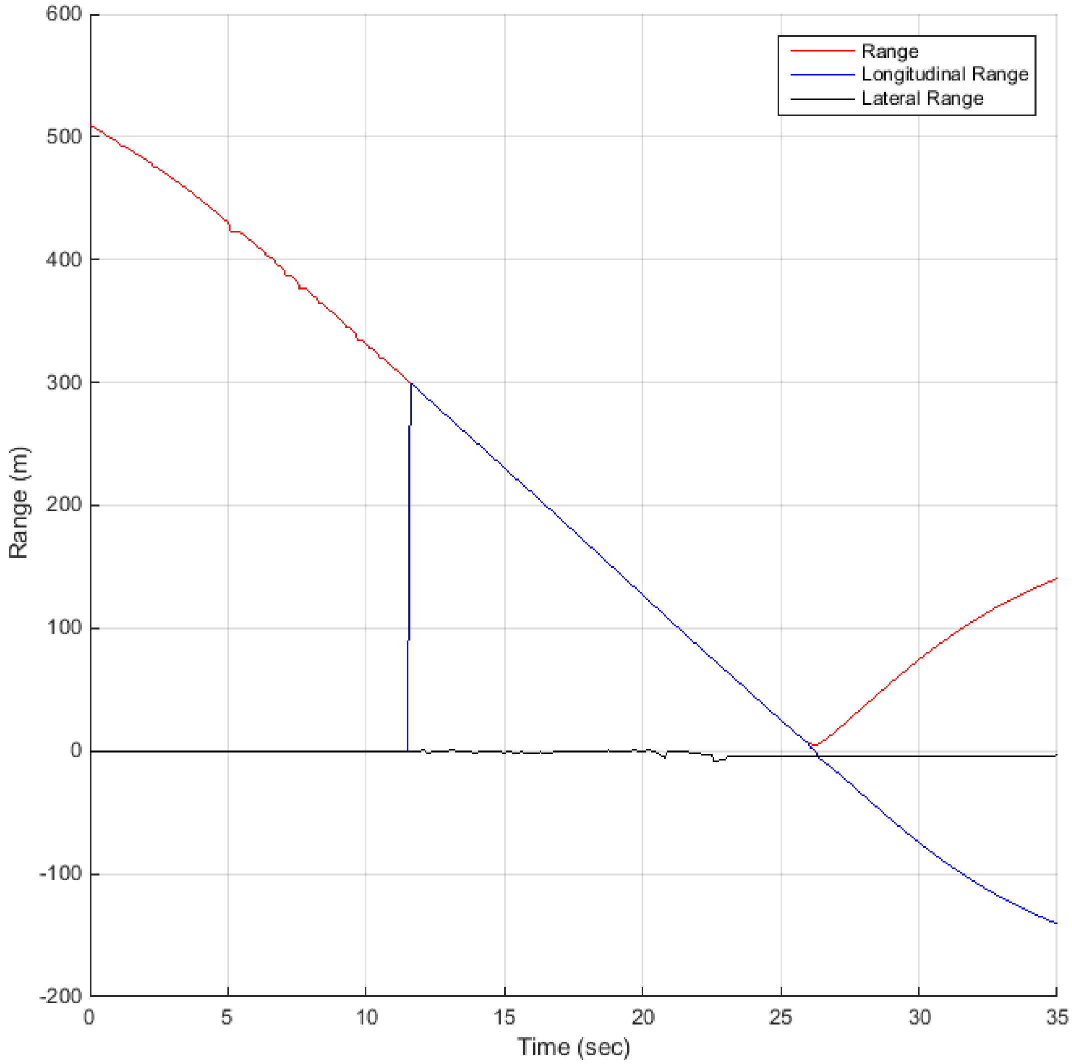


Figure 4: Example HV to RV Range Channels – Test 1459

There are two main metrics that are relevant for the EEBL testing: at what distance does the HV start to recognize hard braking event flags being issued from the RV2 and if the HV is inside that distance, how long does it take to issue the EEBL alert after receiving a hard braking event flag? Both of these metrics will be presented for many of the EEBL test procedures examined below.

The hard braking event flag is contained in the data element called event flags. The event flags data element is not included in the BSM unless at least one of the event flags is set to 1. The hard braking event flag is supposed to be set to 1 when the vehicle has (or is) decelerating at a rate of greater than 0.4 g. We found that the V2V unit on the Mack used 0.3 g to set the hard braking event flag to 1, while the unit on the Odyssey used 0.4 g. The V2V equipment on the red and blue Cascadia trucks did not issue a hard braking event flag. An example of hard braking decelerations observed with the Mack and the Odyssey are shown in Figure 5 and Figure 6 respectively. For the Mack (Figure 5), the hard braking event comes on for the first deceleration data point below -0.3 g and goes off with the first deceleration above -0.3 g. For the Odyssey (Figure 6), the hard braking event comes on for the first deceleration data point below -0.4 g and goes off with the first deceleration above -0.4 g. There is no time delay from when the RV brake deceleration reaches the hard braking threshold to the issuance of the hard braking event flag.

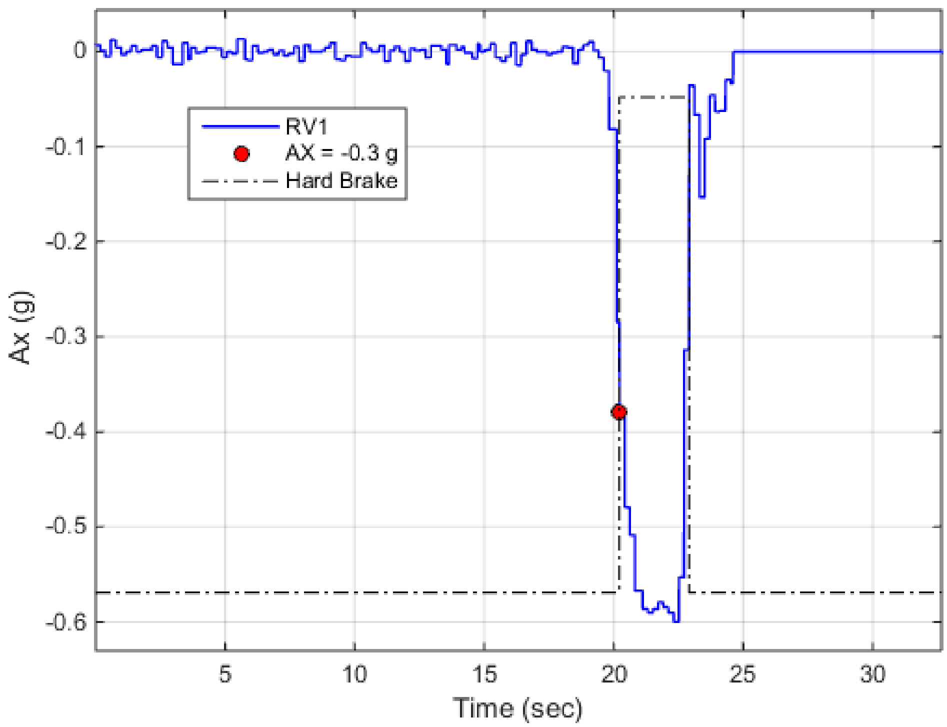


Figure 5: Example Mack Hard Brake Deceleration Threshold = 0.3 g - Test 1720

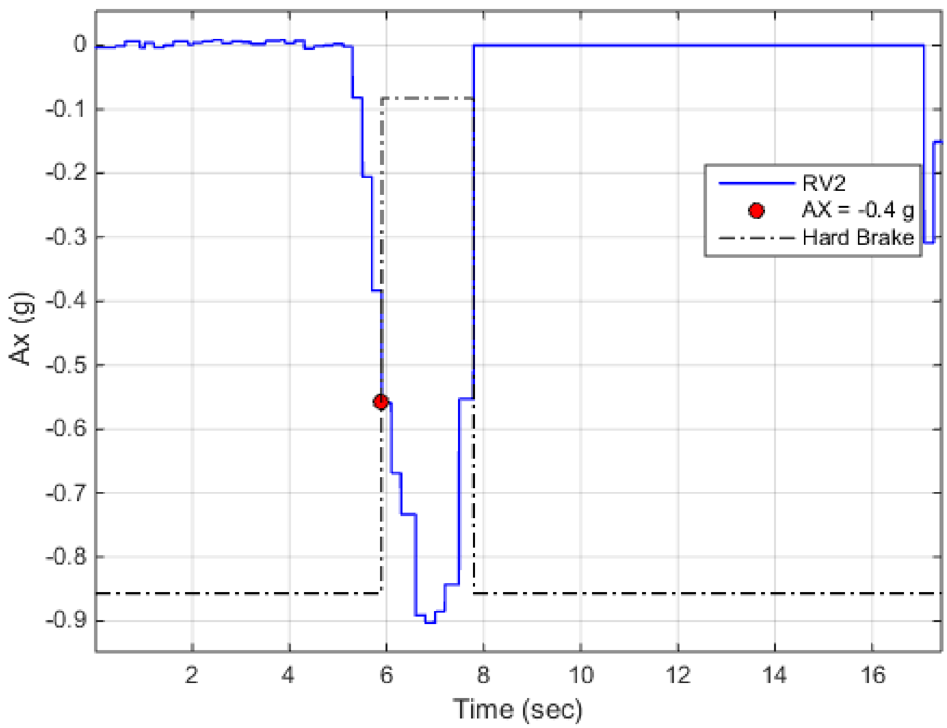


Figure 6: Example Honda Odyssey Hard Brake Deceleration Threshold = 0.4 g - Test 1251

Example results for a test when the HV drives into the EEBL alert range are shown in Figure 7. The top subplot shows the TTC, the second subplot shows the longitudinal range, the third subplot shows the lateral range, and the bottom subplot shows the longitudinal acceleration (braking). The RV2 for this case was the Honda Odyssey. Looking at the bottom subplot, the EEBL alert (a little past 8 seconds) is issued well after the onset of the hard braking event that occurs a little past 6 seconds (coincides with the 0.4 g braking level). This is due to the vehicle being outside of the EEBL alert range. The EEBL alert range is approximately 250 meters as seen in the second subplot (RV2 range trace intersects EEBL Alert onset at approximately 250 meters (a little past 8 seconds).

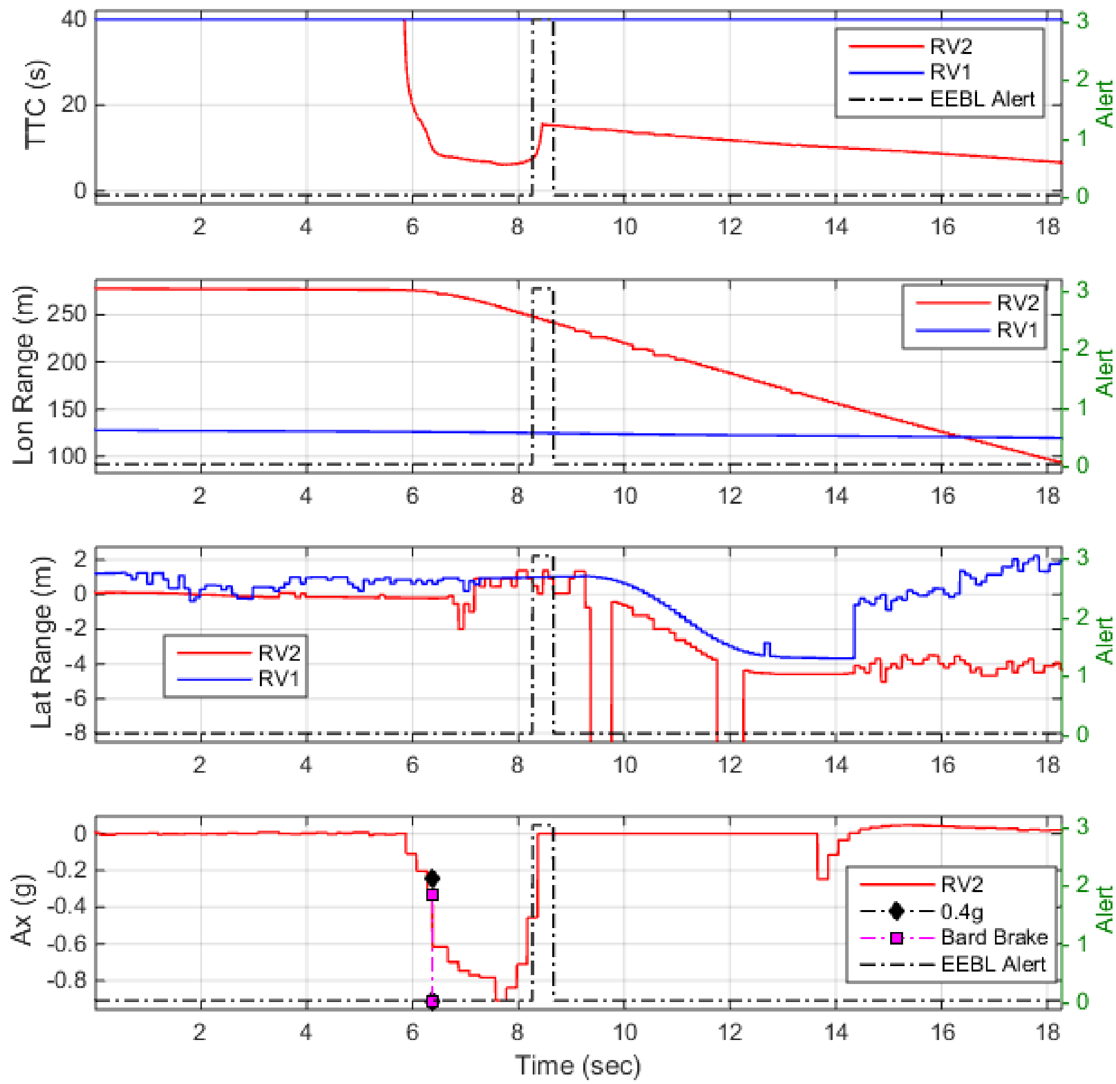


Figure 7: Example EEBL-1 Results – HV Drives Into EEBL Alert Range – Test 1253

Example results for a test when the HV is inside the EEBL alert range when the RV2 brakes are shown in Figure 8. Again the RV2 is the Honda Odyssey. The hard braking event flag coincides with the 0.4 g acceleration level and the EEBL alert is issued a short time after the hard braking event (0.2 seconds). The longitudinal range is approximately 190 meters for this test.

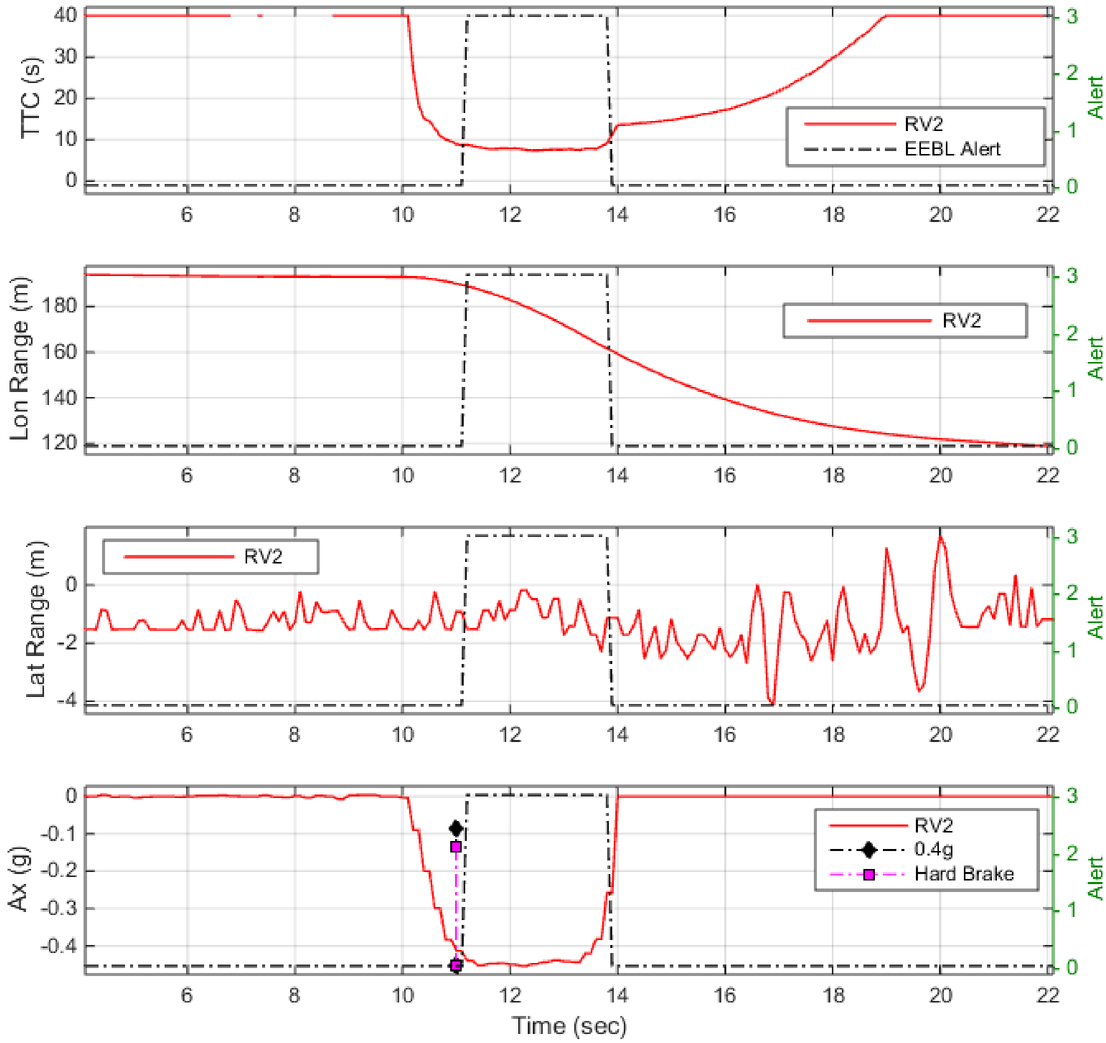


Figure 8: Example EEBL-7 Results – HV Inside EEBL Alert Range – 8.27

The V2V equipment on the red and blue Cascadia trucks responded differently from each other when receiving the hard braking event flag from the V2V equipment on the Mack tractor. Example results for a test when the HV (red Cascadia) is inside the EEBL alert range when the RV2 (Mack) brakes are shown in Figure 9. Looking at the bottom subplot, the EEBL alert is issued shortly after the onset of the 0.4 g braking level, but well after the hard braking event flag was issued (again the Mack issues a hard braking event at 0.3 g instead of 0.4 g). So for the red Cascadia, the hard braking event flag and the 0.4 g deceleration level had to be met before an EEBL alert was issued.

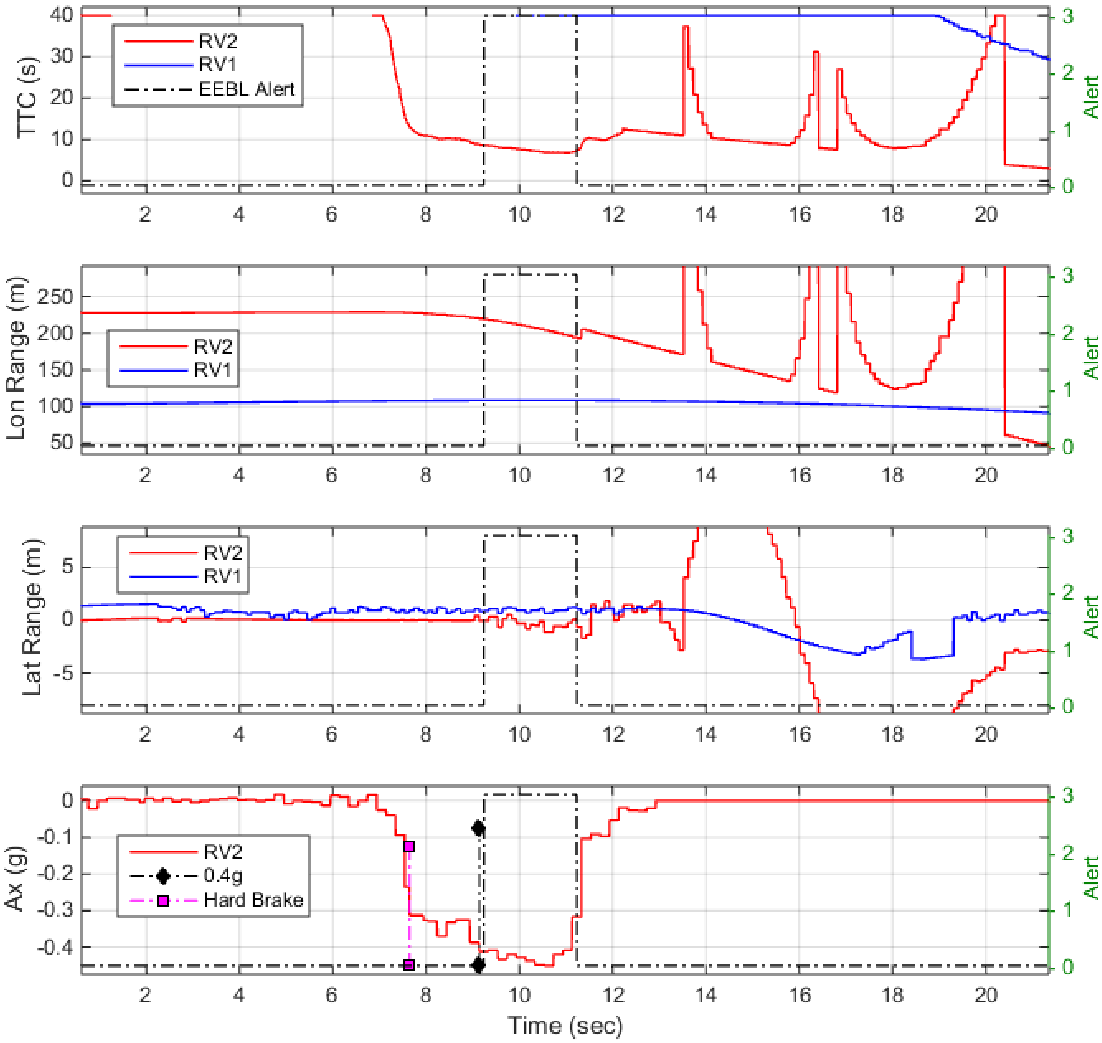


Figure 9: EEBL Alert Shortly After 0.4 g Braking Level but Delayed From Hard Brake Event Flag – Test 1687

Similar results from the V2V equipment on the blue Cascadia tractor are shown in Figure 10. The blue Cascadia was the intermediate vehicle (RV1) for this test and it also issued alerts when the RV2 (Mack tractor) issued Hard Braking events. For the blue Cascadia, the EEBL alert was issued shortly after the hard braking event flag was issued from RV2, but well before the 0.4 g braking level was achieved. So for the blue Cascadia, the hard braking event flag alone was sufficient to issue the EEBL alert (the 0.4 g braking level was not required). Another possible explanation for the earlier onset in the warning for the blue Cascadia is closer proximity to the braking vehicle when the hard braking event flag was issued. Further testing would be required to confirm this as a possible explanation.

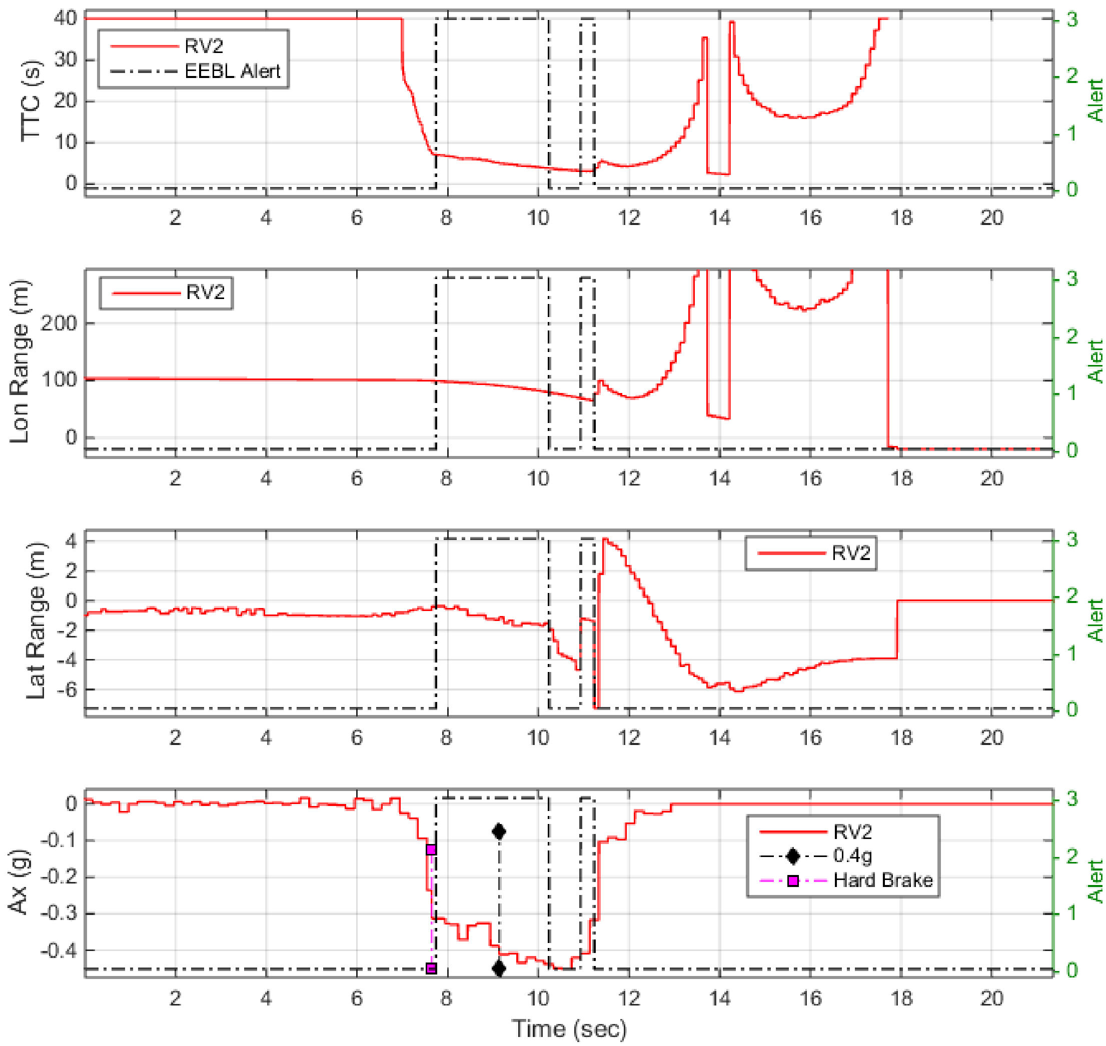


Figure 10: EEBL Alert Shortly After Hard Brake Event Flag (Blue Cascadia Acting as HV) – Test 1687

In the following discussion, the time delay between the issuance of the hard braking event flag to the EEBL alert being issued is used as a metric to examine the performance of the V2V equipment. This time delay is the GPS time when the EEBL alert is issued (from the DAS-HV data packet) minus the GPS time from the RV BSM packet when the hard braking event flag is issued.

4.1 EEBL-1: Hidden Braking Vehicle Ahead In Same Lane, Straight Road

For the EEBL-1 test procedure, three vehicles travel along a straight roadway in the same lane of travel and in the same direction. Initially, the three vehicles travel at the same velocity with the leading vehicle and trailing vehicle (HV) within V2V system communication range. The intermediate vehicle travels between the leading and trailing vehicles and blocks the view of the leading vehicle from the driver of the trailing vehicle. The trial begins when the specified velocity and steady-state headways are attained. The driver of the leading vehicle (RV2) then makes a hard brake application while the driver of the trailing vehicle (HV), unaware that the leading vehicle is braking, maintains the initial velocity. The trial ends when the RV1 to RV2 headway falls below 90 percent of the specified steady-state headway. The expectation is that the trailing vehicle (HV) will issue an EEBL alert after receiving a hard braking event flag transmitted from the braking lead vehicle. Details for this test procedure can be found in Appendix A, Section A.8. The HV and RV initial speeds were 35 mph for the tests conducted in this study.

The HV was the red Cascadia and the RV1 blocking vehicle was the blue Cascadia. The RV2 lead vehicle was either the Honda Odyssey or the Mack. The vehicle/trailer combinations evaluated for this test procedure are presented in Table 2 as well as the number of tests conducted for each combination.

Table 2: EEBL-1 HV, RV1, and RV2 Vehicle/Trailer Combinations Evaluated

HV	HV Trailer	RV2 (Lead)	RV2 Trailer	RV1 (Blocking)	RV1 Trailer	Number of Tests
Red Cascadia	Bobtail	Odyssey	NA	Blue Cascadia	53’ Box	6
Red Cascadia	Bobtail	Mack	53’ Box	Blue Cascadia	53’ Box	6
Red Cascadia	Bobtail	Mack	40’ Ship. Cont.	Blue Cascadia	53’ Box	6
Red Cascadia	Bobtail	Mack	28’ Doubles	Blue Cascadia	53’ Box	4

There are two main metrics that are relevant for the EEBL testing: at what distance does the HV start to recognize hard braking event flags being issued from the RV2 and if the HV is inside that distance, how long does it take to issue the EEBL alert after receiving a hard braking event flag? The first combination listed in Table 2 was used to determine the distance at which the HV starts to recognize the EEBL alerts and the remaining were used to determine how quickly the alert is issued. For the first combination the HV was outside the alert range and drove into the range and the range between the HV and RV2 was determined. For the other combinations, the HV was inside this range and hard braking event flag was monitored to determine how long it took to issue an EEBL alert once the hard braking event flat was issued. For the HV = red Cascadia and RV2 = Mack combinations, the 0.4 g acceleration level was also monitored because this condition also had to be met before the red Cascadia would issue an EEBL alert (again as noted previously Odyssey issues hard brake event at 0.4 g deceleration and the Mack issues at 0.3 g).

The HV to RV2 longitudinal range at RV2 brake threshold and at EEBL alert onset for the first combination of vehicles in Table 2 are shown in Table 3. Both WSU and RT measured range values are presented. The average longitudinal range at alert onset was 247 meters for the WSU data and 250 meters for RT data.

Table 3: HV to RV2 Longitudinal Range at RV2 Brake Threshold and EEBL Alert Onset for HV = Red Cascadia Bobtail, RV2 = Odyssey, and RV1 = Blue Cascadia With 53' Box Trailer

Test No.	Long. Range at RV2 Brake (m)		Long. Range at Alert Onset (m)	
	WSU	RT	WSU	RT
1249	277	277	247.2	251.4
1250	275	273	247.0	249.8
1251	272	271	247.4	250.9
1252	276	274	247.0	249.6
1253	277	276	247.5	251.1
1254	277	276	246.7	249.3
Ave.	276	275	247.1	250.4
Std.	2.0	2.2	0.3	0.9
C. of V. (%)	0.7	0.8	0.1	0.4

As noted in Section 4, the red Cascadia only issued alerts after the hard braking event flag and the 0.4 g brake threshold was reached when tested with the Mack in the RV2 lead position. The average and standard deviation of the EEBL alert delay from RV2 EEBL brake threshold of 0.4 g are listed in Table 4 (WSU data only) for each RV2 Trailer combination evaluated (HV and RV1 vehicles did not change). More complete data for each individual test are presented in Appendix B, Section B.1. WSU, RT, and GPS data are presented in the appendix. The mean EEBL alert delay values were very small ranging from 0.1 to 0.2 seconds for all the trailer combinations and the standard deviation was 0.06 seconds or less.

Table 4: Average and Standard Deviation of Red Cascadia (HV) EEBL Alert Delay From RV2 EEBL Brake Threshold of 0.4 g – WSU Data

RV2 (Lead)	RV2 Trailer	Alert Delay from RV2 Brake Decel. = 0.4g (sec)	
		Mean	Std. Dev.
Mack	53' Box	0.1	0.04
Mack	40' Ship. Cont.	0.1	0.04
Mack	28' Doubles	0.2	0.06

Also as noted in Section 4, the blue Cascadia (RV1 position) issued alerts after the hard braking event flag when tested with the Mack in the RV2 lead position. The average and standard deviation of the EEBL alert delay from RV2 hard braking event flag are listed in Table 5 (WSU data only) for each RV2 Trailer combination evaluated (HV and RV1 vehicles did not change). More complete data for each individual test are presented in Appendix B, Section B.1. The mean EEBL alert delay values were very small ranging from 0.1 to 0.2 seconds for all the trailer combinations and the standard deviation was 0.06 seconds or less.

Table 5: Average and Standard Deviation of Blue Cascadia (RV1) EEBL Alert Delay From RV2 Hard Brake Event Flag – WSU Data

RV2 (Lead)	RV2 Trailer	Alert Delay from RV2 Hard Brake Event Flag (sec)	
		Mean	Std. Dev.
Mack	53' Box	0.1	0.00
Mack	40' Ship. Cont.	0.1	0.05
Mack	28' Doubles	0.2	0.06

4.2 EEBL-2: Reverse Roles, Hidden Braking Vehicle Ahead in Same Lane, Straight Road

For the EEBL-2 test procedure, three vehicles travel along a straight roadway in the same lane of travel and in the same direction. Initially, the three vehicles travel at the same velocity. This time, the HV leads the other vehicles, and remains within V2V system communication range of both following vehicles. The intermediate vehicle travels between the leading and trailing vehicles and physically blocks the trailing vehicle driver's view of the leading vehicle. The trial begins when the specified velocity and steady-state headways are attained. The driver of the leading vehicle (HV) then makes a hard brake application while the driver of the trailing vehicle, unaware that the leading vehicle is braking, maintains the initial velocity. The trial ends when the RV1 to HV headway falls below 90 percent of the specified steady-state headway. Specifically, the EEBL-2 procedure is used to confirm the ability of on-board V2V equipment to broadcast hard braking event flags to other V2V-equipped vehicles. The procedure reverses the roles of the host vehicle (HV) and the leading remote vehicle (RV2) of the EEBL-1 procedure. Details for this test procedure can be found in Appendix A, Section A.9. The HV and RV initial speeds were 35 mph for the tests conducted in this study.

Several tests were conducted with the blue Cascadia in the HV position (Lead Vehicle Braking). The red Cascadia was in the RV2 position. Even though the blue Cascadia braking deceleration was well above the EEBL threshold of 0.4 g, the red Cascadia did not receive an EEBL alert. The tests did yield an FCW alert as the RV approached the braking/stopped HV. An example HV deceleration and FCW alert are shown in Figure 11. The WSU on the blue Cascadia did not issue a hard braking event flag even though the deceleration was above the EEBL threshold of 0.4 g and therefore it did not appear that the WSUs on the Cascadia trucks were programmed to issue hard braking events flags. Therefore, no further EEBL-2 Reversed Role tests were conducted.

As noted in Section 4, the hard braking event flag is contained in the data element called event flags. The event flags data element is not included in the basic safety message unless at least one of the event flags is set to 1. The event flags data element was not found for these tests like it was for the tests conducted with the Mack or the Odyssey in the lead (braking) position.

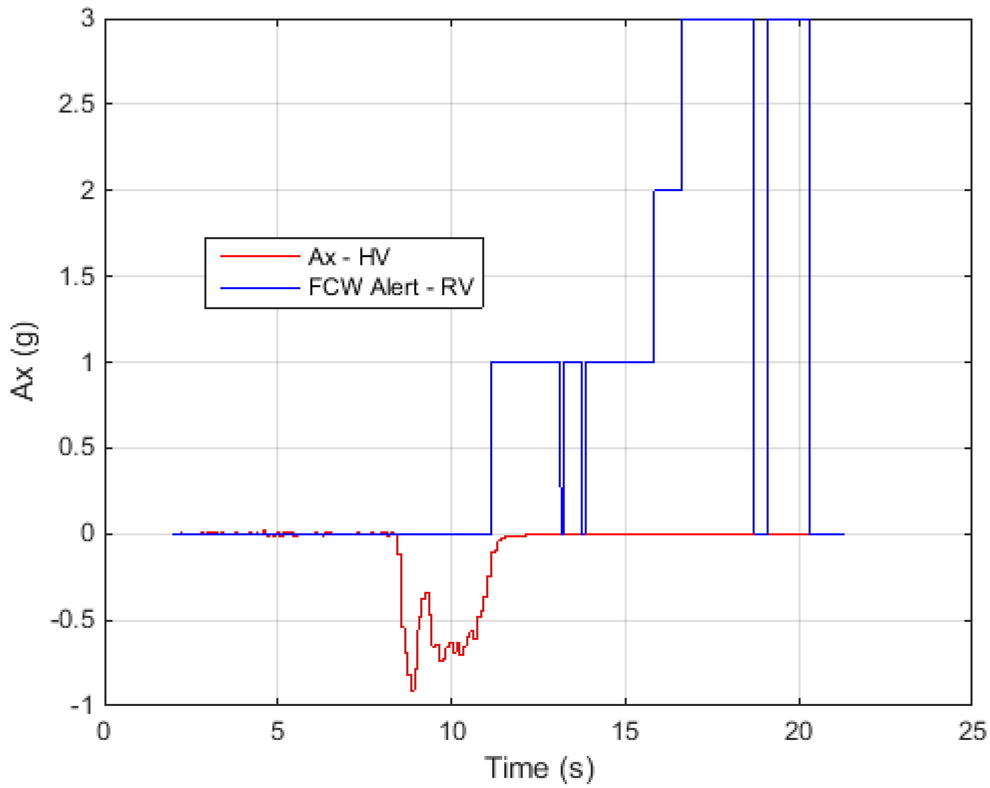


Figure 11: HV (Blue Cascadia) Deceleration and RV (Red Cascadia) FCW Alert - Example EEBL 2 Results – Test 1540

4.3 EEBL-3: Mildly Braking Vehicle Ahead in Same Lane, Straight Road

For the EEBL-3 test procedure, two vehicles travel along a straight roadway in the same lane of travel and in the same direction. Initially, the two vehicles travel at the same velocity with the leading and trailing vehicles within V2V system communication range. The driver of the leading vehicle then makes a mild brake application, while the driver of the trailing vehicle maintains the initial velocity. This procedure is used to evaluate the abilities of the V2V systems to suppress alerts when presented with this normal braking scenario and no alert is warranted. Details for this test procedure can be found in Appendix A, Section A.10.

This test procedure is essentially the same as an FCW test procedure. No EEBL alerts were observed during any of the FCW tests and therefore the WSU systems on the Cascadia trucks are able to suppress alerts when the vehicle is braking below the 0.4 g EEBL hard braking threshold. No specific testing was done for this test procedure due to the overlap with the FCW test procedures that are documented in *Commercial Connected Vehicle Test Procedure Development and Test Results – Forward Collision Warning* [3].

4.4 EEBL-4: Braking Vehicle Ahead in Adjacent Lane, Straight Road

For the EEBL-4 test procedure, three vehicles travel along a straight roadway in the same direction. The lead vehicle (RV2) is in a lane adjacent to the lane in which the intermediate (RV1) and trailing (HV) vehicles are traveling. The RV1 travels longitudinally between the leading and trailing vehicles, blocking the view of the RV2 from the driver of the HV. Initially, the three vehicles travel at the same velocity with the leading and trailing vehicles within the V2V system communication range. The driver of the RV2 then makes a hard brake application while the driver of the HV, unaware that the RV2 is braking, maintains the initial velocity. This test determines the ability of the HV V2V system to receive the decelerating RV2 broadcasted hard braking event flag (deceleration is greater than 0.4g), identify the RV2 as a collision threat, and inform the HV driver of the threat in a timely manner. The RV2 hard braking event flag should result in a HV Level 2 EEBL alert, letting the HV driver know there is an aggressively braking vehicle in an adjacent lane. Details for this test procedure can be found in Appendix A, Section A.11. The HV and RV initial speeds were 35 mph for the tests conducted in this study.

The HV was the red Cascadia and the RV1 blocking vehicle was the blue Cascadia. The RV2 lead vehicle was either the Honda Odyssey or the Mack. The vehicle/trailer combinations evaluated for this test procedure are presented in Table 6 and Table 7 as well as the number of tests conducted and the number that produced alerts for each combination. As was the case for the EEBL-1 tests, some combinations were evaluated with the HV driving into the EEBL alert range (Table 6) and some combinations were evaluated with the HV inside the EEBL alert range when the brakes were applied on RV2 (Table 7).

Table 6: EEBL-4 HV, RV1, and RV2 Vehicle/Trailer Combinations Evaluated - HV Drives Into EEBL Alert Range

HV	HV Trailer	RV2 (Lead)	RV2 Trailer	RV1 (Blocking)	RV1 Trailer	Number of Tests w/ EEBL Alerts
Red Cascadia	Bobtail	Odyssey	NA	Blue Cascadia	53’ Box	5 of 6
Red Cascadia	Bobtail	Mack	Bobtail	Blue Cascadia	Bobtail	6 of 6
Red Cascadia	Bobtail	Mack	53’ Box	Blue Cascadia	53’ Box	4 of 6

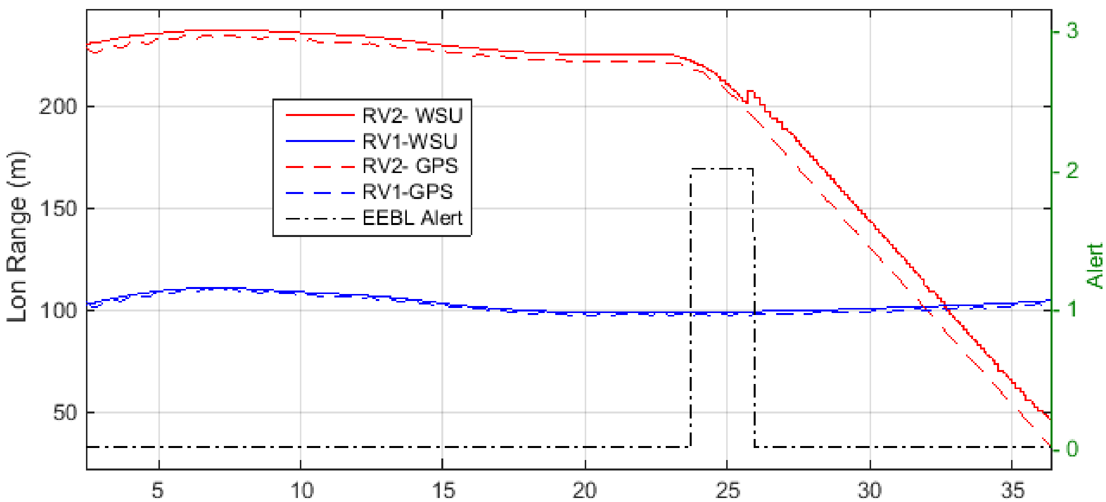
Table 7: EEBL-4 HV, RV1, and RV2 Vehicle/Trailer Combinations Evaluated - HV Inside EEBL Alert Range

HV	HV Trailer	RV2 (Lead)	RV2 Trailer	RV1 (Blocking)	RV1 Trailer	Number of Tests w/ EEBL Alerts
Red Cascadia	Bobtail	Mack	53’ Box	Blue Cascadia	53’ Box	5 of 5
Red Cascadia	Bobtail	Mack	40’ Ship. Cont.	Blue Cascadia	53’ Box	5 of 9
Red Cascadia	Bobtail	Mack	28’ Doubles	Blue Cascadia	53’ Box	5 of 5

Tests were generally conducted with the RV2 on the left and right side of the HV in an alternating fashion. For all the cases where the HV did not get an EEBL alert (or a delayed alert), the RV2 was on the left side of the HV, but many of the left side tests did produce alerts. All four left side tests for the Mack with the 40’ shipping container as the RV2 did not produce valid alerts (3 no alerts and 1 delayed alert). All five right side tests produced an alert.

Longitudinal and lateral range traces for a left side test with valid EEBL alerts (Test 1729, RV2 = Mack with the 28’ Doubles) are shown in Figure 12 along with the EEBL alert. Both WSU and GPS range data are presented. The WSU lateral range for RV2 is quite noisy, but has a similar magnitude on average as the GPS lateral range data for RV2 until the RV2 has come to a stop. At this point the WSU data drifts towards -2 meters near 26 seconds and then reduces back to -3.5

meters. The GPS data is steadier and does not drift in a similar fashion, which shows that the lateral range of the vehicles did not change as dramatically as the WSU data would suggest. Similar data for a left side test with a no EEBL alert (Test 1713, RV2 = Mack with the 40' shipping container) are shown in Figure 13. For this test the RV2 WSU lateral range is more than 1 meter greater than the GPS lateral range and the WSU data shows that the RV2 is further away from the HV than it really is. This error in relative lateral position causes the WSU to classify RV2 as non- threatening because it is estimating RV2 to be more than one lane away and therefore did not issue an EEBL alert. This observation is supported by RV2 WSU lateral range data that dives from -6 meters to -10 meters as RV2 comes to a stop near 10 seconds. The RV2 GPS data has no similar change in value.



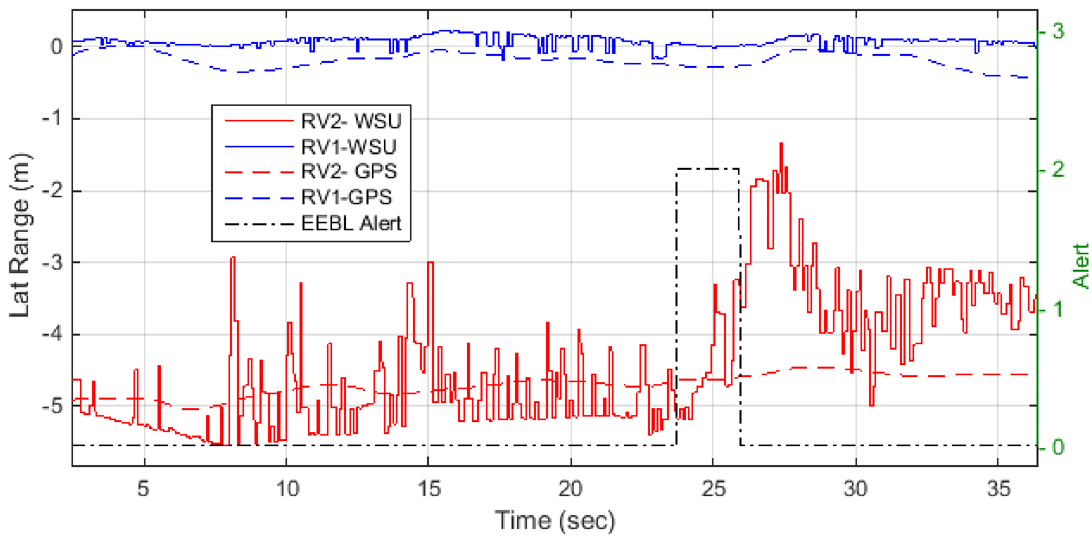


Figure 12: Example EEBL 4 Results –EEBL Alert, Test 1729, RV2 = Mack With 28' Doubles

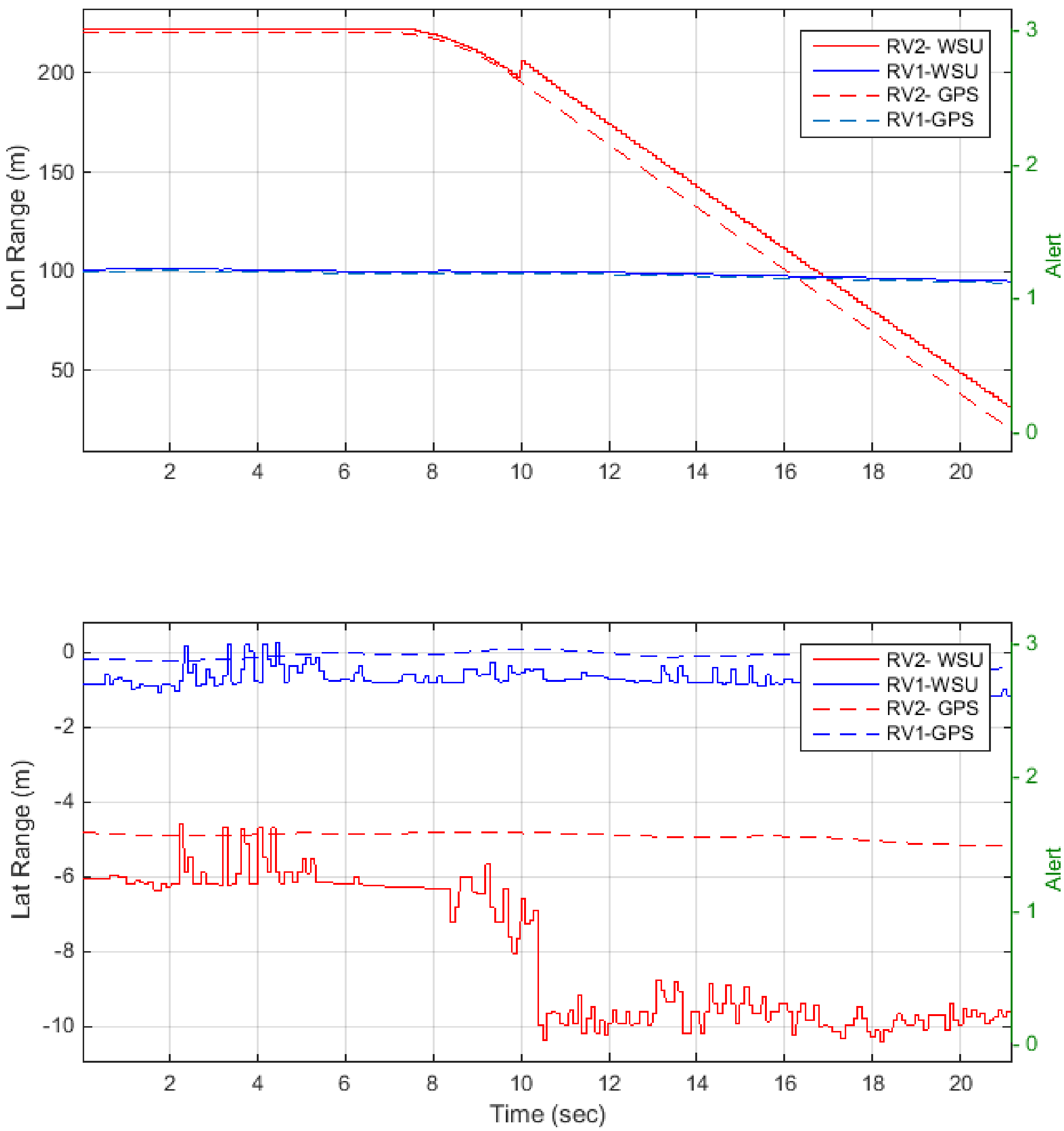


Figure 13: Example EEBL 4 Results – No EEBL Alert, Test 1713, RV2 = Mack With 40' Shipping Container

Average and standard deviation of HV to RV2 longitudinal range at RV2 brake threshold and at EEBL alert onset for the combination of vehicles listed in Table 6 are shown in Table 8 (WSU data). More complete data for each individual test are presented in Appendix B, Section B.2. The average longitudinal range at alert onset ranged from 246 to 249 meters for the WSU data with standard deviation values ranging from 0.5 to 1.2 meters

Table 8: Average and Standard Deviation of HV to RV2 Longitudinal Range at RV2 Brake Threshold and at EEBL Alert Onset – WSU Data

RV2 (Lead)	RV2 Trailer	RV1 (Blocking)	RV1 Trailer	Long. Range at RV2 Brake (m)		Long. Range at Alert Onset (m)	
				Mean	Std. Dev.	Mean	Std. Dev.
Odyssey	-	Blue Cascadia	53’ Box	274	2.5	246	0.5
Mack	Bobtail	Blue Cascadia	Bobtail	259	2.2	249	0.6
Mack	53’ Box	Blue Cascadia	53’ Box	266	1.8	248	1.2

As noted in Section 4, the red Cascadia only issued alerts after the hard braking event flag and the 0.4 g brake threshold was reached when tested with the Mack in the RV2 lead position. The average and standard deviation of the EEBL alert delay from RV2 EEBL brake threshold of 0.4 g are listed in Table 9 (WSU data) for each RV2 Trailer combination evaluated (HV and RV1 vehicles did not change for these tests). More complete data for each individual test are presented in Appendix B, Section B.2. WSU, RT, and GPS data are presented in the appendix. The mean EEBL alert delay values were very small ranging from 0.1 to 0.2 seconds for all the trailer combinations evaluated and the standard deviation was 0.06 seconds or less.

Table 9: Average and Standard Deviation of EEBL Alert Delay From RV2 EEBL Brake Threshold – WSU Data

RV2 (Lead)	RV2 Trailer	Alert Delay from RV1 Brake Decel. = 0.4g (sec)	
		Mean	Std. Dev.
Mack	53’ Box	0.1	0.00
Mack	40’ Ship. Cont.	0.1	0.00
Mack	28’ Doubles	0.2	0.06

4.5 EEBL-5: Braking Vehicle Ahead in Same Lane, Curved Road

For the EEBL-5 test procedure, three vehicles travel along a curved roadway in the same lane of travel and in the same direction. The intermediate vehicle (RV1) travels between the leading (RV2) and trailing HV vehicles and blocks the view of the RV2 from the driver of the HV. Initially, the three vehicles travel at the same velocity with the RV2 and HV vehicles within V2V system communication range. The driver of the RV2 then makes a hard brake application while the driver of the HV, unaware that the RV2 is braking, maintains the initial velocity. The test determines the ability of the HV V2V system to receive the decelerating RV2 broadcast of the hard braking event flag, identify the RV2 as a collision threat, and informing the HV driver of the threat in a timely manner. Details for this test procedure can be found in Appendix A, Section A.12. The HV and RV initial speeds were 35 mph for the tests conducted in this study. This procedure is similar to EEBL-1, except the roadway is curved. Details for the curved roadway used in this study can be found in Appendix A – Section A.7.

One set of vehicles was evaluated with this test procedure. The HV was the red Cascadia and the RV1 blocking vehicle was the blue Cascadia. The RV2 lead vehicle was the Honda Odyssey. For this set of tests, the EEBL-5 test procedure was evaluated with the HV driving into the EEBL alert range. Since this was the case, the RV1 vehicle was treated like an HV in data processing so the HV inside the EEBL alert range could also be evaluated. Even though they are the same set of tests, the combination evaluated with the HV driving into the EEBL alert range is shown in Table 10 and the combination evaluated with the HV (RV1 as HV) inside the EEBL alert range is shown in Table 11. Again, the data presented are from the same set of tests, just switching which vehicle is considered the HV in post processing.

The number of tests with valid EEBL alerts is also shown in these tables. Seven tests were conducted, but it was determined that only 5 of the tests for the HV driving into the EEBL alert range were valid because the RV2 had fully stopped prior to the HV getting to a longitudinal range where it would track the RV2. Therefore no alert was given nor would it be expected to do so. Four of the five valid tests had EEBL Level 3 alerts (hard braking vehicle in lane with HV). The fifth test gave an EEBL Level 2 alert (hard braking vehicle in adjacent lane – right for this case) before switching to an EEBL Level 3 alert. For the tests with the RV1 (blue Cascadia) being treated as the HV, 2 of the 7 tests had EEBL Level 3 alerts. The other 5 tests produced an EEBL Level 2 alert (hard braking vehicle to the right) that in some cases switched to an EEBL Level 3 alert.

Table 10: EEBL-5 HV, RV1, and RV2 Vehicle/Trailer Combinations Evaluated - HV Drives Into EEBL Alert Range

HV	HV Trailer	RV2 (Lead)	RV1 (Blocking)	RV1 Trailer	Number of Tests with the EEBL Alerts
Red Cascadia	Bobtail	Odyssey	Blue Cascadia	53’ Box	4 of 5

Table 11: EEBL-5 HV, RV1, and RV2 Vehicle/Trailer Combinations Evaluated - HV Inside EEBL Alert Range

HV	HV Trailer	RV2 (Lead)	RV1 (Blocking)	RV1 Trailer	Number of Tests with the EEBL Alerts
Blue Cascadia	53’ Box	Odyssey	NA	NA	2 of 7

Example test results for an HV driving into the EEBL alert range is shown in Figure 14. The HV is able to track the RV1 (intermediate vehicle) throughout the test file, but stops tracking the RV2 from 9 seconds to about 26 seconds as is noted by the flat line response for longitudinal and lateral range during this time frame. The lateral range has a scalloped oscillatory response for both of the RVs. The EEBL alert is issued very shortly after the longitudinal and lateral range tracking on the RV2 restarts at about 26 seconds. The longitudinal range at this time is approximately 240 meters. The same data for the RV1 tracking RV2 (RV1 acting as HV) is presented in Figure 15 (same test as Figure 14). The RV1 is inside the EEBL alert range and therefore the EEBL Level 3 alert occurs shortly after the hard braking event flag is issued by the RV2. The EEBL alert level switches to 2 at approximately 26 seconds due to the lateral range increasing to about 2 meters. The scalloped shape of the lateral range is the primary cause of the RV2 being classified as being out of lane. This is also why some of the tests had an initial EEBL Level 2 alert and why only 2 of the 7 tests had initial EEBL Level 3 alerts. For those tests that had the EEBL Level 2 alert prior to a Level 3 alert, the lateral range was in the higher portion of the scallop shape. One could also argue that none of the tests had good alerts due to the Level changing from 3 to 2 during the course of the tests that were classified as having a valid initial alert.

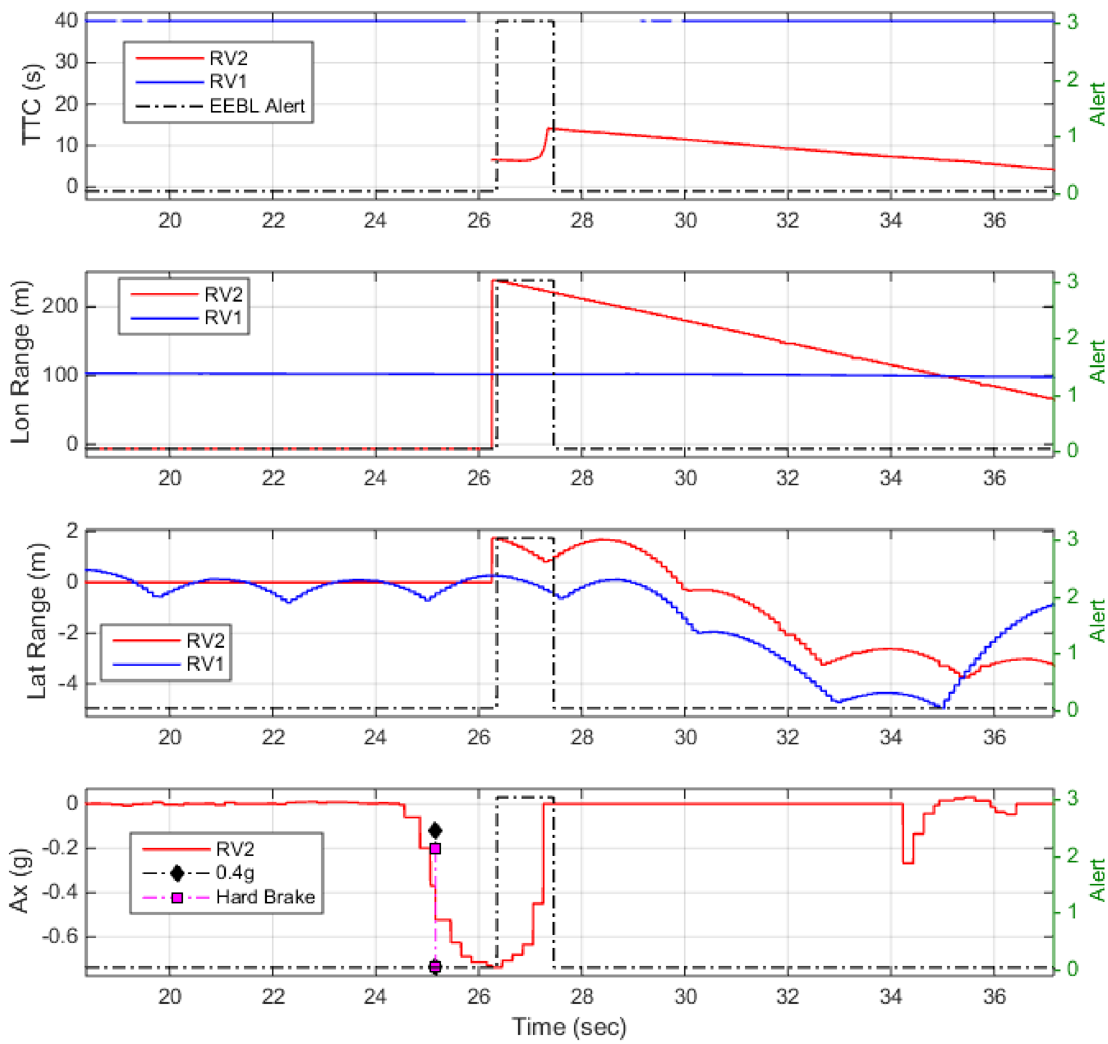


Figure 14: Example EEBL-5 Results - HV Drives Into EEBL Alert Range – Test 1267

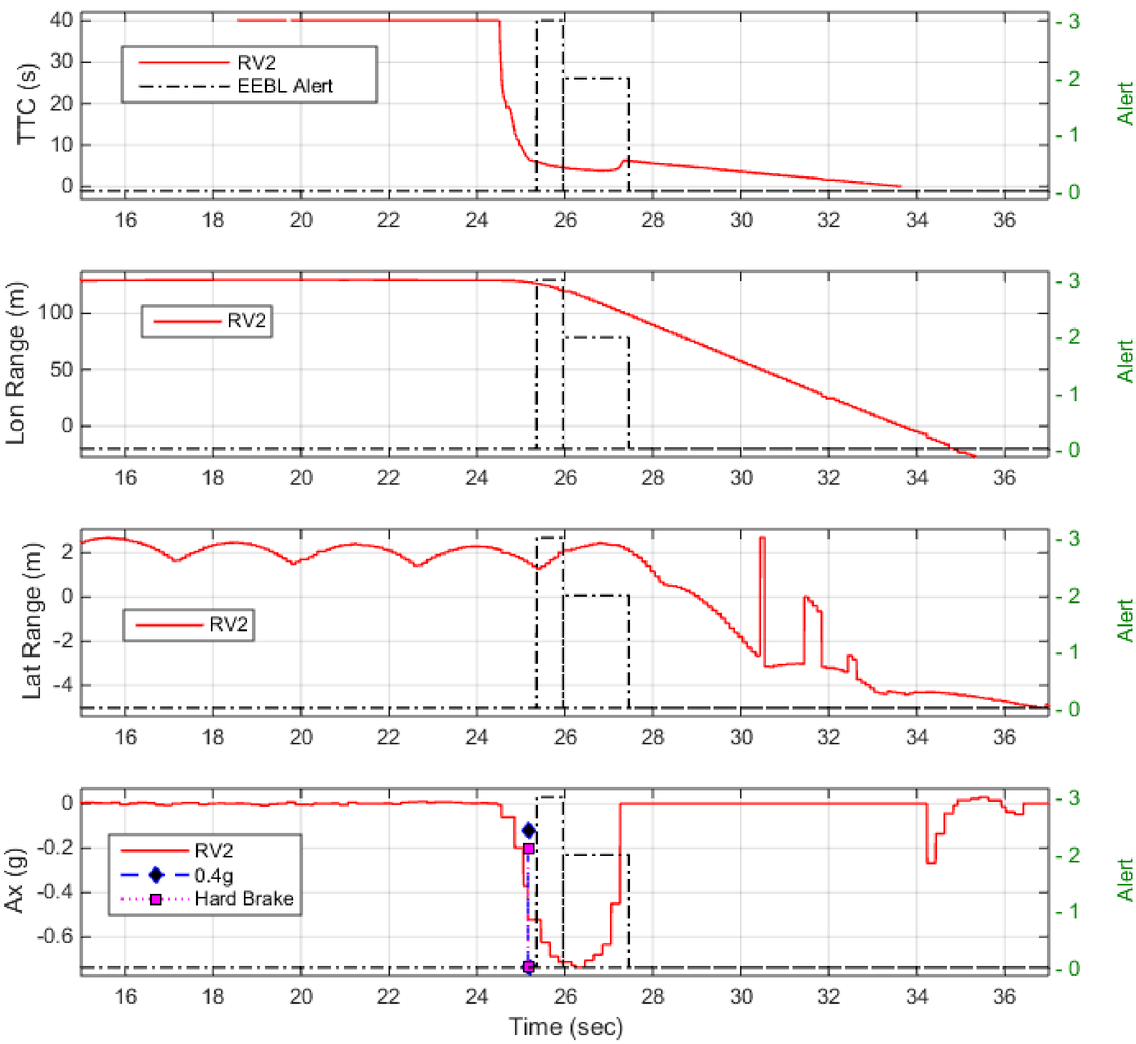


Figure 15: Example EEBL-5 Results – RV1 Acting as HV Inside EEBL Alert Range – Test 1267

The HV to RV2 longitudinal range at RV2 brake threshold and at EEBL alert onset for the HV Drives into EEBL alert range combination are given in Table 12. These values were for the first EEBL alert level seen for each test whether it was Level 3 or Level 2 (R means RV1 seen as being to Right of HV). Both WSU and RT measured range values are presented. The average longitudinal range at alert onset was 232 meters for the WSU data and 235 meters for RT data. These values are slightly less than what was seen with the straight road tests for EEBL-1 (closer to 250 meters).

Table 12: HV to RV2 Longitudinal Range at RV2 Brake Threshold and EEBL Alert Onset for HV = Red Cascadia Bobtail, RV2 = Odyssey, and RV1 = Blue Cascadia With 53' Box

Test No.	Alert Level	Long. Range at RV2 Brake (m)		Long. Range at Alert Onset (m)	
		WSU	RT	WSU	RT
1262	3		255	230	233
1264	3		256	231	235
1265	3		252	229	233
1266	2 R		248	231	235
1267	3		253	237	241
Ave.			253	232	235
Std.			2.6	2.9	2.9
C. of V. (%)			1.0	1.3	1.2

The EEBL alert delay after the RV2 has issued the hard braking event flag is given in Table 13 for the RV1 acting as HV test results. The alert delay is calculated for the first EEBL alert seen whether it was Level 3 or Level 2. The average delay was 0.2 seconds with a standard deviation less than 0.01 seconds. This delay is in line with what was seen with the EEBL-1 test results for a straight road test (0.1 to 0.2 seconds).

Table 13: EEBL Alert Delay From RV2 EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Blue Cascadia With 53' Box (RV1 Acting as HV), RV2 = Mack With 53' Box

Test No.	Alert Level	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Hard Braking Event (sec)
		HV	RV	WSU
1261	2 R	34.2	33.0	0.2
1262	3	35.6	34.1	0.2
1263	2 R	34.7	33.6	0.2
1264	2 R	35.2	34.0	0.2
1265	2 R	34.2	34.1	0.2
1266	2 R	34.2	32.3	0.2
1267	3	34.8	33.6	0.2
Ave.		34.7	33.5	0.2
Std.		0.6	0.7	0.00

4.6 EEBL-6: Braking Vehicle Ahead in Outside Adjacent Lane, Curved Road

For the EEBL-6 test procedure, three vehicles travel along a curved roadway in the same direction. The lead vehicle (RV2) is traveling in a lane adjacent to the lane in which the intermediate (RV1) and trailing (HV) vehicle are traveling. The RV1 travels longitudinally between the RV2 and HV vehicles and blocks (or partially obstructs) the view of the leading vehicle from the driver of the trailing vehicle. The trial begins when the specified velocity and steady-state headways are attained. Then the RV2 driver makes a hard brake application while the driver of the HV, unaware that the RV2 is braking, maintains the initial velocity. This test determines the ability of the HV V2V system to receive the decelerating RV2 broadcast of the hard braking event flag, identify the RV2 as a collision threat, and informing the HV driver with an EEBL Level 2 alert. Details for this test procedure can be found in Appendix A, Section A.13. The HV and RV initial speeds were 35 mph for the tests conducted in this study. This procedure is similar to EEBL-4, except the roadway is curved.

One set of vehicles was evaluated with this test procedure. The HV was the red Cascadia and the RV1 blocking vehicle was the blue Cascadia. The RV2 lead vehicle was the Honda Odyssey. For this set of tests, the EEBL-6 test procedure was evaluated with the HV driving into the EEBL alert range. Since this was the case, the RV1 vehicle was treated like an HV in data processing so the HV inside the EEBL alert range could also be evaluated. Even though they are the same set of tests, the combination evaluated with the HV driving into the EEBL alert range is shown in Table 14 and the combination evaluated with the HV (RV1 as HV) inside the EEBL alert range is shown in Table 15. Again, the data presented are from the same tests, just switching which vehicle is considered the HV in post processing.

The number of tests with EEBL alerts is also shown in these tables. Six tests were conducted, but it was determined that only 1 of the tests for the HV driving into the EEBL alert range was valid because the RV2 had fully stopped prior to the HV getting to a longitudinal range where it would track the RV2. Therefore no alert was given nor would it be expected to do so. This one test was observed to produce an EEBL Level 2 alert. With the RV1 (blue Cascadia) being treated as the HV, five of the six tests resulted in valid EEBL Level 2 alerts. The sixth test produced an EEBL Level 3 alert (EEBL in lane), which later switched to EEBL Level 2 Left Lane. This test will be discussed in more detail below.

Table 14: EEBL-6 HV, RV1, and RV2 Vehicle/Trailer Combinations Evaluated - HV Drives Into EEBL Alert Range

HV	HV Trailer	RV2 (Lead)	RV1 (Blocking)	RV1 Trailer	Number of Tests w/ EEBL Alerts
Red Cascadia	Bobtail	Odyssey	Blue Cascadia	53’ Box	1 of 1

Table 15: EEBL-6 HV, RV1, and RV2 Vehicle/Trailer Combinations Evaluated - HV Inside EEBL Alert Range

HV	HV Trailer	RV2 (Lead)	RV1 (Blocking)	RV1 Trailer	Number of Tests w/ EEBL Alerts
Blue Cascadia	53’ Box	Odyssey	NA	NA	5 of 6

Example test results for an HV driving into the EEBL alert range are shown in Figure 16. The HV is able to track the RV1 (intermediate vehicle) throughout the test file, but does not start tracking the RV2 until a little past 6 seconds as is noted by the flat line response for longitudinal and lateral range before 6 seconds. The lateral range has a scalloped oscillatory response for both of the RVs. The EEBL alert is issued very shortly after the longitudinal and lateral range tracking on the RV2 begins. The longitudinal range at this time is approximately 240 meters. The same data for the RV1 tracking RV2 (RV1 acting as HV) is presented in Figure 17 (same test as Figure 16). Because the RV1 is inside the EEBL alert range, the EEBL Level 2 alert occurs shortly after the hard braking event flag has been issued.

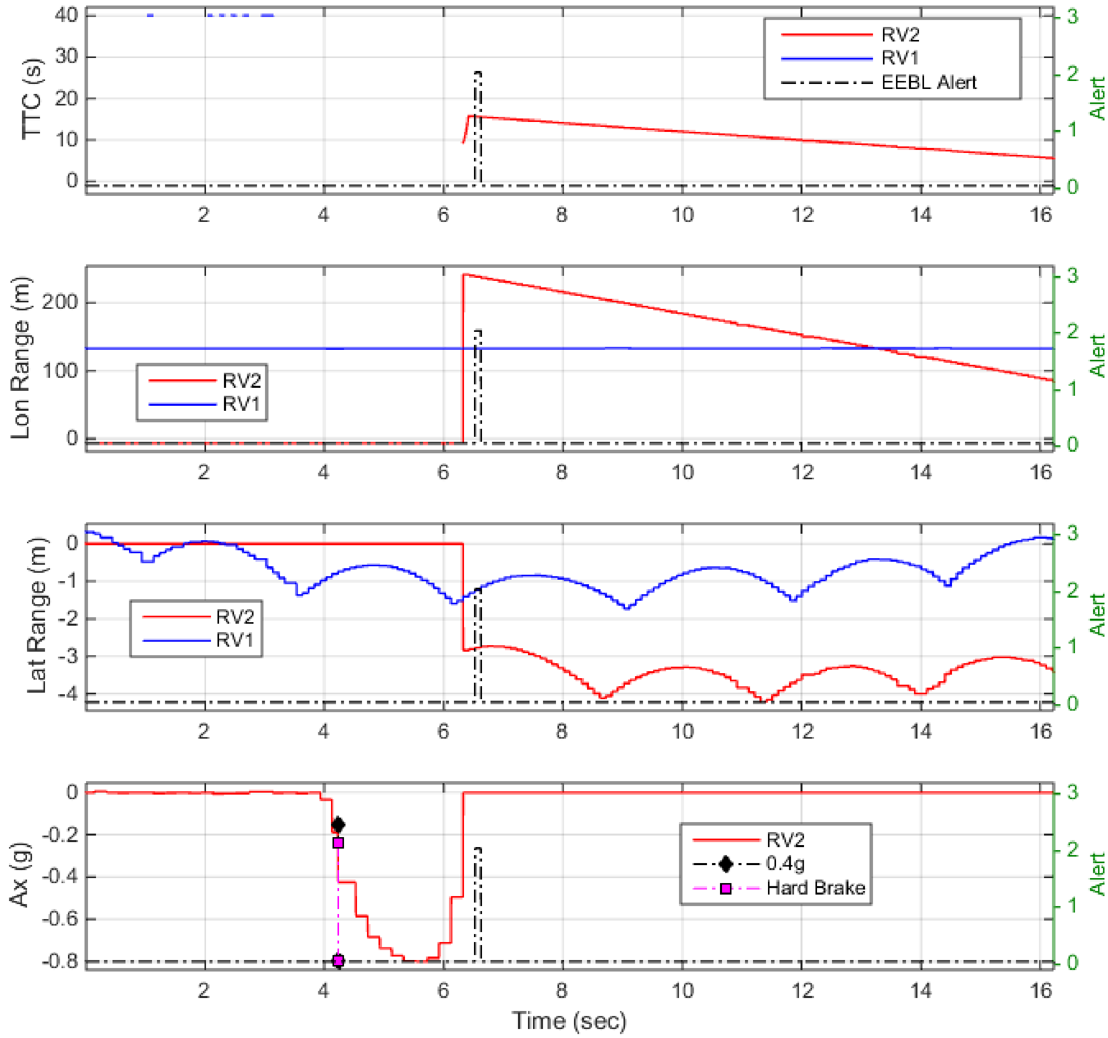


Figure 16: Example EEBL-6 Results - HV Drives Into EEBL Alert Range – Test 1256

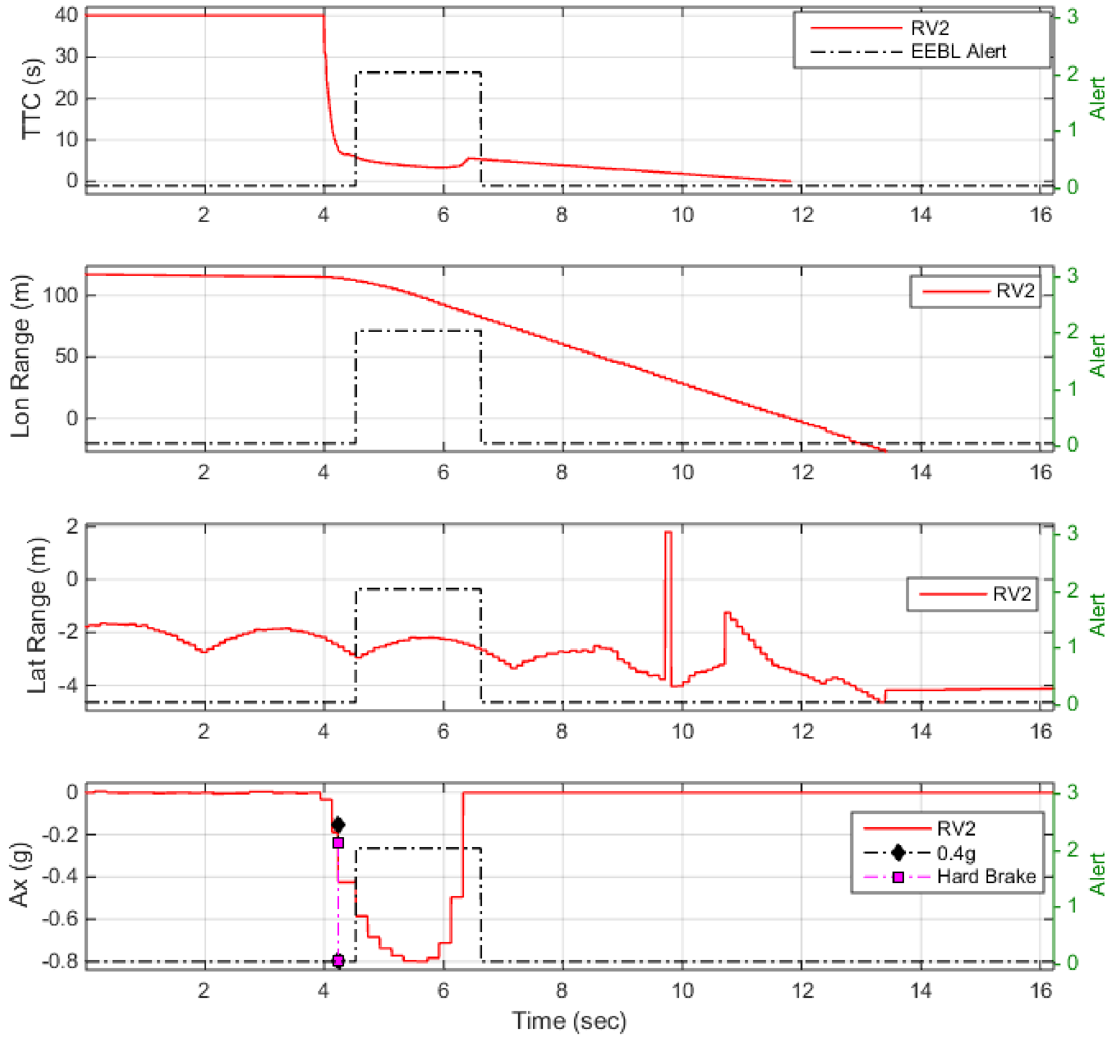


Figure 17: Example EEBL-6 Results – RV1 Acting as HV Inside EEBL Alert Range – Test 1256

For Test 1257, the first alert was an EEBL Level 3 (straight ahead). The results for this test are shown in Figure 18. The EEBL alert starts shortly after 8 seconds at Level 3 and then drops to Level 2 a little before 9 seconds. The lateral range (third subplot) has a scalloped shape that rises above -2 meters shortly before the EEBL alert, which the WSU interprets as the RV2 being in the same lane. The alert lowers to Level 2 as the lateral range increased in magnitude (lower negative value) and moved towards -2 meters.

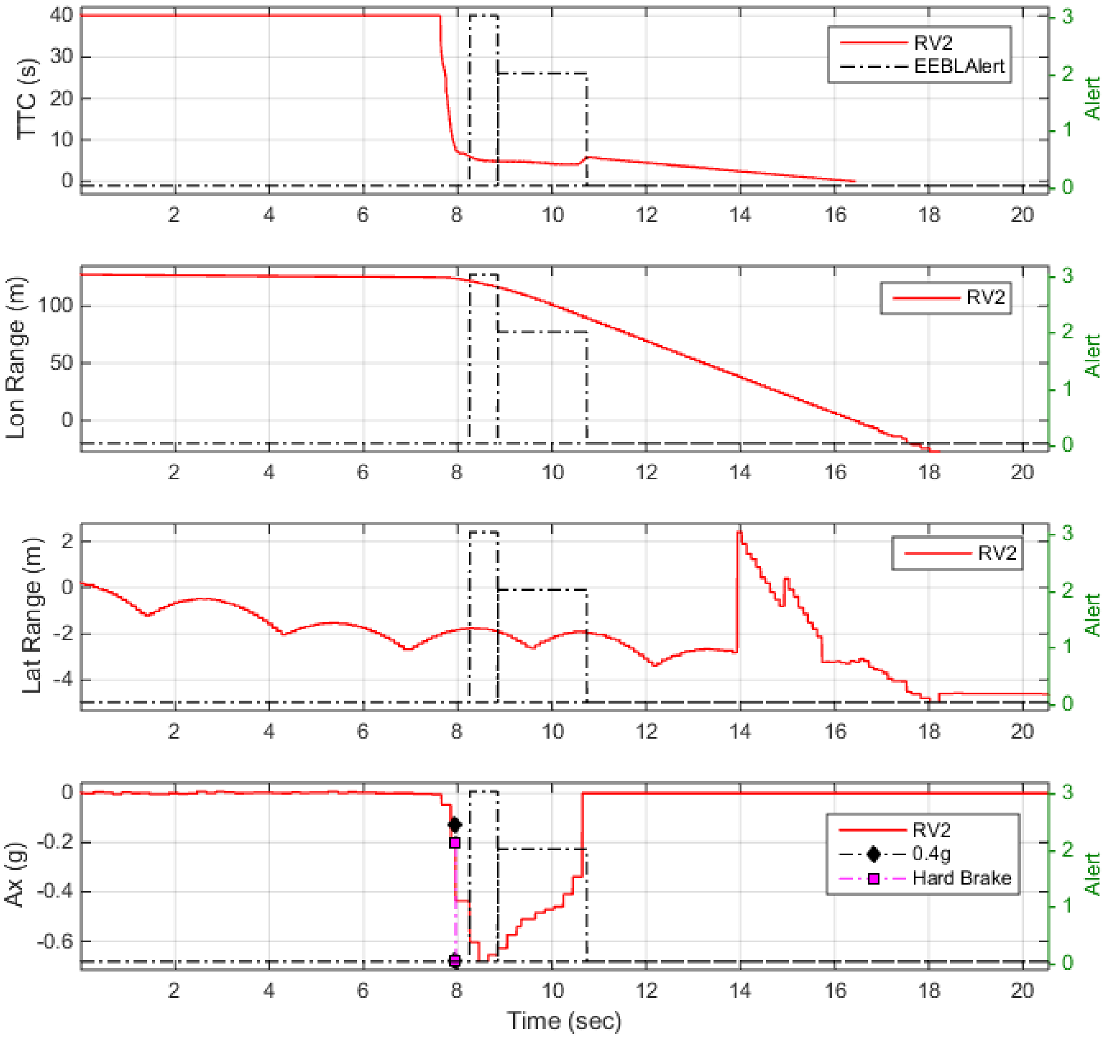


Figure 18: False EEBL Level 3 Alert Prior to EEBL Level 2 Alert – Test 1257

Every time the RV1 moved closer to the RV2 after the EEBL alert, the RV1 received an FCW alert even though the RV2 was a lane to the left of the RV1 (and the HV). This also occurred on the HV as it passed the RV1. Longitudinal and lateral range traces for Test 1255 are shown in Figure 19 in addition to the EEBL and FCW alerts. Near 15.5 seconds the lateral range (second subplot) has a spike up in value that would suggest that the RV1 moved from the right side of the RV2 to the left side of the RV2. This is not physically possible for the given time span of the spike. The lateral range then drifts back to negative values after this spike. As the RV1 approaches the RV2 it reaches a longitudinal range that when coupled with the lateral range being in the ± 2 meter range causes an FCW alert (FCW alert starts shortly before 16 seconds in the plot). The early FCW Level 1 is a tracking level and is not displayed to the driver.

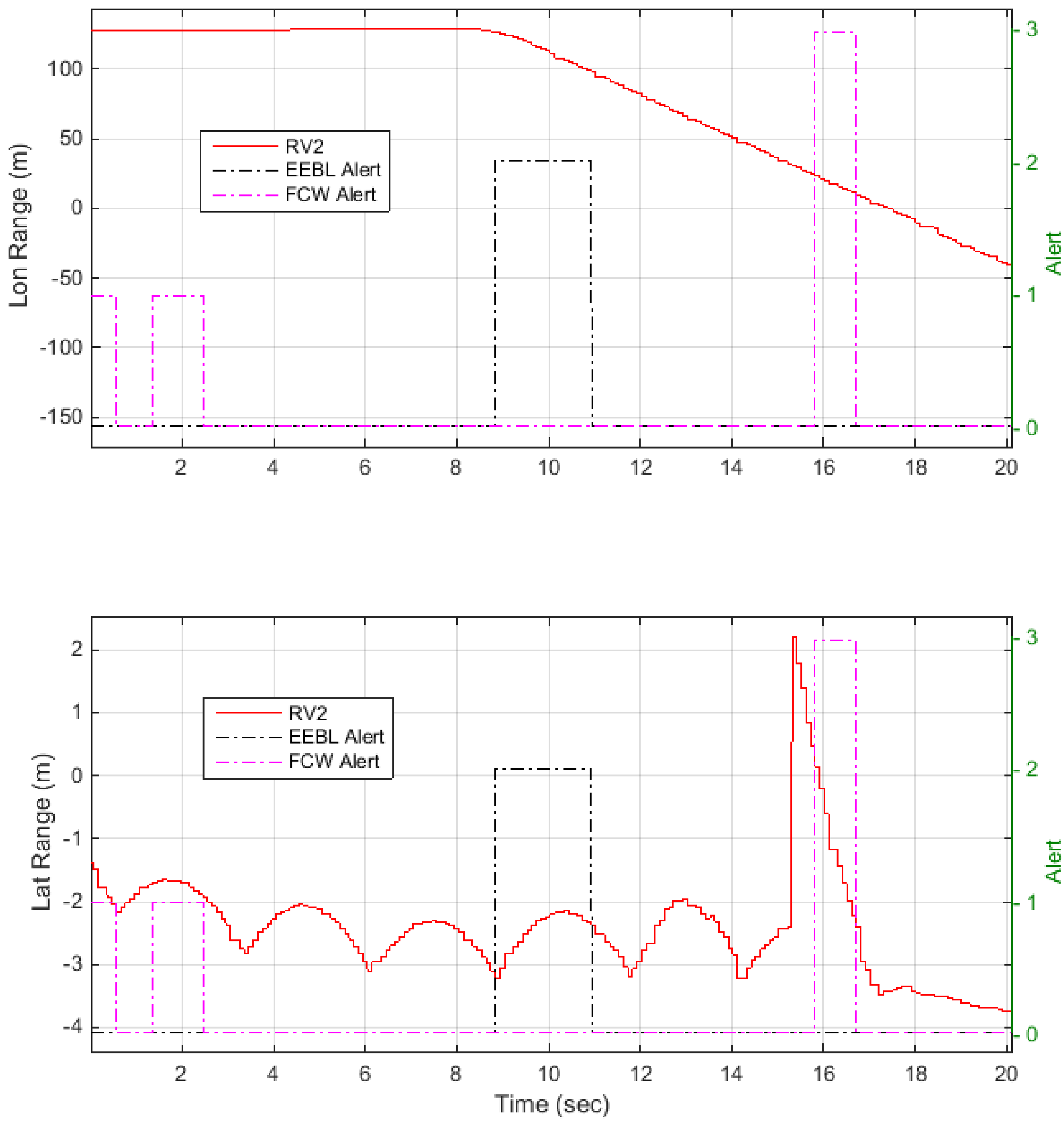


Figure 19: Example False FCW Alert After EEBL Alert – Test 1255 (RV1 as HV)

The HV to RV2 longitudinal range at EEBL alert onset for the one test where the HV drove into EEBL alert range was 241.6 meters. This is consistent with the average longitudinal range at alert onset from the EEBL-5 tests (average of 232 meters for the WSU data).

The EEBL alert delay after the RV2 EEBL brake threshold of 0.4 g is given in Table 16 for the RV1 acting as HV test results. The alert delay is calculated for the first EEBL alert seen whether it was Level 3 or Level 2. The average delay was 0.3 seconds with a standard deviation of 0.04 seconds. This delay is slightly greater than what was seen with the EEBL-4 test results for a straight road test (0.1 to 0.2 seconds).

Table 16: EEBL Alert Delay From RV2 EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Blue Cascadia With 53' Box (RV1 Acting as HV), RV2 = Mack With 53' Box

Test No.	Alert Level	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Hard Braking Event (sec)
		HV	RV	WSU
1255	2 L	33.1	30.6	0.3
1256	2 L	34.7	31.5	0.3
1257	3	34.6	31.2	0.3
1258	2 L	33.3	31.5	0.3
1259	2 L	34.4	31.8	0.3
1260	2 R	33.3	33.2	0.3
Ave.		33.9	31.6	0.3
Std.		0.7	0.9	0.04

4.7 EEBL-7: HV Brakes Upon EEBL Alert

For the EEBL-7 test procedure, two vehicles travel along a straight roadway in the same lane of travel and in the same direction. Initially, the vehicles travel at the same velocity with the leading (RV) and trailing (HV) vehicles within V2V system communication range. The driver of the leading vehicle then makes a hard brake application to initiate the broadcast of the hard braking Event flag in the RV BSM. The HV driver, unaware that the leading vehicle is braking, maintains the initial velocity until the EEBL alert is presented, at which point the HV driver then applies the HV brakes to avoid the RV. The primary measure of interest is if the EEBL alert is suppressed (cancelled) in the HV after the HV driver applies the brakes. Details for this test procedure can be found in Appendix A, Section A.14. The HV and RV initial speeds were 35 mph for the tests conducted in this study.

Just one HV/RV combination was evaluated for the EEBL-7 Test procedure. For these tests the HV was the red Cascadia and the RV was the Honda Odyssey. This vehicle combination is listed in Table 17. Five tests were conducted.

Table 17: EEBL-7 HV and RV Vehicle/Trailer Combinations Evaluated

HV	HV Trailer	RV
Red Cascadia	Bobtail	Odyssey

The primary metric of interest is the time delay between the onset of braking and the offset of the EEBL alert. HV braking is a channel available in the WSU data. An example of this channel along with the EEBL alert channel is shown in Figure 20. The HV brake onset is at 12.4 seconds and the EEBL alert offset is at 13.8 seconds, which gives a time delay between the HV brake onset and the EEBL alert offset of 1.4 seconds. The time delay is listed in Table 18 for each trial conducted. The time delays ranged from 0.8 to 1.4 seconds. This length of time suggests that the EEBL alert offset is not related to the HV brake onset. Examining other results from the EEBL 7 tests and the EEBL 1 tests, it appears the EEBL alert offset is related to the RV having come to a stop or near stop. The RV speed channel is shown with the HV Brake and EEBL alert channel in Figure 21. The EEBL alert returns to zero as the RV speed nears 0. This pattern was seen in the

EEBL-1 tests where the HV did not brake upon EEBL alert. This result in combination with the long time delays between brake onset and EEBL offset suggest that the WSU does not suppress the alert at brake onset.

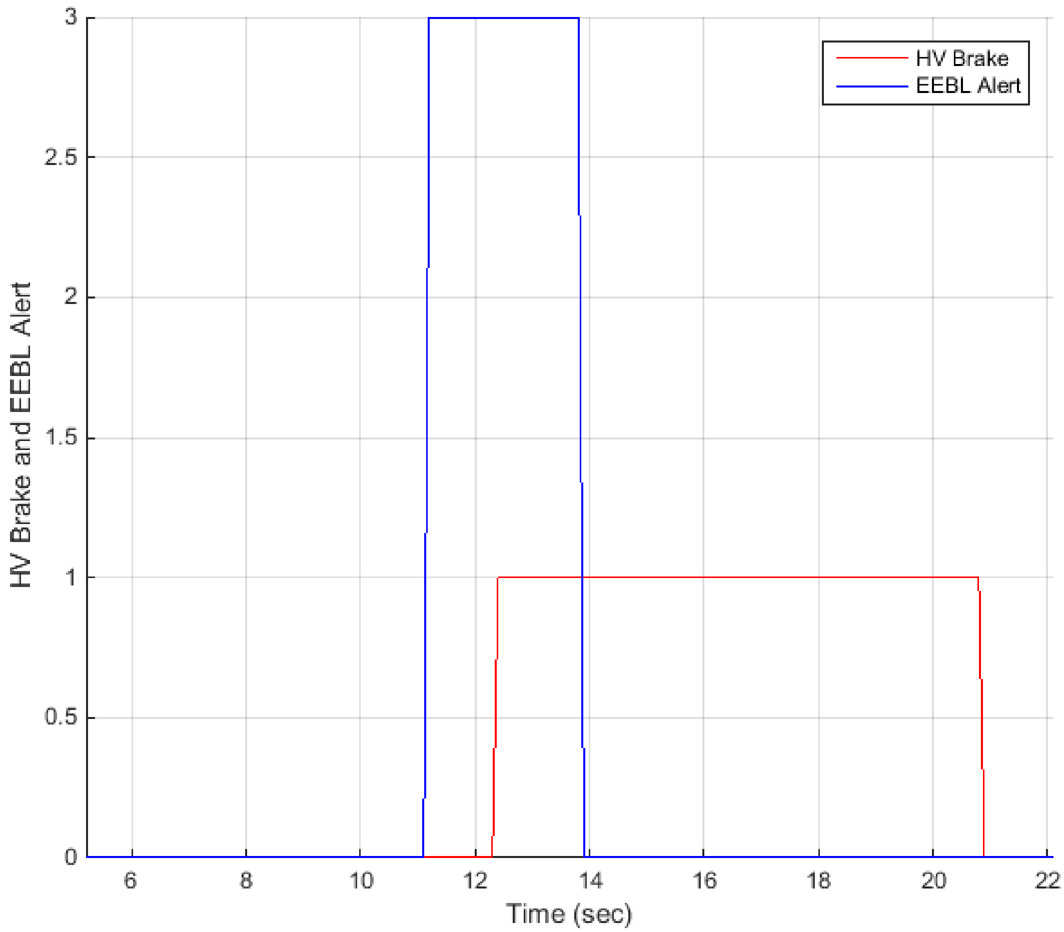


Figure 20: Example HV Brake and EEBL Alert Traces for an EEBL-7 Test

Table 18: EEBL-7 Time Delay Between HV Brake Onset and EEBL Alert Offset

Trial	Time Delay (sec)
1	1.2
2	0.8
3	1.4
4	1.1
5	0.8

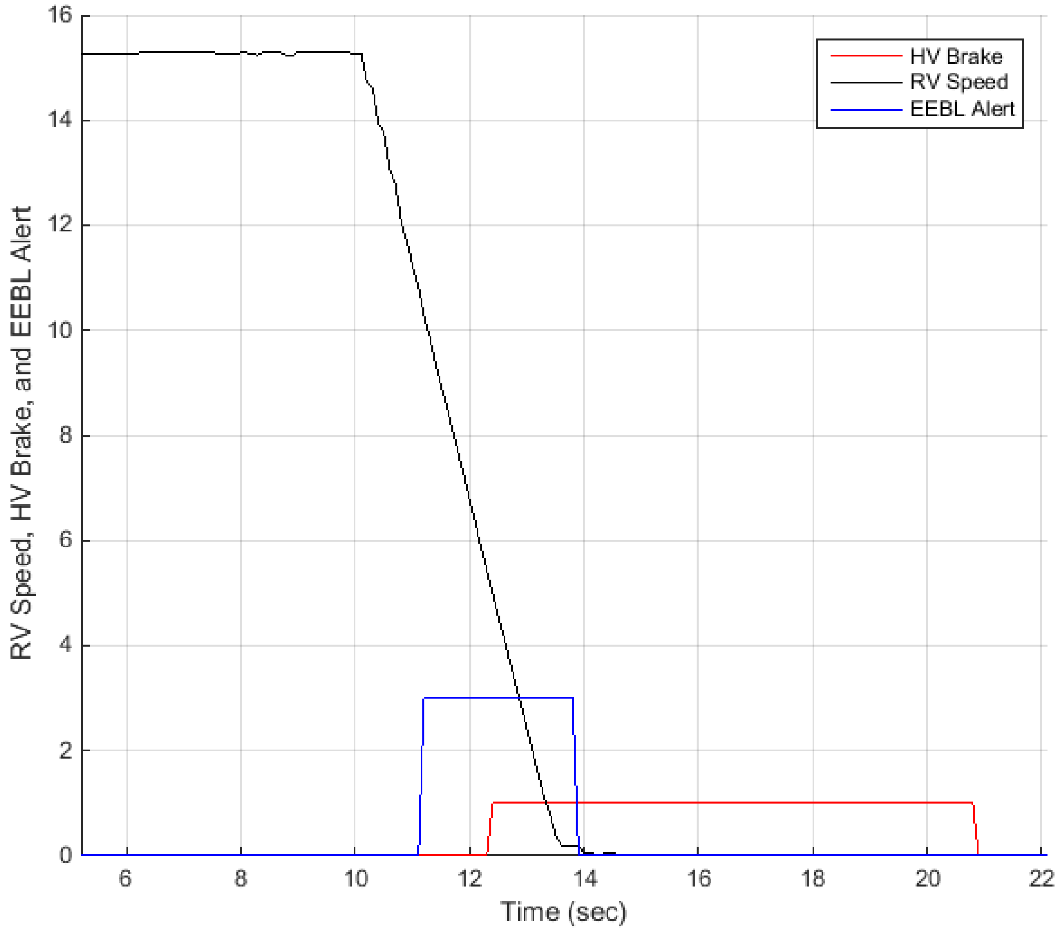


Figure 21: Example RV Speed, HV Brake, and EEBL Alert Traces for an EEBL-7 Test

4.8 EEBL-8: Slow Moving HV

For the EEBL-8 test procedure, two vehicles travel along a straight roadway in the same lane of travel and in the same direction. Initially, the vehicles travel at the same velocity with the leading (RV) and trailing (HV) vehicles within V2V system communication range. The driver of the RV then makes a hard brake application to initiate the broadcast of the hard braking Event flag in the RV BSM. The driver of the HV, unaware that the leading vehicle is braking, maintains the initial velocity until the EEBL alert is presented, at which point the HV driver switches lanes to avoid the lead vehicle. The primary measure of interest is at what speed does the RV V2V broadcast an hard braking event flag and when does the HV V2V system alert the driver. On successive runs, the initial speed of the HV and RV are ramped up from a low value until the speeds are high enough to achieve a hard braking event flag from the RV and the display of the EEBL alert on the HV V2V system. Details for this test procedure can be found in Appendix A, Section A.15.

Just one HV/RV combination was evaluated for the EEBL-8 test procedure. For these tests the HV was the red Cascadia and the RV was the Honda Odyssey. This vehicle combination is listed in Table 19.

Table 19: EEBL-8 HV and RV Vehicle/Trailer Combinations Evaluated

HV	HV Trailer	RV
Red Cascadia	Bobtail	Odyssey

Tests were conducted at speeds starting at 10 mph and ranging up to 28.5 mph. The RV speed prior to RV braking is listed in Table 20 for each test. The table also lists whether or not the RV deceleration was above 0.4 g, the RV issued a hard braking event flag, and whether an EEBL alert was issued. For the slow speed tests (up to 19 mph), the RV deceleration was less than 0.4 g, but for speeds greater than 25 mph the RV deceleration was above the EEBL alert threshold of 0.4 g. The RV started to issue hard braking event flags at 26.8 mph. The HV always issued the EEBL alert if the hard braking event flag was issued. The highest speed without a hard braking event flag was 25.3 mph, so the speed at which the RV broadcasts a hard braking event is somewhere between 25.3 and 26.6 mph.

Table 20: EEBL-8 RV Speed Prior to Braking and EEBL Alert

RV Speed Prior to Braking (mph)	RV Decel > 0.4 g?	Hard Brake Event Flag?	EEBL Alert?
9.6	No	No	No
13.8	No	No	No
17.8	No	No	No
25.3	Yes	No	No
28.1	Yes	Yes	Yes
26.6	Yes	Yes	Yes
24.5	Yes	No	No
26.8	Yes	Yes	Yes

5 Conclusions and Recommendations

A series of EEBL test procedures were developed and evaluated using the class 8 trucks from the Model Deployment study. In general the prototype V2V equipment was observed to be capable of tracking potential EEBL threats, but had some issues when vehicles were on a curved roadway. The V2V equipment on these trucks did not issue Hard Braking event flags and were not able to suppress EEBL alerts when the driver applied corrective action under the conditions tested.

For the tests conducted on a curved roadway, the V2V system's error in the estimate of the lateral distance between vehicles for certain scenarios resulted in the generation of a few false FCW alerts and incorrect EEBL alerts. The false FCW alerts were generated in tests where the vehicles were not in the same lane. Both incorrect in-lane and out-of-lane EEBL alerts occurred (in-lane alerts when vehicles were not in-lane with each other and vice versa).

The V2V equipment on the trucks from the Model Deployment study was not observed to broadcast the hard braking event flag in the basic safety message and therefore the EEBL-2: Reversed Role test could not be evaluated with these vehicles.

The V2V equipment did not suppress EEBL alerts when the HV brakes were applied in the EEBL-7: HV Brakes upon EEBL Alert test.

References

1. LeBlanc, D., Bogard, S., and Gilbert, M. (2014, January 31). *Connected commercial vehicles—Integrated Truck Project: Vehicle build test report* (Report Number FHWA-JPO-13-104). Washington, DC: Federal Highway Administration. Available at http://ntl.bts.gov/lib/51000/51700/51751/104.pdf

2. Stephens, D., Pape, D., LeBlanc, D., Bogard, S., Peredo, G., Berg, R., & Wells, B. (2014, January). *Connected commercial vehicles—Integrated Truck project driver clinics, performance tests, and lessons learned* (Report No. FHWA-JPO-13-112). Washington, DC: Federal Highway Administration. Available at http://ntl.bts.gov/lib/51000/51700/51726/13-112.pdf

3. Howe, G., Xu, G., Hoover, R., Elsasser, D., & Barickman, F. (in press). *Commercial connected-vehicle test procedure development and test results – Forward collision warning*. Washington, DC: National Highway Traffic Safety Administration.

Appendix A - EEBL 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 EEBL 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] Forward Collision Warning System Confirmation Test, Washington, DC : National Highway Traffic Safety Administration, Office of Vehicle Safety, Office of Crash Avoidance Standards, February 2013

[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). None the OBE packages tested provided a means to directly control the operation of the vehicle. The driver remained in command of the vehicle operations at all times.

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. The ISS provides auditory, visual, or haptic feedback (alerts and warnings) to the driver.

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. The RSD provides auditory or visual feedback (alerts and warnings) to the driver.

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. The ASD provides auditory or visual feedback (alerts and warnings) to the driver.

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. 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 both 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.7 Test Facility

For EEBL tests, the test facility is a straight, flat, and level roadway which includes three adjacent driving lanes 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. The only exceptions to this are the curved road EEBL tests where the roadway is curved instead of straight. The length of the roadway will be sufficient to allow the HV's driver to establish and maintain a specified speed before the HV enters the test course and to allow the HV to stop or safely exit the course after passing the RV. The length of the test course is at least greater than the maximum EEBL alert range.

All of the curved roadway tests will be performed in the berm lanes in the South Loop of the Vehicle Dynamics Area (VDA) at the Transportation Research Center Inc. The berm is two lanes wide and has minimal banking especially in comparison to the two main driving lanes.

A survey of the VDA south loop was performed and the distances between points A-I shown in Figure A-1 were measured. It was determined that the best area to conduct the test maneuvers with curved roads is between points C and F. The points A through C designate the area where the vehicles are brought up to speed and proper orientation/spacing for the various curved road tests conducted. If the RV is a parked vehicle, then it is positioned between points D and E. The points F to G is used as an area for the vehicles to slow down/ stop.

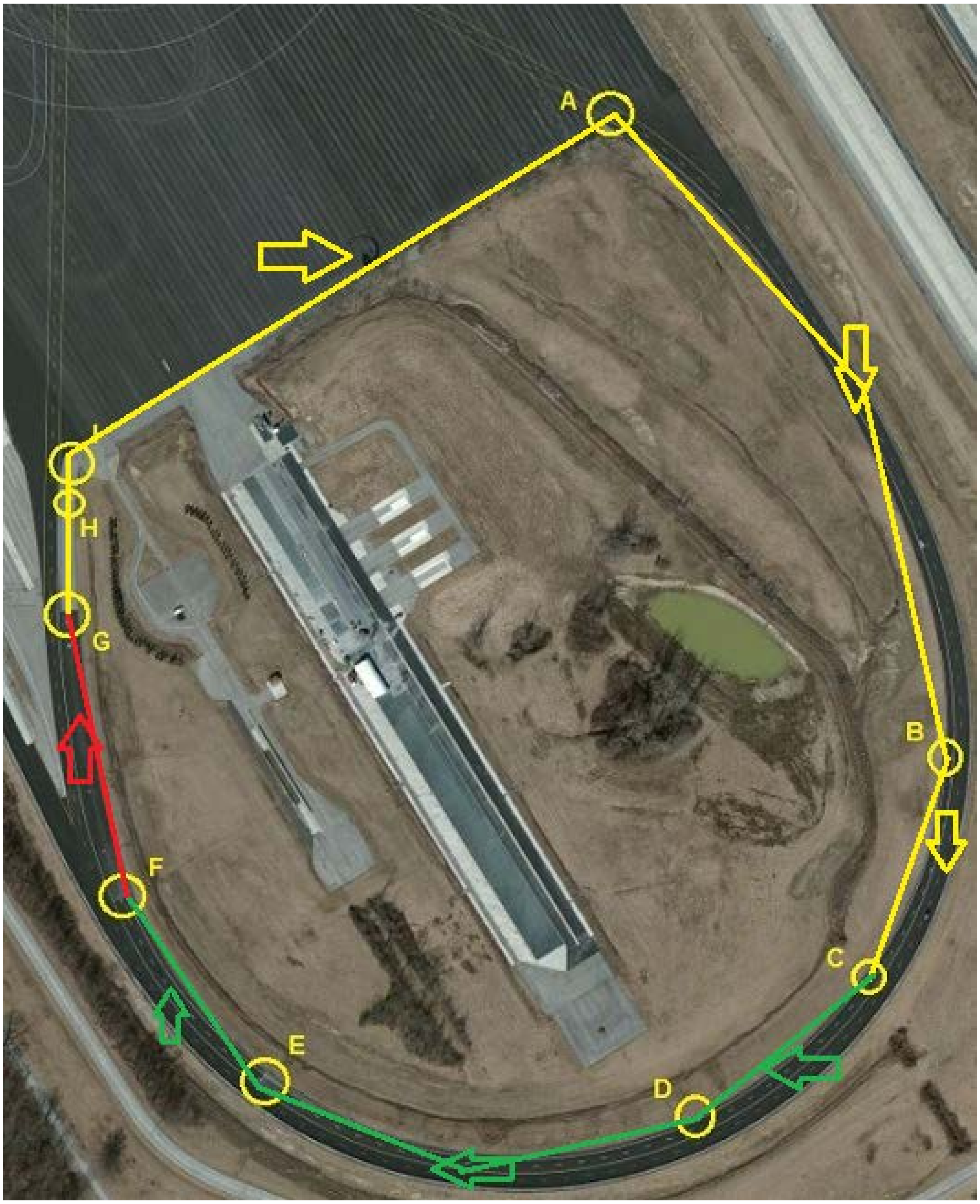


Figure A-1: Curved Road Testing on South Loop Berms Lanes of the Vehicle Dynamics Area at the Transportation Research Center Inc.

A.8 EEBL-1 - Hidden Braking Vehicle Ahead in Same Lane, Straight Road

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

A.8.1 Pre-Crash Scenario

Three vehicles travel along a straight roadway in the same lane of travel and in the same direction. The trailing vehicle is a commercial truck equipped with a V2V system that features an EEBL application. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The leading vehicle's V2V system also broadcasts a hard braking event flag if its driver makes a hard brake application.

An intermediate vehicle travels between the leading and trailing vehicles. It blocks the view of the leading vehicle from the driver of the trailing vehicle, and it might interfere with V2V system radio communication between the other vehicles. Initially, the three vehicles travel at the same velocity with the leading and trailing vehicles within V2V system communication range. The driver of the leading vehicle then makes a hard brake application while the driver of the trailing vehicle, unaware that the leading vehicle is braking, maintains the initial velocity.

A.8.2 Test Subject and Purpose

The subject of this test is the V2V-based collision warning system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to receive the decelerating lead vehicle's EEBL broadcast, identify the leading vehicle as a collision threat, and inform the trailing vehicle's driver of the threat in a timely manner.

A.8.3 Initial Condition

A.8.3.1 Test Velocities

A test velocity is specified for each trial or set of trials. The velocity of the HV and RV1 is equal to the specified velocity until a trial end condition occurs. The velocity of RV2 is equal to the specified velocity until braking is initiated. A minimum test velocity may be specified above which RV2's OBE will broadcast RV2's location, velocity, direction of travel, and hard braking event flags, and above which the HV's ISS or RSD 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 EEBL alerts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.8.3.2 Headways

Initial headways between RV2 and RV1, and between RV1 and the HV, are specified for each trial or set of trials. The specified headways are such that the HV is within EEBL alert activation range of RV2 during the course of each trial; and such that at the end of each trial RV1 is able to avoid RV2 and the HV is able to avoid RV1. The headway may be specified as a distance between the rear of a vehicle and the front of the following vehicle, or as an interval of time from when the rear of one vehicle clears a reference point to when the front of the following vehicle attains the same point. A headway error tolerance is also specified.

A.8.4 Specifications

A.8.4.1 Steady-State Time Interval

A steady-state time interval is specified for each trial or set of trials. The steady-state time interval begins when the drivers of the RVs and the HV have established the specified test velocity and headways. At the end of the interval, RV2 is decelerated as specified.

A.8.4.2 RV Deceleration Profile

At a specified point in the procedure, RV2 is decelerated by applying its service brakes. Deceleration specifications are determined for each trial or set of trials and may include the target deceleration rate, the time interval from the initiation of brake application to the target deceleration rate, an acceptable target deceleration rate error magnitude, and an acceptable magnitude and maximum duration of an overshoot of the target deceleration rate.

A.8.5 Metric

A.8.5.1 Timeliness and Duration of Alert Presentation

An EEBL alert must be presented to the HV driver within a specified period of time after RV2's V2V system broadcasts a hard braking event flag. If the HV's V2V system provides two EEBL alert levels, the alert presented must be the high-level alert. Once the alert is presented to the driver, it must persist for a specified duration.

A.8.6 Execution of Procedure

Because application of the HV's service brakes will typically suppress EEBL alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the end of each trial. If unsafe conditions or events are encountered during any trial, the HV and RV drivers should abort the trial and brake and/or control their vehicles as needed for safety.

Each trial begins when the RVs and the HV have attained the specified test velocity and headways. There may be a variety of methods for establishing these initial conditions. Steps 1 through 3 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 4 through 7 comprise the specified procedure.

The test procedure is depicted in Figure A-2 and Figure A-3.

1. The two RVs and the HV are staged in the primary test lane at one end of the straight road test facility. The HV is staged behind RV1 which is staged behind RV2 and all vehicles are oriented to travel toward the opposite end of the test facility. It is recommended that the three vehicles be staged in positions relative to each other which reflect the specified headways.
2. The experimenter arms the HV's data acquisition system and directs the all drivers to begin driving.
3. The drivers begin driving to establish the specified test velocity and headways.
4. The drivers maintain the specified test velocity and headways for the duration of the specified steady-state interval.

5. At the end of the steady-state interval, the driver of RV2 applies the service brakes to decelerate RV2 as specified while the drivers of the HV and RV1 maintain the specified test velocity.
6. When the headway between RV1 and RV2 falls to less than 90 percent of the specified headway for RV1 and RV2, the trial ends.
7. After the end of the trial, RV1 changes lanes to the right and passes RV2, and the HV changes lanes to the left and passes RV2.

A.8.7 Trial Validity

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

1. The HV's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the required EEBL alert or before the headway between RV1 and RV2 falls to less than 90 percent of the specified headway.
2. RV2's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the initiation of braking.
3. The HV's service brakes were not applied prior to the required EEBL alert or before the headway between RV1 and RV2 falls to less than 90 percent of the specified headway.
4. The lateral distance between the centerlines of the three vehicles did not exceed 2.0 feet.
5. The yaw rates of the HV and RV2 did not exceed ±1 degree/second.
6. The deceleration of RV2 conformed to the specified deceleration profile.
7. Deviations in headways do not exceed the specified error tolerance at two instants during the procedures. The two instants are 1) three seconds prior to initiation of RV2 braking; and 2) at the instant of initiation of RV2 braking.

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.8.8 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful only if both of the following responses occur:

1. The HV OBE initiates a high-level EEBL alert within the specified period of time after RV2's V2V system broadcasts a hard braking event flag, and
2. The alert persists for a specified duration.

A trial is unsuccessful if either or both responses fail to occur.

Each test series is comprised of a specified quantity of consecutive trials. An EEBL system passes if, within each series, a specified percentage of the specified quantity of consecutive trials is successful.

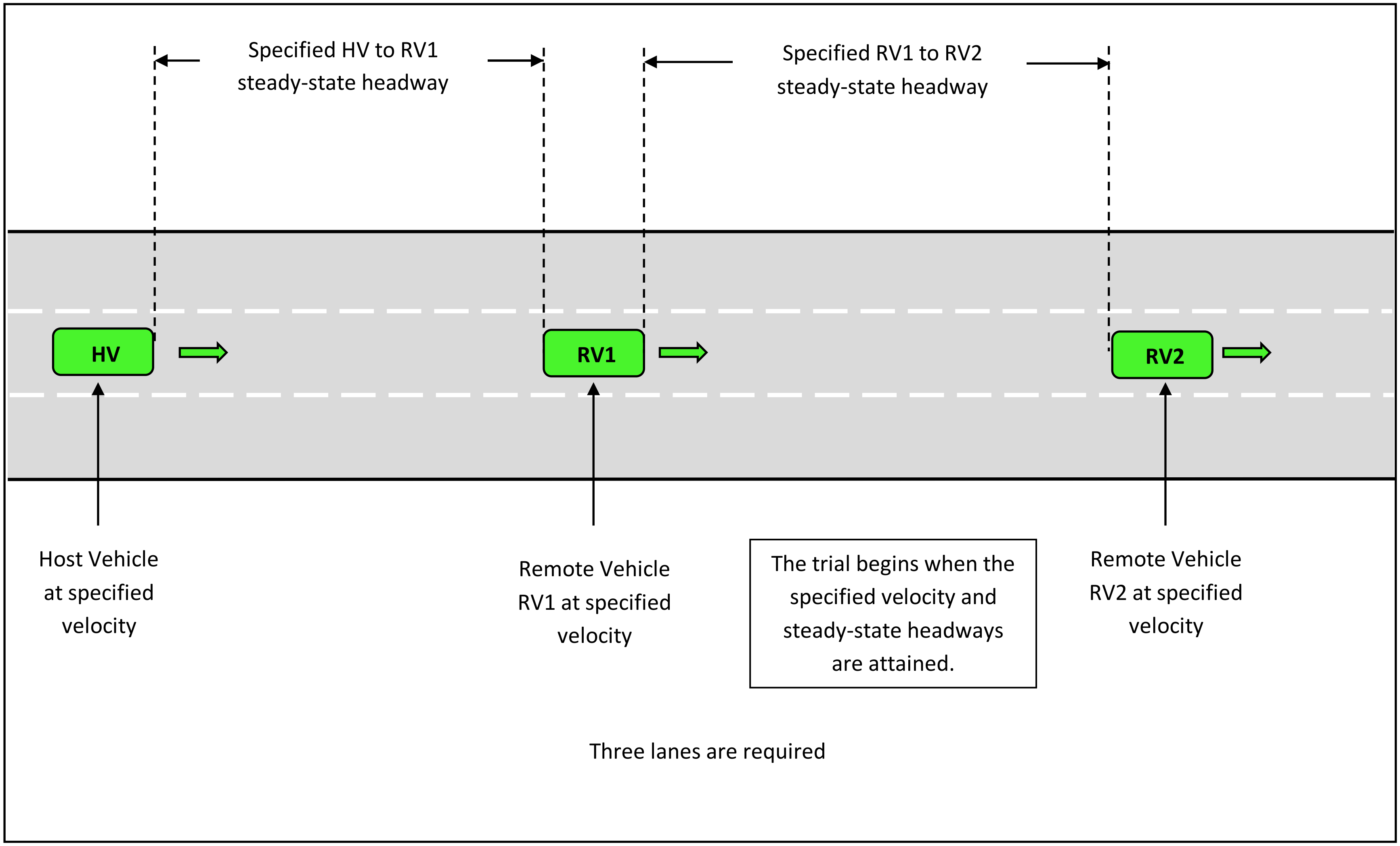


Figure A-2 - EEBL-1 Test Course Graphic, Initial Conditions (not to scale)

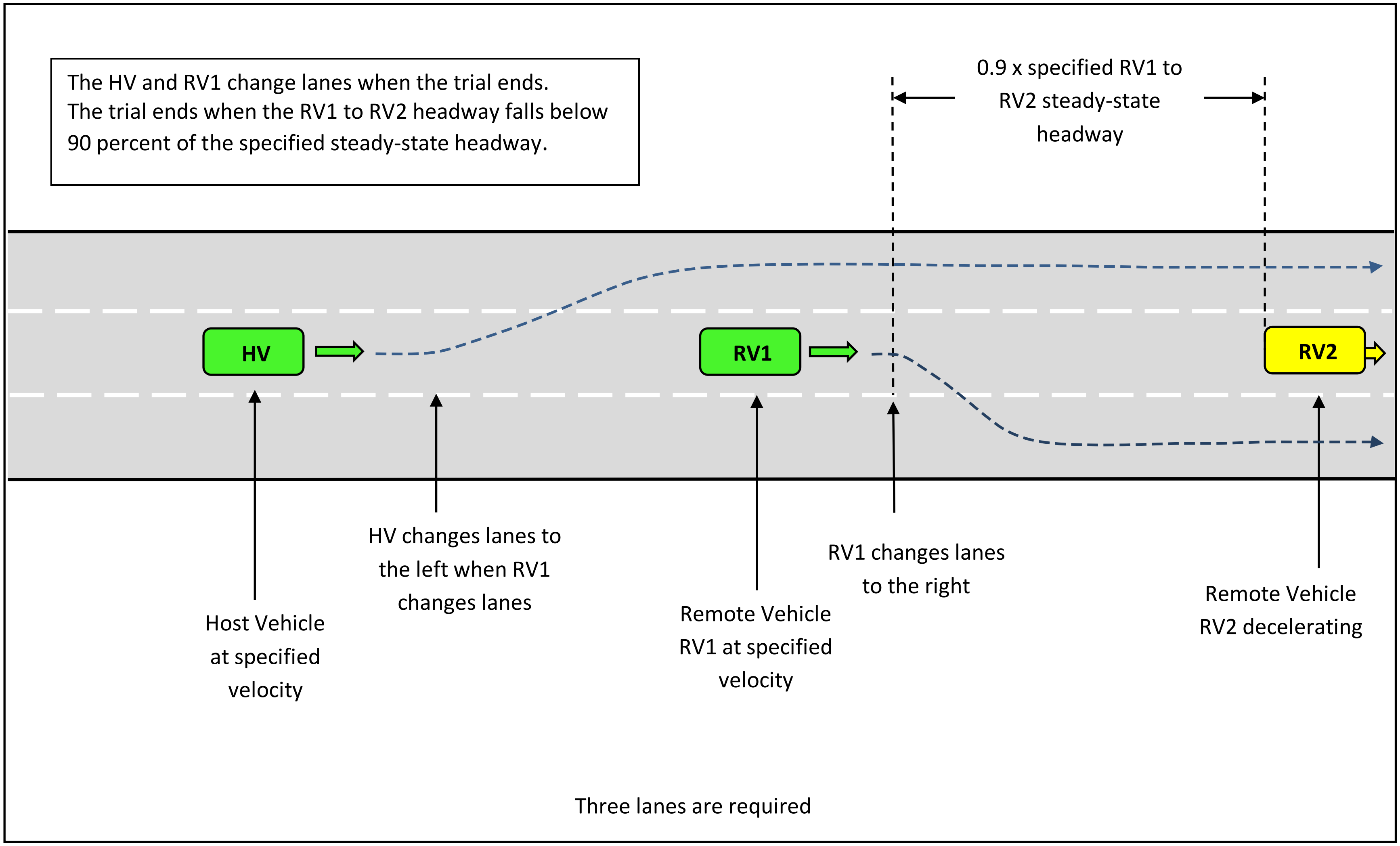


Figure A-3 - EEBL-1 Test Course Graphic, End of Trial (not to scale)

A.9 EEBL-2 - Reverse Roles, Hidden Braking Vehicle Ahead in Same Lane, Straight Road

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific EEBL pre-crash scenario. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to alert drivers of impending collisions with other V2V-equipped vehicles. Specifically, the EEBL-2 procedure is used to confirm the ability of on-board V2V equipment to broadcast hard braking event flags to other V2V-equipped vehicles. The procedure reverses the roles of the host vehicle (HV) and the leading remote vehicle (RV2) of the EEBL-1 procedure.

A.9.1 Pre-Crash Scenario

Three vehicles travel along a straight roadway in the same lane of travel and in the same direction. The leading vehicle is a commercial truck equipped with a V2V system that broadcasts the truck's position, speed, direction of travel, and path history. The truck's V2V system also broadcasts a hard braking event flag if its driver makes a hard brake application. The trailing vehicle is a vehicle equipped with a V2V system that features an EEBL application.

An intermediate vehicle travels between the leading and trailing vehicles. It blocks the view of the leading vehicle from the driver of the trailing vehicle, and it might interfere with V2V system radio communication between the other vehicles. Initially, the three vehicles travel at the same velocity with the leading and trailing vehicles within V2V system communication range. The driver of the leading vehicle then makes a hard brake application while the driver of the trailing vehicle, unaware that the leading vehicle is braking, maintains the initial velocity.

A.9.2 Test Subject and Purpose

The subject of this test is the V2V-based collision warning system of the leading vehicle. The test determines the ability of the leading vehicle's system to broadcast hard braking event flags, which in turn would allow the V2V systems of following vehicles to identify the leading vehicle as a collision threat and inform the drivers of the other vehicles of the threat in a timely manner.

A.9.3 Initial Condition

A.9.3.1 Test Velocities

A test velocity is specified for each trial or set of trials. The velocity of RV1 and RV2 is equal to the specified velocity until a trial end condition occurs. The velocity of the HV 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, direction of travel, and hard braking event flags, and above which RV2'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 hard braking event flag broadcasts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.9.3.2 Headways

Initial headways between RV2 and RV1, and between RV1 and the HV, are specified for each trial or set of trials. The specified headways are such that RV2 is within hard braking event flag broadcast range of the HV during the course of each trial; and such that at the end of each trial RV1 is able to avoid the HV and RV2 is able to avoid RV1. The headway may be specified as a distance between the rear of a vehicle and the front of the following vehicle, or as an interval of time from when the rear of one vehicle clears a reference point to when the front of the following vehicle attains the same point. A headway error tolerance is also specified.

A.9.4 Specifications

A.9.4.1 Steady-State Time Interval

A steady-state time interval is specified for each trial or set of trials. The steady-state time interval begins when the drivers of the RVs and the HV have established the specified test velocity and headways. At the end of the interval, the HV is decelerated as specified.

A.9.4.2 RV Deceleration Profile

At a specified point in the procedure, the HV is decelerated by applying its service brakes. Deceleration specifications are determined for each trial or set of trials and may include the target deceleration rate, the time interval from the initiation of brake application to the target deceleration rate, an acceptable target deceleration rate error tolerance, and an acceptable magnitude and maximum duration of an overshoot of the target deceleration rate.

A.9.5 Metric

A.9.5.1 Timeliness and Duration of Hard Braking Event Flag Broadcast From the HV's OBE

The HV's OBE (ISS or RSD) must initiate the broadcast of a hard braking event flag within a specified period of time after the deceleration rate of the HV rises above a specified magnitude and the event broadcast must persist while the deceleration rate magnitude remains above the specified magnitude.

A.9.5.2 Timeliness and Duration of Alert Presentation at RV2's DVI

An EEBL alert must be presented to the driver of RV2 within a specified period of time after the HV's V2V system broadcasts a hard braking event flag. If RV2's V2V system provides two EEBL alert levels, the alert presented must be the high-level alert. Once the alert is presented to the driver, it must persist for a specified duration.

A.9.6 Execution of Procedure

Because application of the RV2's service brakes will typically suppress EEBL alerts, RV2's driver should refrain from applying RV2's brakes during the trial. The driver may apply the brakes after the end of each trial. If unsafe conditions or events are encountered during any trial, the HV and RV drivers should abort the trial and brake and/or control their vehicles as needed for safety.

Each trial begins when the RVs and the HV have attained the specified test velocity and headways. There may be a variety of methods for establishing these initial conditions. Steps 1 through 3 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 4 through 7 comprise the specified procedure.

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

1. The two RVs and the HV are staged in the primary test lane at one end of the straight road test facility. The HV is staged ahead of RV1 which is staged ahead of RV2 and all vehicles are oriented to travel toward the opposite end of the test facility. It is recommended that the three vehicles be staged in positions relative to each other which reflect the specified headways.
2. The experimenter arms the HV's data acquisition system and directs the all drivers to begin driving.
3. The drivers begin driving to establish the specified test velocity and headways.
4. The drivers maintain the specified test velocity and headways for the duration of the specified steady-state interval.
5. At the end of the steady-state interval, the driver of the HV applies the service brakes to decelerate the HV as specified while the drivers of RV1 and RV2 maintain the specified test velocity.
6. When the headway between RV1 and the HV falls to less than 90 percent of the specified headway for RV1 and the HV, the trial ends.
7. After the end of the trial, RV1 changes lanes to the right and passes the HV, and RV2 changes lanes to the left and passes the HV.

A.9.7 Trial Validity

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

1. RV2's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the required EEBL alert or before the headway between RV1 and the HV falls to less than 90 percent of the specified headway.
2. The HV's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the initiation of braking.
3. RV2's service brakes were not applied prior to the required EEBL alert or before the headway between RV1 and the HV falls to less than 90 percent of the specified headway.
4. The lateral distance between the longitudinal centerlines of the three vehicles did not exceed 2.0 feet.
5. The yaw rates of the HV and RV2 did not exceed ±1 degree/second.
6. The deceleration of the HV conformed to the specified deceleration profile.
7. Deviations in headways do not exceed the specified error tolerance at two instants during the procedures. The two instants are 1) three seconds prior to initiation of HV braking; and 2) at the instant of initiation of HV braking.

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.9.8 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

Working draft note: If the timeliness and duration of hard braking event flag broadcast from the HV's OBE metric is used, the following applies.

A trial is successful only if both of the following responses occur:

1. The HV's OBE broadcasts a hard braking event flag within a specified period of time after the deceleration rate of the HV rises above a specified magnitude, and
2. The event broadcast must persist while the deceleration rate magnitude remains above the specified magnitude.

A trial is unsuccessful if either or both responses fail to occur.

Each test series is comprised of a specified quantity of consecutive trials. An EEBL system passes if, within each series, a specified percentage of the specified quantity of consecutive trials is successful.

Working draft note: If the timeliness and duration of alert presentation at RV2's DVI metric is used, the following applies.

A trial is successful only if both of the following responses occur:

3. RV2's OBE initiates a high-level EEBL alert within the specified period of time after the HV's V2V system broadcasts a hard braking event flag, and
4. The alert persists for a specified duration.

A trial is unsuccessful if either or both responses fail to occur.

Each test series is comprised of a specified quantity of consecutive trials. An EEBL system passes if, within each series, a specified percentage of the specified quantity of consecutive trials is successful.

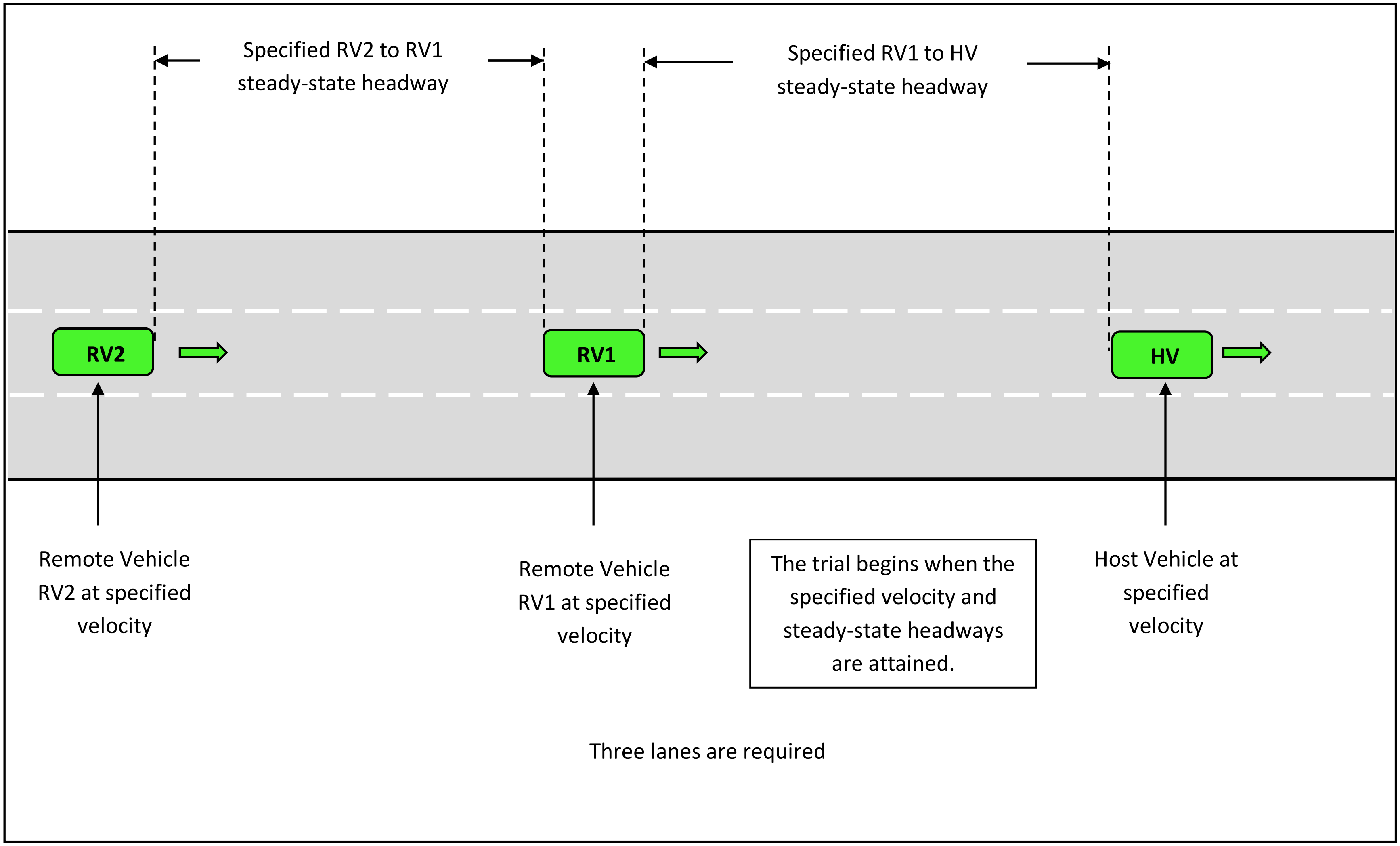


Figure A-4 - EEBL-2 Test Course Graphic, Initial Conditions (not to scale)

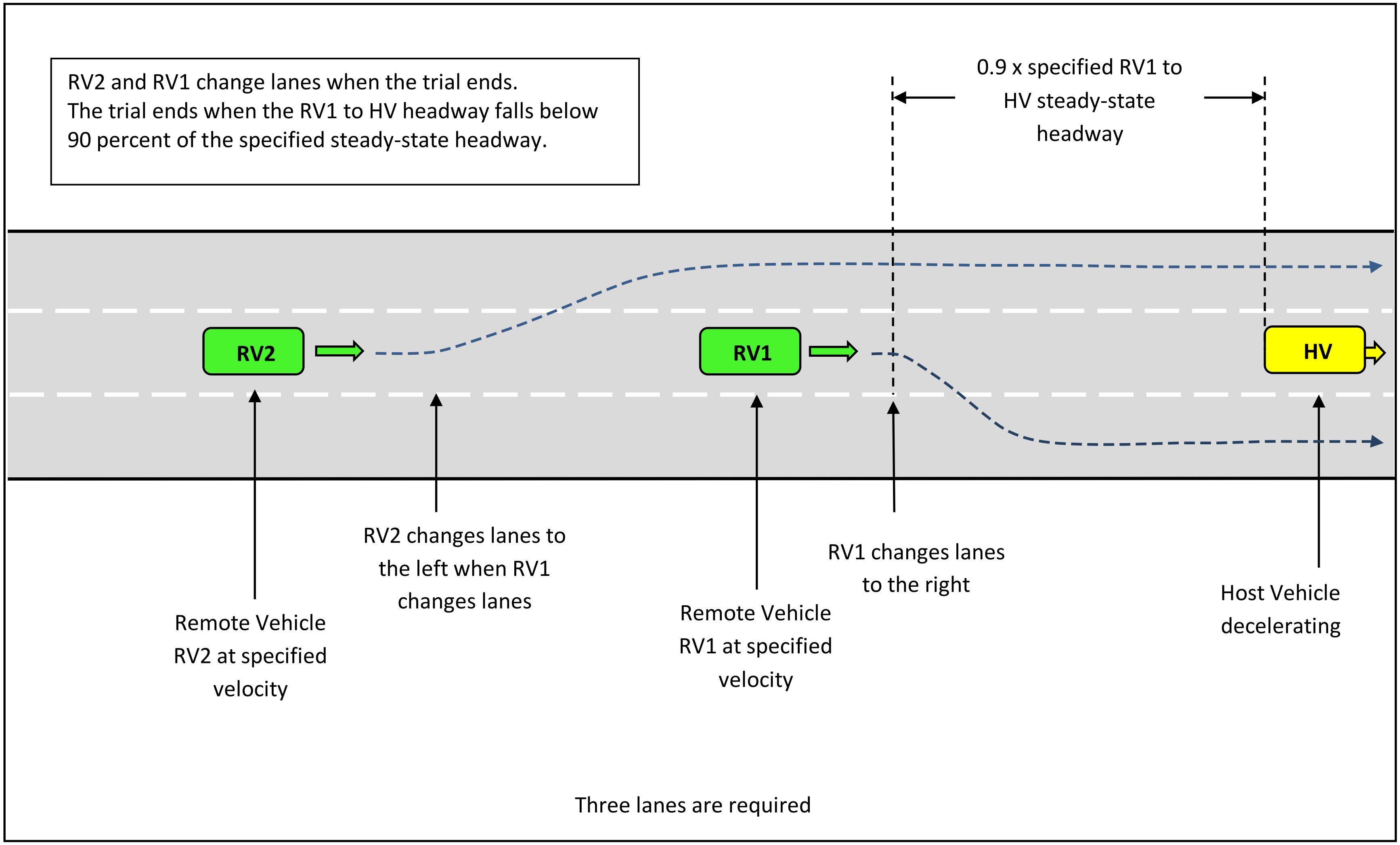


Figure A-5 - EEBL-2 Test Course Graphic, End of Trial (not to scale)

A.10 EEBL-3 - Mildly Braking Vehicle Ahead in Same Lane, Straight Road

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific EEBL pre-crash scenario wherein no alert is warranted. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to suppress alerts when presented with this scenario.

A.10.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The trailing vehicle is a commercial truck equipped with a V2V system that features an EEBL application. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The leading vehicle's V2V system also broadcasts a hard braking event flag if its driver makes a hard brake application.

Initially, the two vehicles travel at the same velocity with the leading and trailing vehicles within V2V system communication range. The driver of the leading vehicle then makes a mild brake application while the driver of the trailing vehicle maintains the initial velocity.

A.10.2 Test Subject and Purpose

The subject of this test is the V2V-based collision warning system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to receive the decelerating lead vehicle's EEBL broadcast, identify the threat level presented by the leading vehicle based on the leading vehicle's magnitude of deceleration, and, if the deceleration magnitude is below a threshold level, suppress EEBL alerts.

A.10.3 Initial Condition

A.10.3.1 Test Velocities

A test velocity is specified for each trial or set of trials. The velocity of the HV is equal to the specified velocity until a trial end condition occurs. 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 RV's OBE will broadcast the RV's location, velocity, direction of travel, and hard braking event flags, and above which the HV's ISS or RSD would issue an alert in scenarios where an alert is expected. A single, standard test velocity—not necessarily a minimum velocity—may be specified. A range of test velocities may be specified to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.10.3.2 Headways

Initial headway between the RV and the HV, is specified for each trial or set of trials. The specified headway is such that the HV is within EEBL alert activation range of the RV during the course of each trial; and such that at the end of each trial the HV is able to avoid the RV. The headway may be specified as a distance between the rear of the RV and the front of the HV, or as an interval of time from when the rear of the RV clears a reference point to when the front of the HV attains the same point. A headway error tolerance is also specified.

A.10.4 Specifications

A.10.4.1 Steady-State Time Interval

A steady-state time interval is specified for each trial or set of trials. The steady-state time interval begins when the drivers of the RV and the HV have established the specified test velocity and headways. At the end of the interval, the RV is decelerated as specified.

A.10.4.2 RV Deceleration Profile

At a specified point in the procedure, the RV is decelerated by applying its service brakes. Deceleration specifications are determined for each trial or set of trials and include the target deceleration rate, the time interval from the initiation of brake application to the target deceleration rate, an acceptable target deceleration rate error tolerance, and an acceptable magnitude and maximum duration of an overshoot of the target deceleration rate. The maximum deceleration is lower in magnitude that the EEBL threshold magnitude.

A.10.5 Metric

A.10.5.1 Driver-Vehicle Interface Response

The metric for test procedures with scenarios in which an alert is not expected is the response of the HV's V2V system DVI including the response of any visual alert interface and any auditory alert interface.

A.10.6 Execution of Procedure

Because application of the HV's service brakes will typically suppress EEBL alerts, the HV driver should refrain from applying the HV's brakes during the trial. Although an alert is not expected during the execution of the CCV EEBL-3 test procedure, it is important to avoid confounding test trials by inadvertently suppressing any false alerts via brake application or other means. The driver may apply the brakes after the HV passes the RV. If unexpected events are encountered during any trial, the HV driver should brake and/or control the HV as needed for safety and abort the trial.

Each trial begins when the RV and the HV have attained the specified test velocity and headway. There may be a variety of methods for establishing these initial conditions. Steps 1 through 3 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 4 through 7 comprise the specified procedure.

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

1. The RV and the HV are staged in the primary test lane at one end of the straight road test facility. The HV is staged behind the RV and the vehicles are oriented to travel toward the opposite end of the test facility. It is recommended that the vehicles be staged in positions relative to each other which reflect the specified headways.
2. The experimenter arms the HV's data acquisition system and directs the drivers to begin driving.
3. The drivers begin driving to establish the specified test velocity and headways.
4. The drivers maintain the specified test velocity and headways for the duration of the specified steady-state interval.

5. At the end of the steady-state interval, the driver of the RV applies the service brakes to decelerate the RV as specified while the driver of the HV maintains the specified test velocity.
6. When the headway between the HV and the RV falls to less than 90 percent of the specified headway, the trial ends.
7. After the end of the trial, the HV changes lanes and passes the RV.

A.10.7 Trial Validity

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

1. The HV's velocity did not deviate from the specified velocity by more than 1.0 mph during the steady-state time interval and before the headway between the HV and the RV falls to less than 90 percent of the specified headway.
2. The RV's velocity did not deviate from the specified velocity by more than 1.0 mph during the steady-state time interval.
3. The HV's service brakes were not applied during the steady-state time interval and before the headway between the HV and the RV falls to less than 90 percent of the specified headway.
4. The lateral distance between the centerlines of the vehicles did not exceed 2.0 feet.
5. The yaw rates of the HV and RV2 did not exceed ±1 degree/second.
6. The deceleration of the RV conformed to the specified deceleration profile.
7. Deviations in the headway did not exceed the specified error tolerance at two instants during the procedure. The two instants are 1) three seconds prior to initiation of RV braking; and 2) at the instant of initiation of RV braking.

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.10.8 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful if the HV OBE issues no alerts. A trial is unsuccessful if the HV OBE issues any alert.

Each test series is comprised of a specified quantity of consecutive trials. An EEBL system passes if, within each series, a specified percentage of the specified quantity of consecutive trials is successful.

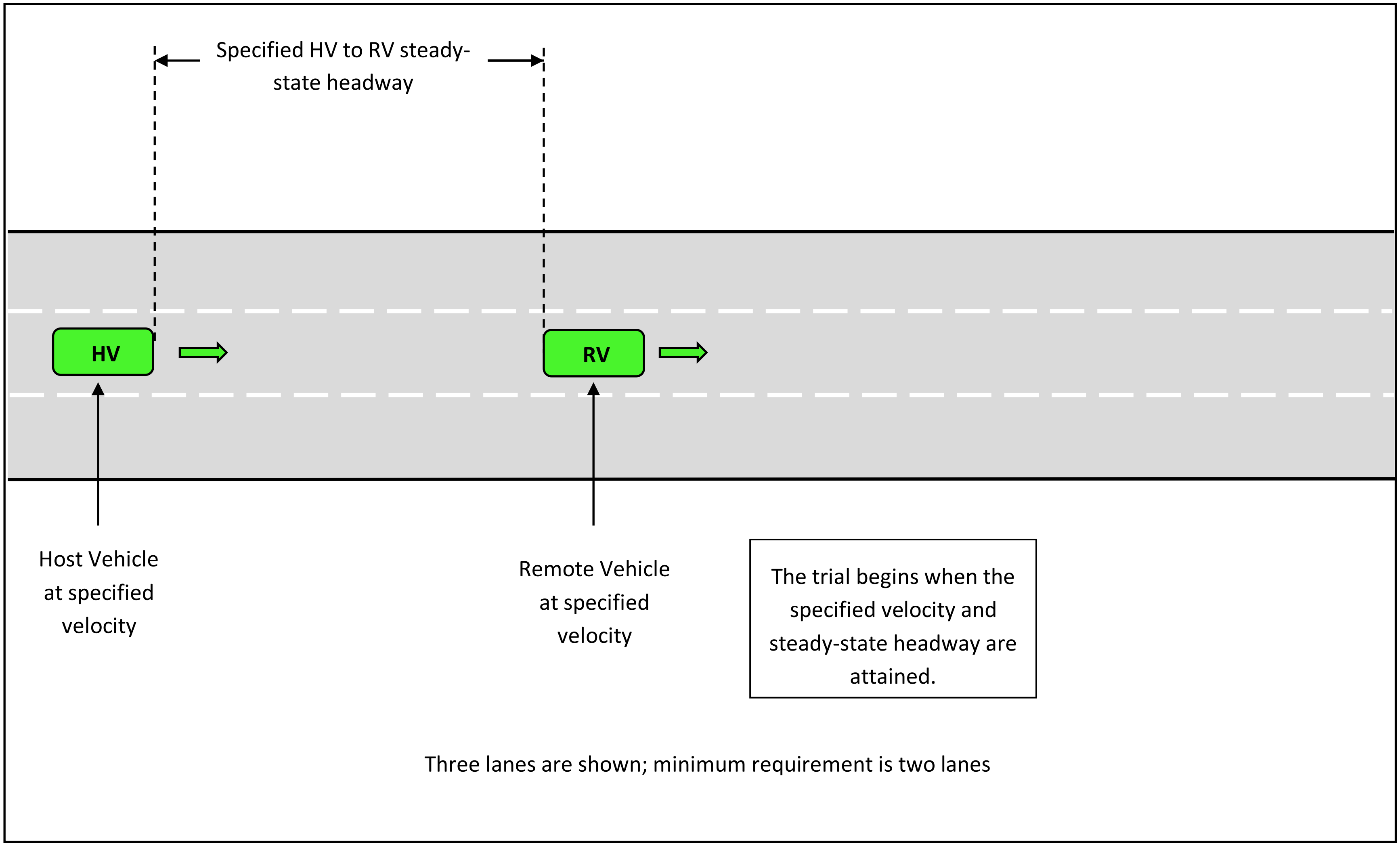


Figure A-6 - EEBL-3 Test Course Graphic, Initial Conditions (not to scale)

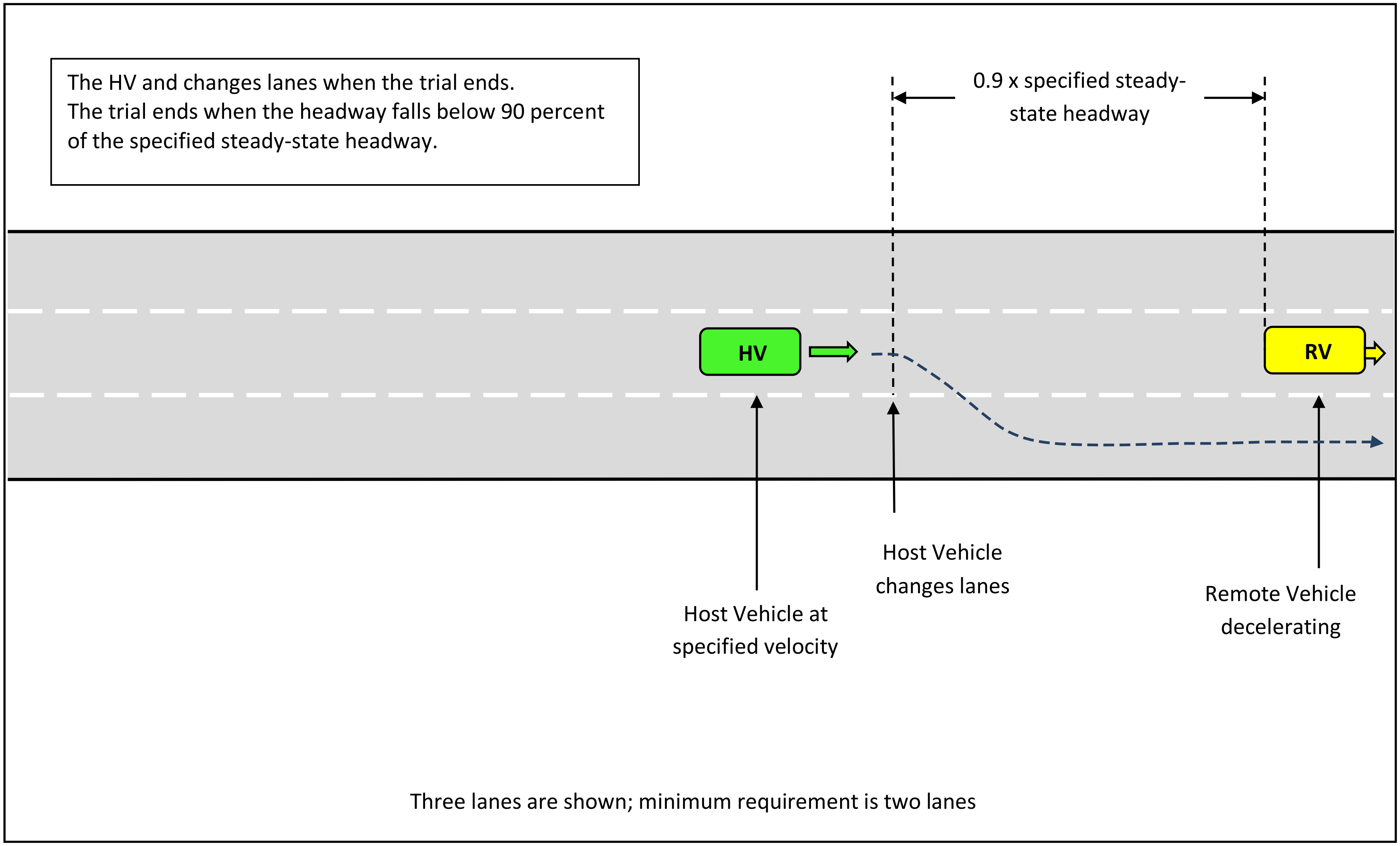


Figure A-7 - EEBL-3 Test Course Graphic, End of Trial (not to scale)

A.11 EEBL-4 – Braking Vehicle Ahead in Adjacent Lane, Straight Road

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

A.11.1 Pre-Crash Scenario

Three vehicles travel along a straight roadway in the same direction. The lead vehicle is in a lane adjacent to the lane the intermediate and trailing vehicle are traveling in. The trailing vehicle is a commercial truck equipped with a V2V system that features an EEBL application. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The leading vehicle's V2V system also broadcasts a hard braking event flag if its driver makes a hard brake application.

An intermediate vehicle travels between the leading and trailing vehicles. It blocks (or partially obstructs) the view of the leading vehicle from the driver of the trailing vehicle, and it might interfere with V2V system radio communication between the other vehicles. Initially, the three vehicles travel at the same velocity with the leading and trailing vehicles within V2V system communication range. The driver of the leading vehicle then makes a hard brake application while the driver of the trailing vehicle, unaware that the leading vehicle is braking, maintains the initial velocity.

A.11.2 Test Subject and Purpose

The subject of this test is the V2V-based collision warning system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to receive the decelerating lead vehicle's EEBL broadcast, identify the leading vehicle as a collision threat, and inform the trailing vehicle's driver of the threat in a timely manner. The EEBL broadcast should result in a Level 2 Warning, letting the trailing vehicle driver know there is an aggressively braking vehicle in an adjacent lane.

A.11.3 Initial Condition

A.11.3.1 Test Velocities

A test velocity is specified for each trial or set of trials. The velocity of the HV and RV1 is equal to the specified velocity until a trial end condition occurs. The velocity of RV2 is equal to the specified velocity until braking is initiated. A minimum test velocity may be specified above which RV2's OBE will broadcast RV2's location, velocity, direction of travel, and hard braking event flags, and above which the HV's ISS or RSD 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 EEBL alerts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.11.3.2 Headways

Initial headways between RV2 and RV1, and between RV1 and the HV, are specified for each trial or set of trials. The specified headways are such that the HV is within EEBL alert activation range of RV2 during the course of each trial; and such that at the end of each trial RV1 is able to avoid RV2 and the HV is able to avoid RV1. The headway may be specified as a distance between the rear of a vehicle and the front of the following vehicle, or as an interval of time from when the rear of one vehicle clears a reference point to when the front of the following vehicle attains the same point. A headway error tolerance is also specified.

A.11.4 Specifications

A.11.4.1 Steady-State Time Interval

A steady-state time interval is specified for each trial or set of trials. The steady-state time interval begins when the drivers of the RVs and the HV have established the specified test velocity and headways. At the end of the interval, RV2 is decelerated as specified.

A.11.4.2 RV Deceleration Profile

At a specified point in the procedure, RV2 is decelerated by applying its service brakes. Deceleration specifications are determined for each trial or set of trials and may include the target deceleration rate, the time interval from the initiation of brake application to the target deceleration rate, an acceptable target deceleration rate error tolerance, and an acceptable magnitude and maximum duration of an overshoot of the target deceleration rate.

A.11.5 Metric

A.11.5.1 Timeliness and Duration of Alert Presentation

An EEBL alert must be presented to the HV driver within a specified period of time after RV2's V2V system broadcasts a hard braking event flag. If the HV's V2V system provides two EEBL alert levels, the alert presented must be the lower-level alert. Once the alert is presented to the driver, it must persist for a specified duration.

A.11.6 Execution of Procedure

Because application of the HV's service brakes will typically suppress EEBL alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the end of each trial. If unsafe conditions or events are encountered during any trial, the HV and RV drivers should abort the trial and brake and/or control their vehicles as needed for safety.

Each trial begins when the RVs and the HV have attained the specified test velocity and headways. There may be a variety of methods for establishing these initial conditions. Steps 1 through 3 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 4 through 7 comprise the specified procedure.

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

1. The HV and RV1 are staged in the primary test lane and RV2 is staged in an adjacent lane at one end of the straight road test facility. The HV is staged behind RV1 which is staged behind RV2 and all vehicles are oriented to travel toward the opposite end of the test facility. It is recommended that the three vehicles be staged in positions relative to each other which reflect the specified headways.
2. The experimenter arms the HV's data acquisition system and directs the all drivers to begin driving.
3. The drivers begin driving to establish the specified test velocity and headways.
4. The drivers maintain the specified test velocity and headways for the duration of the specified steady-state interval.
5. At the end of the steady-state interval, the driver of RV2 applies the service brakes to decelerate RV2 as specified while the drivers of the HV and RV1 maintain the specified test velocity.
6. The trial ends when an EEBL alert is presented in the HV. If no EEBL alert is presented, the trial ends when the headway between RV1 and RV2 falls to less than 90 percent of the specified headway for RV1 and RV2, the trial ends.
7. After the end of the trial, RV1 and the HV maintain their current lane and pass RV2 which maintains the adjacent lane.

A.11.7 Trial Validity

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

1. The HV's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the required EEBL alert or before the headway between RV1 and RV2 falls to less than 90 percent of the specified headway.
2. RV2's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the initiation of braking.
3. The HV's service brakes were not applied prior to the required EEBL alert or before the headway between RV1 and RV2 falls to less than 90 percent of the specified headway.
4. The lateral distance between the centerlines of the HV and RV1 did not exceed 2.0 feet and RV2 maintains the center of the adjacent lane within ±1 foot.
5. The yaw rates of the HV and RV2 did not exceed ±1 degree/second.
6. The deceleration of RV2 conformed to the specified deceleration profile.
7. Deviations in headways do not exceed the specified error tolerance at two instants during the procedures. The two instants are 1) three seconds prior to initiation of RV2 braking; and 2) at the instant of initiation of RV2 braking.

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.11.8 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful only if both of the following responses occur:

1. The HV OBE initiates a low-level EEBL alert within the specified period of time after RV2's V2V system broadcasts a hard braking event flag, and
2. The alert persists for a specified duration.

A trial is unsuccessful if either or both responses fail to occur.

Each test series is comprised of a specified quantity of consecutive trials. An EEBL system passes if, within each series, a specified percentage of the specified quantity of consecutive trials is successful.

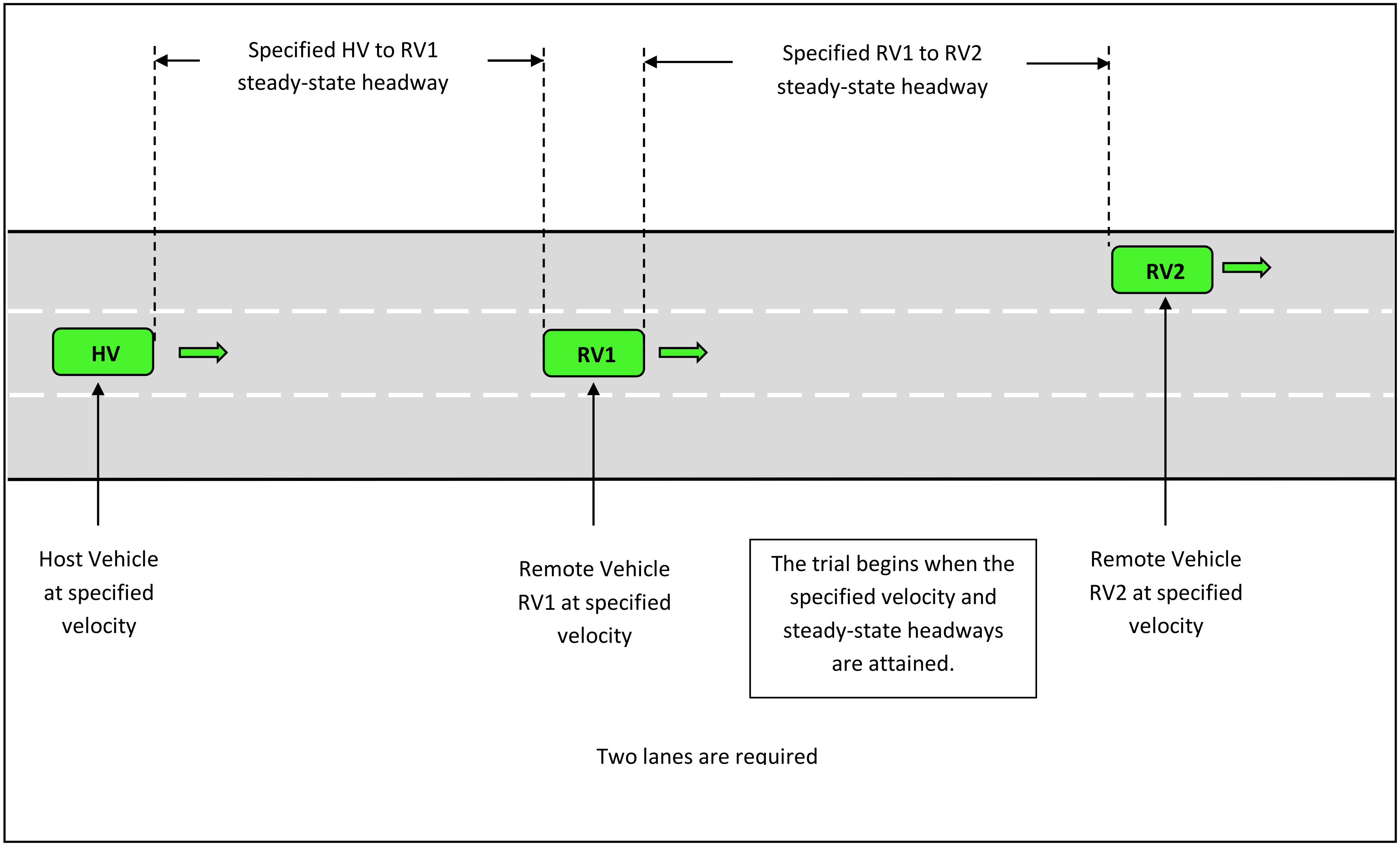


Figure A-8 - EEBL-4 Test Course Graphic, Initial Conditions (not to scale)

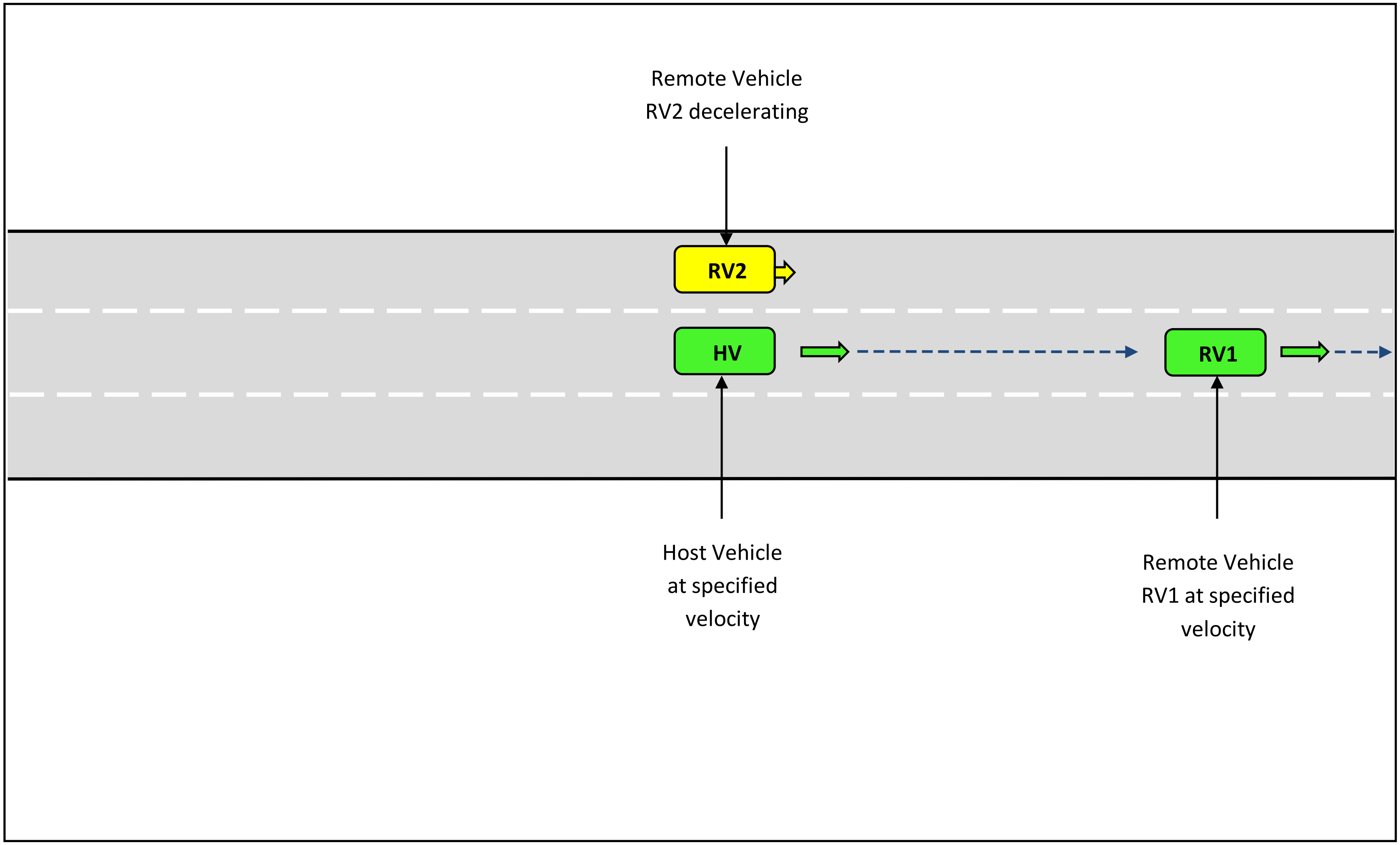


Figure A-9 - EEBL-4 Test Course Graphic, End of Trial (not to scale)

A.12 EEBL-5 – Braking Vehicle Ahead in Same Lane, Curved Road

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

A.12.1 Pre-Crash Scenario

Three vehicles travel along a curved roadway in the same lane of travel and in the same direction. The trailing vehicle is a commercial truck equipped with a V2V system that features an EEBL application. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The leading vehicle's V2V system also broadcasts a hard braking event flag if its driver makes a hard brake application.

An intermediate vehicle travels between the leading and trailing vehicles. It blocks the view of the leading vehicle from the driver of the trailing vehicle, and it might interfere with V2V system radio communication between the other vehicles. Initially, the three vehicles travel at the same velocity with the leading and trailing vehicles within V2V system communication range. The driver of the leading vehicle then makes a hard brake application while the driver of the trailing vehicle, unaware that the leading vehicle is braking, maintains the initial velocity.

A.12.2 Test Subject and Purpose

The subject of this test is the V2V-based collision warning system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to receive the decelerating lead vehicle's EEBL broadcast, identify the leading vehicle as a collision threat, and inform the trailing vehicle's driver of the threat in a timely manner.

A.12.3 Initial Condition

A.12.3.1 Test Velocities

A test velocity is specified for each trial or set of trials. The velocity of the HV and RV1 is equal to the specified velocity until a trial end condition occurs. The velocity of RV2 is equal to the specified velocity until braking is initiated. A minimum test velocity may be specified above which RV2's OBE will broadcast RV2's location, velocity, direction of travel, and hard braking event flags, and above which the HV's ISS or RSD 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 EEBL alerts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.12.3.2 Headways

Initial headways between RV2 and RV1, and between RV1 and the HV, are specified for each trial or set of trials. The specified headways are such that the HV is within EEBL alert activation range of RV2 during the course of each trial; and such that at the end of each trial RV1 is able to avoid RV2 and the HV is able to avoid RV1. The headway may be specified as a distance between the rear of a vehicle and the front of the following vehicle, or as an interval of time from when the rear of one vehicle clears a reference point to when the front of the following vehicle attains the same point. A headway error tolerance is also specified.

A.12.4 Specifications

A.12.4.1 Steady-State Time Interval

A steady-state time interval is specified for each trial or set of trials. The steady-state time interval begins when the drivers of the RVs and the HV have established the specified test velocity and headways. At the end of the interval, RV2 is decelerated as specified.

A.12.4.2 RV Deceleration Profile

At a specified point in the procedure, RV2 is decelerated by applying its service brakes. Deceleration specifications are determined for each trial or set of trials and may include the target deceleration rate, the time interval from the initiation of brake application to the target deceleration rate, an acceptable target deceleration rate error tolerance, and an acceptable magnitude and maximum duration of an overshoot of the target deceleration rate.

A.12.5 Metric

A.12.5.1 Timeliness and Duration of Alert Presentation

An EEBL alert must be presented to the HV driver within a specified period of time after RV2's V2V system broadcasts a hard braking event flag. If the HV's V2V system provides two EEBL alert levels, the alert presented must be the high-level alert. Once the alert is presented to the driver, it must persist for a specified duration.

A.12.6 Execution of Procedure

Because application of the HV's service brakes will typically suppress EEBL alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the end of each trial. If unsafe conditions or events are encountered during any trial, the HV and RV drivers should abort the trial and brake and/or control their vehicles as needed for safety.

Each trial begins when the RVs and the HV have attained the specified test velocity and headways. There may be a variety of methods for establishing these initial conditions. Steps 1 through 3 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 4 through 7 comprise the specified procedure.

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

1. The two RVs and the HV are staged to enter the curved road test facility. The HV is staged behind RV1 which is staged behind RV2 and all vehicles are oriented to travel toward the curved road test facility. It is recommended that the three vehicles be staged in positions relative to each other which reflect the specified headways.
2. The experimenter arms the HV's data acquisition system and directs the all drivers to begin driving.
3. The drivers begin driving to establish the specified test velocity and headways.

4. The drivers maintain the specified test velocity and headways for the duration of the specified steady-state interval.
5. At the end of the steady-state interval, the driver of RV2 applies the service brakes to decelerate RV2 as specified while the drivers of the HV and RV1 maintain the specified test velocity.
6. When the headway between RV1 and RV2 falls to less than 90 percent of the specified headway for RV1 and RV2, the trial ends.
7. After the end of the trial, RV1 and HV change lanes to the right and pass RV2.

A.12.7 Trial Validity

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

1. The HV's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the required EEBL alert or before the headway between RV1 and RV2 falls to less than 90 percent of the specified headway.
2. RV2's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the initiation of braking.
3. The HV's service brakes were not applied prior to the required EEBL alert or before the headway between RV1 and RV2 falls to less than 90 percent of the specified headway.
4. The three vehicles maintain the center of the curve road lane within ±1 feet.
5. The deceleration of RV2 conformed to the specified deceleration profile.
6. Deviations in headways do not exceed the specified error tolerance at two instants during the procedures. The two instants are 1) three seconds prior to initiation of RV2 braking; and 2) at the instant of initiation of RV2 braking.

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.12.8 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful only if both of the following responses occur:

1. The HV OBE initiates a high-level EEBL alert within the specified period of time after RV2's V2V system broadcasts a hard braking event flag, and
2. The alert persists for a specified duration.

A trial is unsuccessful if either or both responses fail to occur.

Each test series is comprised of a specified quantity of consecutive trials. An EEBL system passes if, within each series, a specified percentage of the specified quantity of consecutive trials is successful.

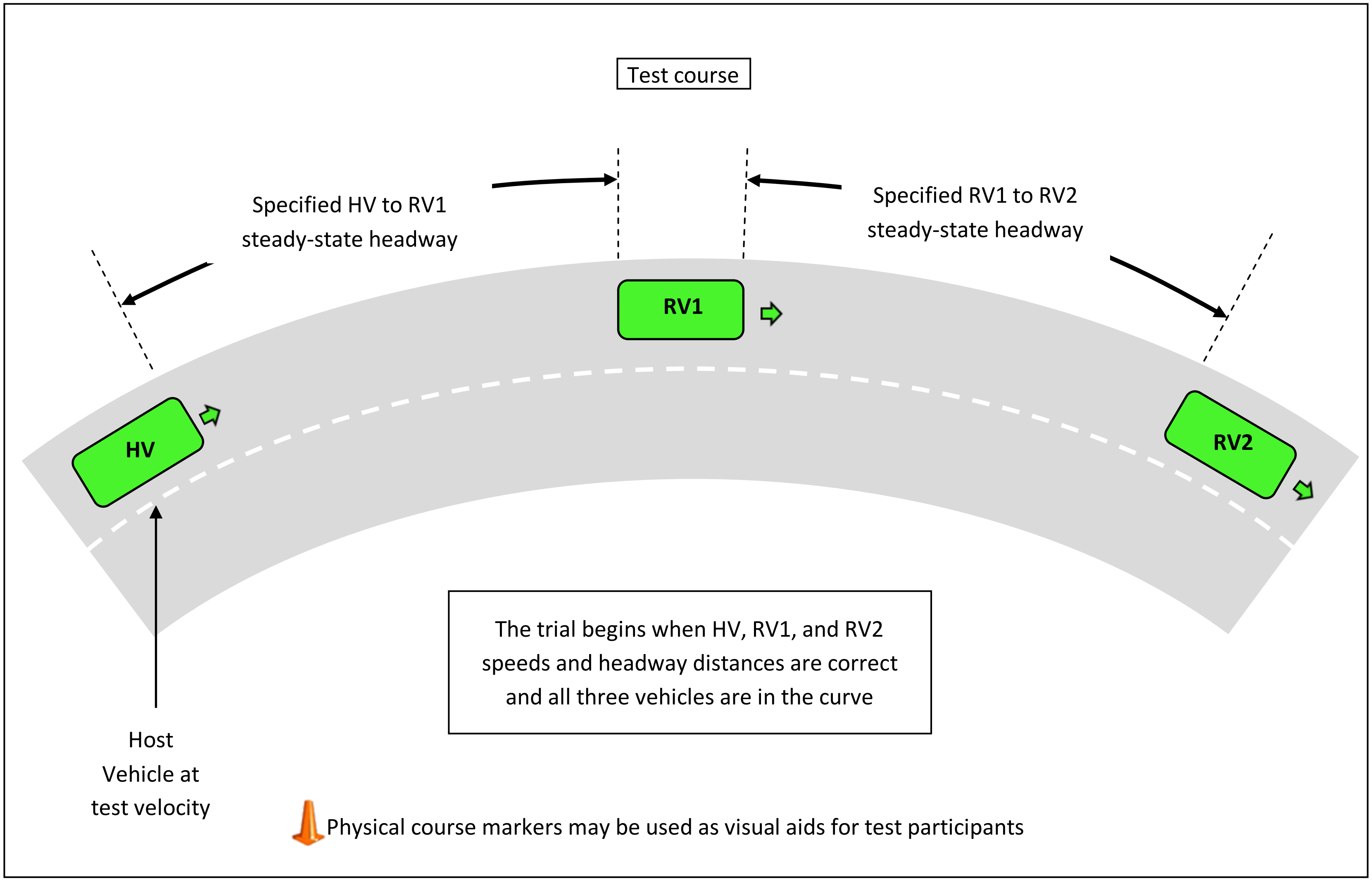


Figure A-10 - EEBL-5 Test Course Graphic, Initial Conditions (not to scale)

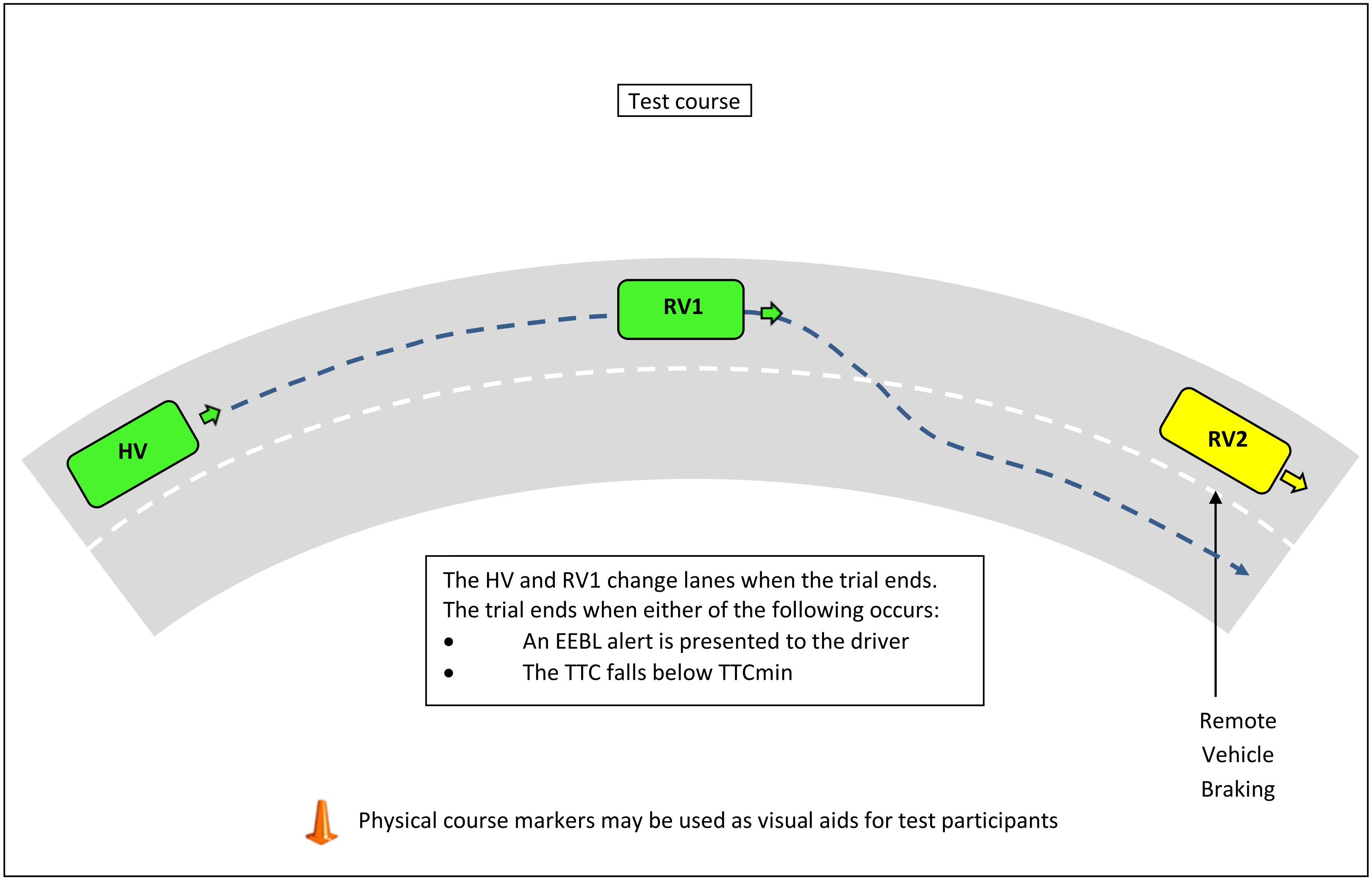


Figure A-11 - EEBL-5 Test Course Graphic, End of Trial (not to scale)

A.13 EEBL-6 - Braking Vehicle Ahead in Outside Adjacent Lane, Curved Road

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

A.13.1 Pre-Crash Scenario

Three vehicles travel along a curved roadway in the same direction. The lead vehicle is in a lane adjacent to the lane the intermediate and trailing vehicle are traveling in. The trailing vehicle is a commercial truck equipped with a V2V system that features an EEBL application. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The leading vehicle's V2V system also broadcasts a hard braking event flag if its driver makes a hard brake application.

An intermediate vehicle travels between the leading and trailing vehicles. It blocks (or partially obstructs) the view of the leading vehicle from the driver of the trailing vehicle, and it might interfere with V2V system radio communication between the other vehicles. Initially, the three vehicles travel at the same velocity with the leading and trailing vehicles within V2V system communication range. The driver of the leading vehicle then makes a hard brake application while the driver of the trailing vehicle, unaware that the leading vehicle is braking, maintains the initial velocity.

A.13.2 Test Subject and Purpose

The subject of this test is the V2V-based collision warning system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to receive the decelerating lead vehicle's EEBL broadcast, identify the leading vehicle as a collision threat, and inform the trailing vehicle's driver of the threat in a timely manner. The EEBL broadcast should result in a Level 2 Warning, letting the trailing vehicle driver know there is an aggressively braking vehicle in an adjacent lane.

A.13.3 Initial Condition

A.13.3.1 Test Velocities

A test velocity is specified for each trial or set of trials. The velocity of the HV and RV1 is equal to the specified velocity until a trial end condition occurs. The velocity of RV2 is equal to the specified velocity until braking is initiated. A minimum test velocity may be specified above which RV2's OBE will broadcast RV2's location, velocity, direction of travel, and hard braking event flags, and above which the HV's ISS or RSD 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 EEBL alerts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.13.3.2 Headways

Initial headways between RV2 and RV1, and between RV1 and the HV, are specified for each trial or set of trials. The specified headways are such that the HV is within EEBL alert activation range of RV2 during the course of each trial; and such that at the end of each trial RV1 is able to avoid RV2 and the HV is able to avoid RV1. The headway may be specified as a distance between the rear of a vehicle and the front of the following vehicle, or as an interval of time from when the rear of one vehicle clears a reference point to when the front of the following vehicle attains the same point. A headway error tolerance is also specified.

A.13.4 Specifications

A.13.4.1 Steady-State Time Interval

A steady-state time interval is specified for each trial or set of trials. The steady-state time interval begins when the drivers of the RVs and the HV have established the specified test velocity and headways. At the end of the interval, RV2 is decelerated as specified.

A.13.4.2 RV Deceleration Profile

At a specified point in the procedure, RV2 is decelerated by applying its service brakes. Deceleration specifications are determined for each trial or set of trials and may include the target deceleration rate, the time interval from the initiation of brake application to the target deceleration rate, an acceptable target deceleration rate error tolerance, and an acceptable magnitude and maximum duration of an overshoot of the target deceleration rate.

A.13.5 Metric

A.13.5.1 Timeliness and Duration of Alert Presentation

An EEBL alert must be presented to the HV driver within a specified period of time after RV2's V2V system broadcasts a hard braking event flag. If the HV's V2V system provides two EEBL alert levels, the alert presented must be the lower-level alert. Once the alert is presented to the driver, it must persist for a specified duration.

A.13.6 Execution of Procedure

Because application of the HV's service brakes will typically suppress EEBL alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the end of each trial. If unsafe conditions or events are encountered during any trial, the HV and RV drivers should abort the trial and brake and/or control their vehicles as needed for safety.

Each trial begins when the RVs and the HV have attained the specified test velocity and headways. There may be a variety of methods for establishing these initial conditions. Steps 1 through 3 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 4 through 7 comprise the specified procedure.

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

1. The HV and RV1 are staged in the primary test lane and RV2 is staged in an adjacent lane at one end of the straight road test facility. The HV is staged behind RV1 which is staged behind RV2 and all vehicles are oriented to travel toward the opposite end of the test facility. It is recommended that the three vehicles be staged in positions relative to each other which reflect the specified headways.
2. The experimenter arms the HV's data acquisition system and directs the all drivers to begin driving.
3. The drivers begin driving to establish the specified test velocity and headways.
4. The drivers maintain the specified test velocity and headways for the duration of the specified steady-state interval.
5. At the end of the steady-state interval, the driver of RV2 applies the service brakes to decelerate RV2 as specified while the drivers of the HV and RV1 maintain the specified test velocity.
6. The trial ends when an EEBL alert is presented in the HV. If no EEBL alert is presented, the trial ends when the headway between RV1 and RV2 falls to less than 90 percent of the specified headway for RV1 and RV2, the trial ends.
7. After the end of the trial, RV1 and the HV maintain their current lane and pass RV2 which maintains the adjacent lane.

A.13.7 Trial Validity

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

1. The HV's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the required EEBL alert or before the headway between RV1 and RV2 falls to less than 90 percent of the specified headway.
2. RV2's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the initiation of braking.
3. The HV's service brakes were not applied prior to the required EEBL alert or before the headway between RV1 and RV2 falls to less than 90 percent of the specified headway.
4. The three vehicles maintain the center of the assigned curve road lane within ±1 feet.
5. The deceleration of RV2 conformed to the specified deceleration profile.
6. Deviations in headways do not exceed the specified error tolerance at two instants during the procedures. The two instants are 1) three seconds prior to initiation of RV2 braking; and 2) at the instant of initiation of RV2 braking.

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.13.8 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful only if both of the following responses occur:

1. The HV OBE initiates a low-level EEBL alert within the specified period of time after RV2's V2V system broadcasts a hard braking event flag, and
2. The alert persists for a specified duration.

A trial is unsuccessful if either or both responses fail to occur.

Each test series is comprised of a specified quantity of consecutive trials. An EEBL system passes if, within each series, a specified percentage of the specified quantity of consecutive trials is successful.

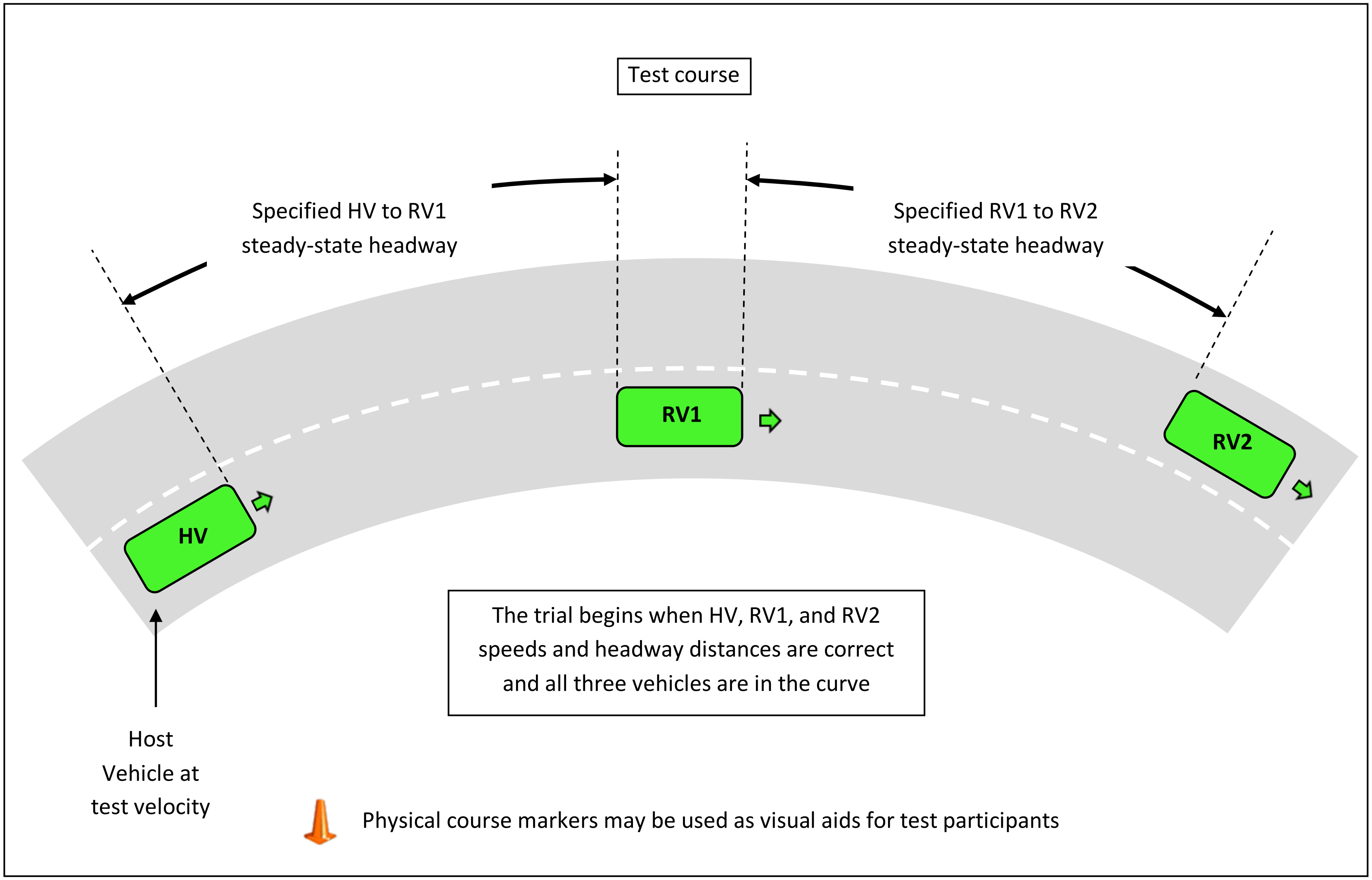


Figure A-12 - EEBL-6 Test Course Graphic, Initial Conditions (not to scale)

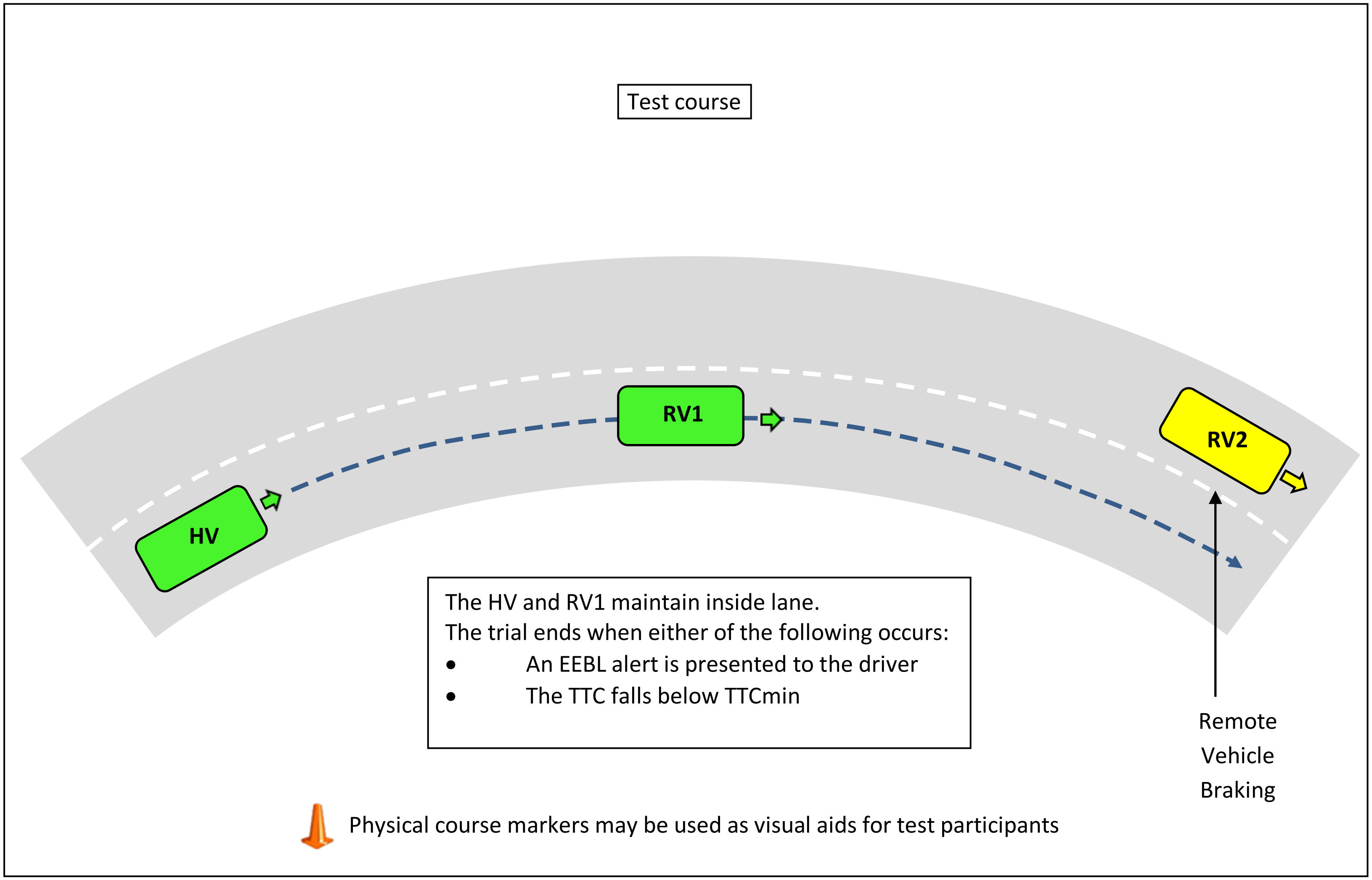


Figure A-13 - EEBL-6 Test Course Graphic, End of Trial (not to scale)

A.14 EEBL-7 – HV Brakes Upon EEBL Alert

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

A.14.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The trailing vehicle is a commercial truck equipped with a V2V system that features an EEBL application. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The leading vehicle's V2V system also broadcasts a hard braking event flag if its driver makes a hard brake application.

Unlike most other EEBL tests, there is no intermediate vehicle for EEBL-7. This is because the primary measure of interest is if the EEBL alert is suppressed when the HV driver applies the brakes. Initially, the vehicles travel at the same velocity with the leading and trailing vehicles within V2V system communication range. The driver of the leading vehicle then makes a hard brake application while the driver of the trailing vehicle, unaware that the leading vehicle is braking, maintains the initial velocity until the EEBL alert is presented, at which point the HV driver applies the brakes to avoid the lead vehicle.

A.14.2 Test Subject and Purpose

The subject of this test is the V2V-based collision warning system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to receive the decelerating lead vehicle's hard braking event flag broadcast, identify the leading vehicle as a collision threat, alert the trailing vehicle's driver of the threat in a timely manner, and to turn the alert off when the trailing vehicle driver applies the brakes (as the driver takes corrective action – braking to avoid lead vehicle – the alert should be suppressed).

A.14.3 Initial Condition

A.14.3.1 Test Velocities

A test velocity is specified for each trial or set of trials. The velocity of the HV and RV is equal to the specified velocity until a trial end condition occurs. A minimum test velocity may be specified above which the RV's OBE will broadcast RV's location, velocity, direction of travel, and hard braking event flags, and above which the HV's ISS or RSD 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 EEBL alerts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.14.3.2 Headways

An initial headway between RV and the HV is specified for each trial or set of trials. The specified headway is such that the HV is within EEBL alert activation range of the RV during the course of each trial; and such that at the end of each trial HV is able to avoid RV. The headway may be specified as a distance between the rear of a vehicle and the front of the following vehicle, or as an interval of time from when the rear of one vehicle clears a reference point to when the front of the following vehicle attains the same point. A headway error tolerance is also specified.

A.14.4 Specifications

A.14.4.1 Steady-State Time Interval

A steady-state time interval is specified for each trial or set of trials. The steady-state time interval begins when the drivers of the RV and the HV have established the specified test velocity and headways. At the end of the interval, the RV is decelerated as specified.

A.14.4.2 RV Deceleration Profile

At a specified point in the procedure, RV is decelerated by applying its service brakes. Deceleration specifications are determined for each trial or set of trials and may include the target deceleration rate, the time interval from the initiation of brake application to the target deceleration rate, an acceptable target deceleration rate error tolerance, and an acceptable magnitude and maximum duration of an overshoot of the target deceleration rate.

A.14.5 Metric

A.14.5.1 Timeliness of Alert Suppression

An EEBL alert must be presented to the HV driver within a specified period of time after RV's V2V system broadcasts a hard braking event flag. If the HV's V2V system provides two EEBL alert levels, the alert presented must be the high-level alert. Once the alert is presented to the driver, the driver will depress his brakes which in turn should suppress the EEBL alert. The time between the onset of the brake and the offset of the alert determines the timeliness of the alert suppression.

A.14.5.2 Execution of Procedure

Because application of the HV's service brakes will typically suppress EEBL alerts, the HV driver should refrain from applying the HV's brakes during the trial until the EEBL alert is presented. The driver then applies the brakes after receiving the EEBL alert. If unsafe conditions or events are encountered during any trial, the HV and RV drivers should abort the trial and brake and/or control their vehicles as needed for safety.

Each trial begins when the RV and the HV have attained the specified test velocity and headway. There may be a variety of methods for establishing these initial conditions. Steps 1 through 3 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 4 through 7 comprise the specified procedure.

The test procedure is depicted in Figure A-14 and Figure A-15.

1. The RV and the HV are staged in the primary test lane at one end of the straight road test facility. The HV is staged behind the RV and both vehicles are oriented to travel toward the opposite end of the test facility. It is recommended that the vehicles be staged in positions relative to each other which reflect the specified headway.
2. The experimenter arms the HV’s data acquisition system and directs the RV driver to begin driving.
3. The drivers begin driving to establish the specified test velocity and headways.
4. The drivers maintain the specified test velocity and headways for the duration of the specified steady-state interval.
5. At the end of the steady-state interval, the driver of the RV applies the service brakes to decelerate the RV as specified while the driver of the HV maintains the specified test velocity until an EEBL alert is presented.
6. Once an EEBL alert is presented, the HV driver applies the HV brakes to attempt to suppress the EEBL alert (the alert should be suppressed as the HV driver takes the corrective action of braking to avoid the RV). The trial is over after the EEBL alert has been suppressed.
7. If necessary the HV can change lanes to avoid the braking RV.

A.14.6 Trial Validity

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

1. The HV’s velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the required EEBL alert.
2. RV’s velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the initiation of braking.
3. The HV’s service brakes were not applied prior to the required EEBL alert.
4. The lateral distance between the centerlines of the HV and RV did not exceed 2.0 feet.
5. The yaw rates of the HV and RV did not exceed ±1 degree/second.
6. The deceleration of RV conformed to the specified deceleration profile.
7. Deviations in headways do not exceed the specified error tolerance at two instants during the procedures. The two instants are 1) three seconds prior to initiation of RV braking; and 2) at the instant of initiation of RV braking.
8. The HV driver applies the brakes within 1 second of the onset of the EEBL alert.

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.14.7 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful only if the following responses occur:

1. The HV OBE initiates a high-level EEBL alert within the specified period of time after RV’s V2V system broadcasts a hard braking event flag,
2. The HV driver applies the brakes within 1 second of the onset of the EEBL alert, and
3. The alert is suppressed within a certain time frame after the HV driver has applied the brakes.

A trial is unsuccessful if any of the above responses fail to occur.

Each test series is comprised of a specified quantity of consecutive trials. An EEBL system passes if, within each series, a specified percentage of the specified quantity of consecutive trials is successful.

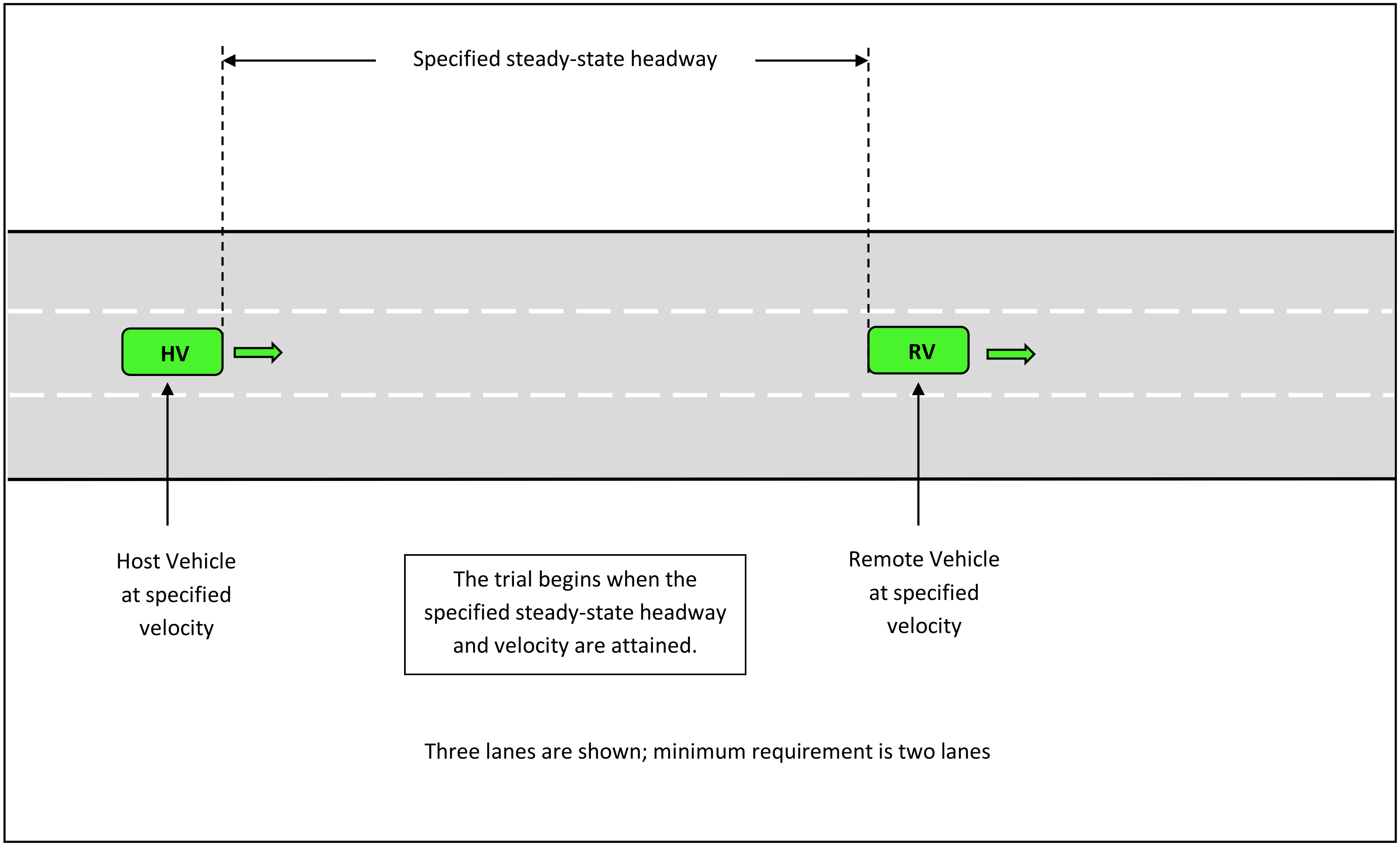


Figure A-14 - EEBL-7 Test Course Graphic, Initial Conditions (not to scale)

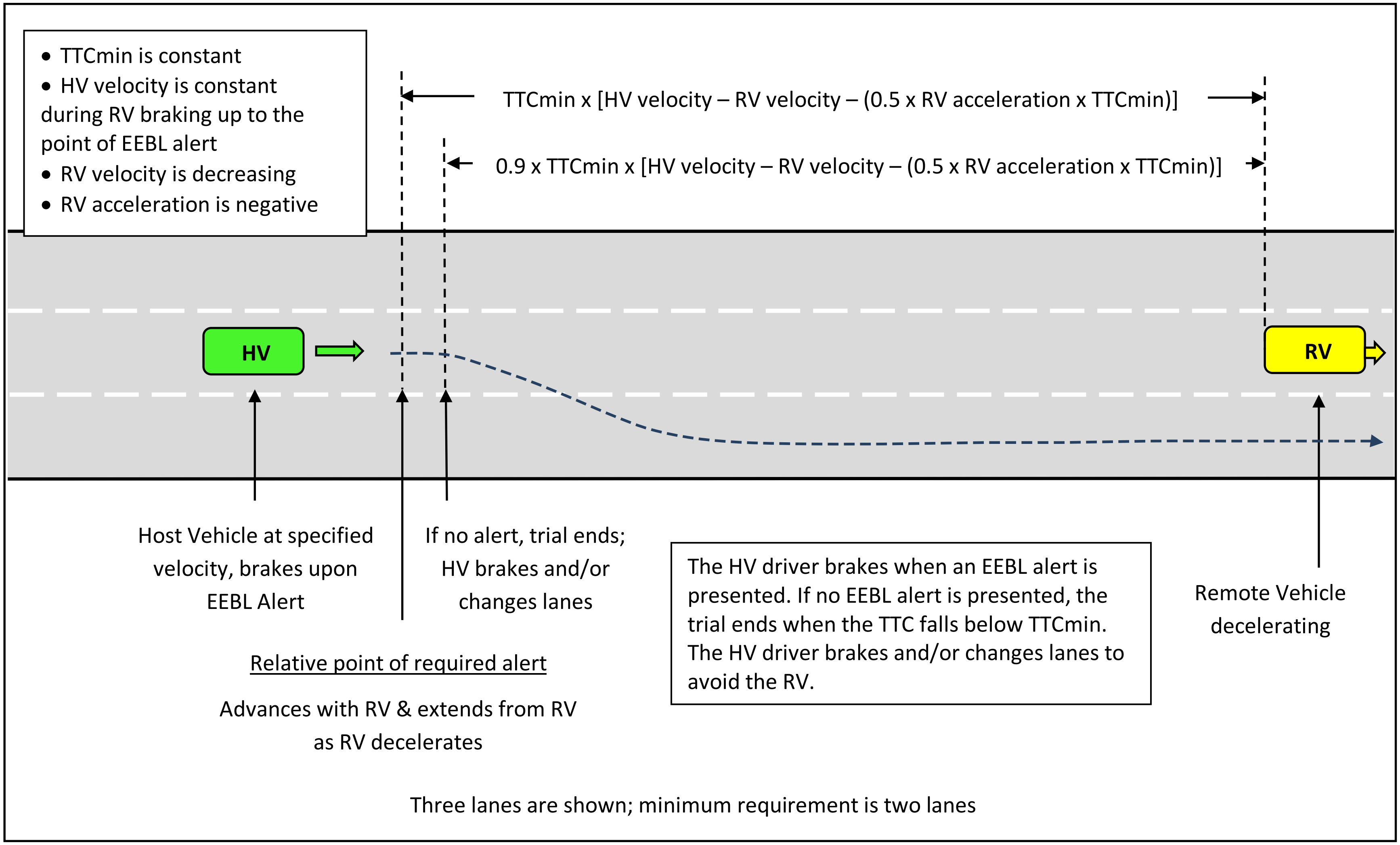


Figure A-15 - EEBL-7 Test Course Graphic, Test Procedure End of Trial (not to scale)

A.15 EEBL-8 – Slow Moving HV

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

A.15.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The trailing vehicle is a commercial truck equipped with a V2V system that features an EEBL application. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The leading vehicle's V2V system also broadcasts a hard braking event flag if its driver makes a hard brake application.

Unlike most other EEBL tests, there is no intermediate vehicle for EEBL-8. This is because the primary measure of interest is at what speed does the RV/V2V combination broadcast an EEBL alert and the HV/V2V system presents a warning to the trailing HV driver. Initially, the vehicles travel at the same velocity with the leading and trailing vehicles within V2V system communication range. The driver of the leading vehicle then makes a hard brake application while the driver of the trailing vehicle, unaware that the leading vehicle is braking, maintains the initial velocity until the EEBL alert is presented at which point the HV driver switches lanes to avoid the lead vehicle.

A.15.2 Test Subject and Purpose

The subject of this test is the V2V-based collision warning system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to receive the decelerating lead vehicle's EEBL broadcast, identify the leading vehicle as a collision threat. The speed of the HV and RV are ramped up from a low value on successive runs until the speeds are high enough to achieve an EEBL broadcast from the RV and the display of the EEBL alert on the HV V2V system.

A.15.3 Initial Condition

A.15.3.1 Test Velocities

A minimum test velocity is specified and is ramped up for each trial or set of trials. The velocity of the HV and RV is equal to the specified velocity until a trial end condition occurs. The velocity of RV is equal to the specified velocity until braking is initiated. A minimum test velocity is specified below which the RV's OBE will not broadcast RV's hard braking event flags. This speed is then ramped up for successive runs until the RV's OBE does broadcast RV's hard braking event flags and above which the HV's ISS or RSD would issue an alert to produce a successful trial.

A.15.3.2 Headways

An initial headway between RV and the HV is specified for each trial or set of trials. The specified headway is such that the HV is within EEBL alert activation range of the RV during the course of each trial; and such that at the end of each trial HV is able to avoid the RV. The headway may be specified as a distance between the rear of a vehicle and the front of the following vehicle, or as an interval of time from when the rear of one vehicle clears a reference point to when the front of the following vehicle attains the same point. A headway error tolerance is also specified.

A.15.4 Specifications

A.15.4.1 Steady-State Time Interval

A steady-state time interval is specified for each trial or set of trials. The steady-state time interval begins when the drivers of the RV and the HV have established the specified test velocity and headways. At the end of the interval, the RV is decelerated as specified.

A.15.4.2 RV Deceleration Profile

At a specified point in the procedure, RV is decelerated by applying its service brakes. Deceleration specifications are determined for each trial or set of trials and may include the target deceleration rate, the time interval from the initiation of brake application to the target deceleration rate, an acceptable target deceleration rate error tolerance, and an acceptable magnitude and maximum duration of an overshoot of the target deceleration rate.

A.15.5 Metric

A.15.5.1 HV/RV Speed when EEBL Alerts are First Presented.

An EEBL alert must be presented to the HV driver within a specified period of time after RV's V2V system broadcasts a hard braking event flag. If the HV's V2V system provides two EEBL alert levels, the alert presented must be the high-level alert. The HV/RV speed is started low and ramped up on successive runs until a sufficient speed is reached such that an EEBL alert is presented.

A.15.6 Execution of Procedure

Because application of the HV's service brakes will typically suppress EEBL alerts, the HV driver should refrain from applying the HV's brakes during the trial until the EEBL alert is presented. If unsafe conditions or events are encountered during any trial, the HV and RV drivers should abort the trial and brake and/or control their vehicles as needed for safety.

Each trial begins when the RV and the HV have attained the specified test velocity and headway. There may be a variety of methods for establishing these initial conditions. Steps 1 through 3 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 4 through 7 comprise the specified procedure.

The test procedure is depicted in Figure A-16 and Figure A-17.

1. The RV and the HV are staged in the primary test lane at one end of the straight road test facility. The HV is staged behind the RV and both vehicles are oriented to travel toward the opposite end of the test facility. It is recommended that the vehicles be staged in positions relative to each other which reflect the specified headway.
2. The experimenter arms the HV's data acquisition system and directs the RV driver to begin driving.

3. The drivers begin driving to establish the specified test velocity and headways.
4. The drivers maintain the specified test velocity and headways for the duration of the specified steady-state interval.
5. At the end of the steady-state interval, the driver of the RV applies the service brakes to decelerate RV as specified while the driver of the HV maintains the specified test velocity.
6. When the headway between HV and RV falls to less than 90 percent of the specified headway for RV and HV, the trial ends.
7. After the end of the trial, the HV changes lanes and passes the RV.

A.15.7 Trial Validity

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

1. The HV's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the required EEBL alert.
2. RV's velocity did not deviate from the specified velocity by more than 1.0 mph for a period of three seconds prior to the initiation of braking.
3. The HV's service brakes were not applied prior to the required EEBL alert.
4. The lateral distance between the centerlines of the HV and RV did not exceed 2.0 feet.
5. The yaw rates of the HV and RV did not exceed ±1 degree/second.
6. The deceleration of RV conformed to the specified deceleration profile.
7. Deviations in headways do not exceed the specified error tolerance at two instants during the procedures. The two instants are 1) three seconds prior to initiation of RV braking; and 2) at the instant of initiation of RV braking.

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.15.8 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful only if the following responses occur:

1. The HV OBE initiates a high-level EEBL alert within the specified period of time after the RV's V2V system broadcasts a hard braking event flag, and
2. The alert persists for a specified duration.

A trial is unsuccessful if any of the above responses fail to occur. The speed is incremented higher for the following run after an unsuccessful run.

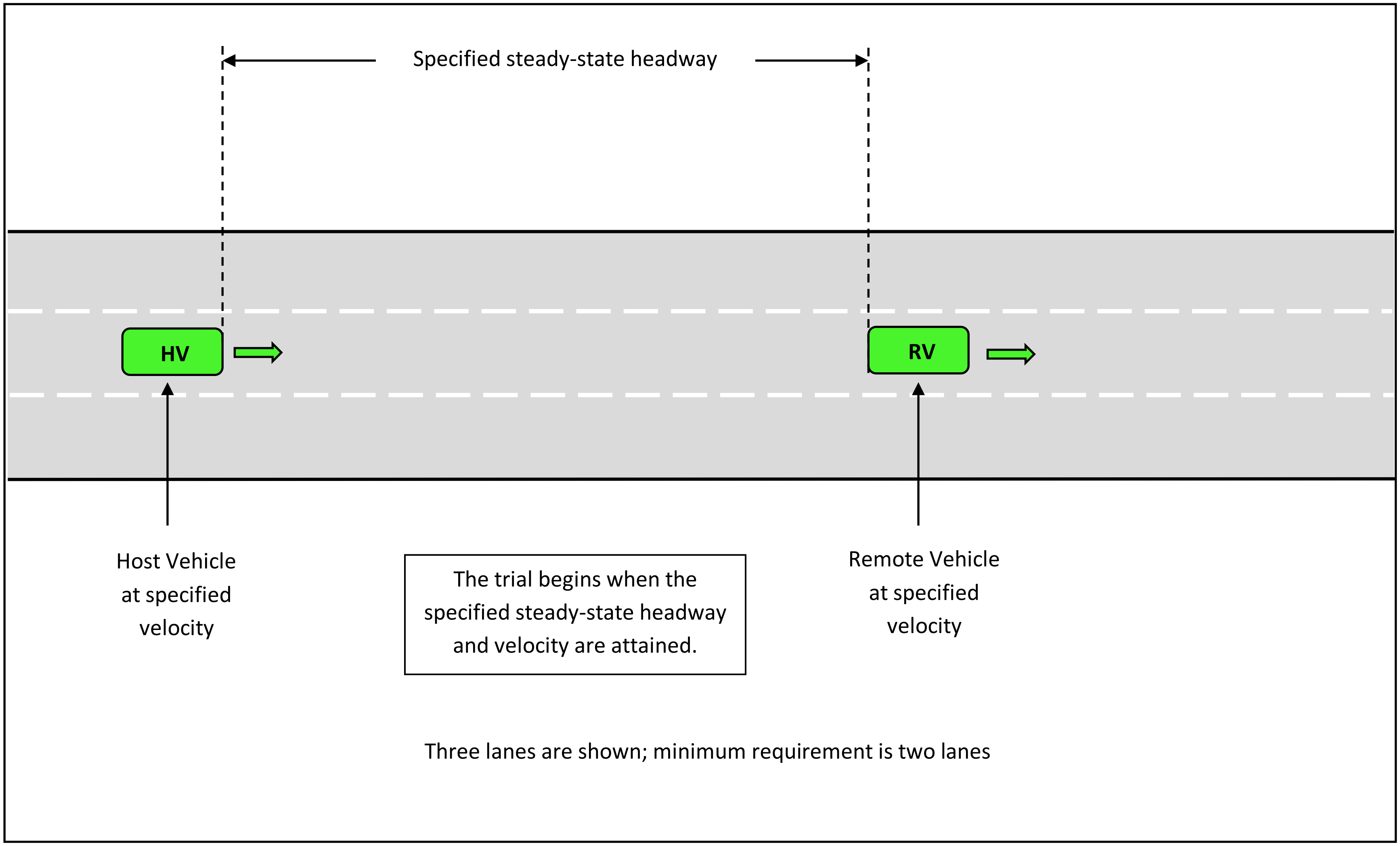


Figure A-16 - EEBL-8 Test Course Graphic, Initial Conditions (not to scale)

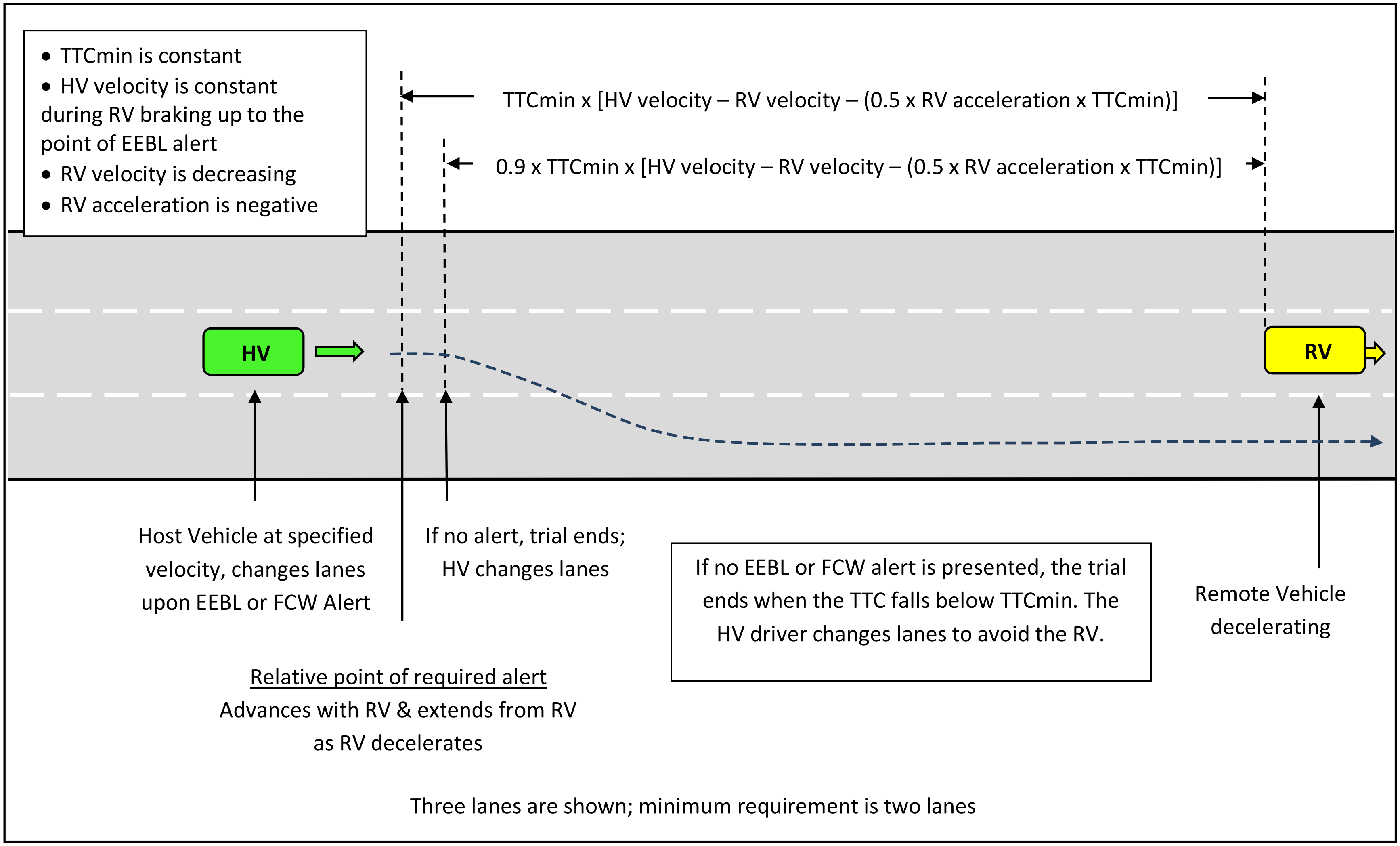


Figure A-17 - EEBL-8 Test Course Graphic, Test Procedure End of Trial (not to scale)

Appendix B - Tabulated Test Results

B.1 EEBL-1 Tabulated Test Results

Table B-1: EEBL Alert Delay From RV2 Hard Brake Event and EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Red Cascadia Bobtail, RV2 = Mack With 53’ Box, RV1 = Blue Cascadia With 53’ Box

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1687	34.8	33.4	0.1	0.8	0.9	1.6	-3.1
1688	34.6	33.5	0.1	0.3	0.7	0.8	-3.0
1689	35.2	32.7	0.1	1.5	0.6	1.2	-3.0
1690	34.8	33.7	0.2	-0.7	0.7	0.4	-3.6
1691	34.1	33.5	0.1		0.8	2.6	-3.3
1692	34.6	33.0	0.1	0.2	0.7	0.6	-3.2
Ave.	34.7	33.3	0.1	0.4	0.7	1.2	-3.2
Std.	0.3	0.4	0.0	0.8	0.1	0.8	0.2

Table B-2: EEBL Alert Delay From RV2 Hard Brake Event and EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Red Cascadia Bobtail, RV2 = Mack With 40’ Ship. Cont., RV1 = Blue Cascadia With 53’ Box

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1717	35.5	33.9	0.1	0.0	0.8	0.5	-3.3
1718	34.7	32.5	0.1	0.9	0.9	0.6	-3.2
1719	35.0	34.5	0.1		0.8	0.3	-3.9
1720	35.1	35.0	0.1	0.5	0.7	0.3	-3.7
1721	35.0	34.9	0.1	0.8	0.6	0.3	-3.1
1722	34.3	32.4	0.2	0.8	0.9	0.2	-5.8
Ave.	34.9	33.9	0.1	0.6	0.8	0.4	-3.8
Std.	0.4	1.2	0.0	0.4	0.1	0.2	1.0

Table B-3: EEBL Alert Delay From RV2 Hard Brake Event and EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Red Cascadia Bobtail, RV2 = Mack With 28' Doubles, RV1 = Blue Cascadia With 53' Box

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1734	34.8	34.8	0.1	0.7	0.7	0.3	-3.3
1735	34.9	35.1	0.2	0.2	0.7	0.7	-3.4
1736	35.7	35.1	0.1	1.1	1.0	0.6	-3.2
1737	34.1	34.8	0.2	-0.2	0.8	0.6	-3.3
Ave.	34.9	34.9	0.2	0.4	0.8	0.6	-3.3
Std.	0.7	0.2	0.1	0.6	0.1	0.2	0.1

Table B-4: EEBL Alert Delay From RV2 Hard Brake Event and EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Blue Cascadia With 53' Box, RV2 = Odyssey

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1249	34.6	33.4	0.3			0.3	-4.3
1250	35.5	33.1	0.2			0.3	-4.1
1251	34.5	33.6	0.3			0.3	-5.5
1252	34.5	32.4	0.2			0.3	-4.0
1253	34.6	33.2	0.3			0.3	-6.1
1254	35.6	31.5	0.2			0.3	-4.1
Ave.	34.9	32.9	0.3			0.3	-4.6
Std.	0.5	0.8	0.1			0.0	0.9

Table B-5: EEBL Alert Delay From RV2 Hard Brake Event and EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Blue Cascadia With 53' Box, RV2 = Mack With 53' Box

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1687	35.8	33.4	-1.4	-0.7	-0.6	0.1	-3.1
1688	34.7	33.5	-0.5	-0.4	0.0	0.1	-3.0
1689	35.1	32.7	-1.1	0.4	-0.5	0.1	-3.0
1690	33.8	33.7	-0.1	-1.0	0.4	0.1	-3.6
1691	34.7	33.5	-2.4		-1.7	0.1	-3.3
1692	35.1	33.0	-0.5	-0.3	0.2	0.1	-3.2
Ave.	34.9	33.3	-1.0	-0.4	-0.4	0.1	-3.1
Std.	0.6	0.4	0.8	0.5	0.8	0.0	-3.0

Table B-6: EEBL Alert Delay From RV2 Hard Brake Event and EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Blue Cascadia With 53' Box, RV2 = Mack With 40' Ship. Cont.

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1717	35.0	33.9	-0.2	-0.4	0.4	0.1	-3.3
1718	35.1	32.5	-0.2	0.5	0.5	0.2	-3.2
1719	34.9	34.5	0.0		0.6	0.1	-3.9
1720	35.4	35.0	-0.1	0.3	0.5	0.1	-3.7
1721	35.4	34.9	-0.1	0.6	0.4	0.1	-3.1
1722	35.9	32.4	0.1	0.8	0.9	0.2	-5.8
Ave.	35.3	33.9	-0.1	0.3	0.6	0.1	-3.8
Std.	0.3	1.2	0.1	0.4	0.2	0.1	1.0

Table B-7: EEBL Alert Delay From RV2 Hard Brake Event and EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Blue Cascadia With 53' Box, RV2 = Mack With 28' Doubles

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1734	35.4	34.8	-0.1	0.5	0.5	0.1	-3.3
1735	34.7	35.1	-0.5	-0.4	0.1	0.1	-3.4
1736	35.0	35.1	-0.2	0.7	0.6	0.2	-3.2
1737	34.6	34.8	-0.2	-0.6	0.4	0.2	-3.3
Ave.	34.9	34.9	-0.3	0.0	0.4	0.2	-3.3
Std.	0.4	0.2	0.2	0.6	0.2	0.1	0.1

B.2 EEBL-4 Tabulated Test Results

Table B-8: HV to RV2 Longitudinal Range at RV2 Brake Threshold and EEBL Alert Onset for HV = Red Cascadia Bobtail, RV2 = Odyssey, and RV1 = Blue Cascadia With 53' Box Trailer

Test No.	Long. Range at RV2 Brake (m)		Long. Range at Alert Onset (m)	
	WSU	RT	WSU	RT
1243	276	274	245.7	247.9
1244	274	274		
1245	273	273	246.0	250.1
1246	276	275	246.2	248.9
1247	277	276	245.3	249.0
1248	270	269	246.9	249.8
Ave.	274	273	246.0	249.1
Std.	2.5	2.6	0.5	0.8
C. of V. (%)	0.9	0.9	0.2	0.3

Table B-9: HV to RV2 Longitudinal Range at RV2 Brake Threshold and EEBL Alert Onset for HV = Red Cascadia Bobtail, RV2 = Mack Bobtail, and RV1 = Blue Cascadia Bobtail

Test No.	Long. Range at RV2 Brake (m)		Long. Range at Alert Onset (m)	
	WSU	GPS	WSU	GPS
1591	256	254	248.4	237.6
1592	256	257	249.4	240.2
1593	259	257	248.5	236.6
1594	260	259	248.8	237.6
1595	262	259	248.6	234.2
1596	260	259	250.0	238.1
Ave.	259	258	249.0	237.4
Std.	2.2	2.0	0.6	2.0
C. of V. (%)	0.8	0.8	0.3	0.8

Table B-10: HV to RV2 Longitudinal Range at RV2 Brake Threshold and EEBL Alert Onset for HV = Red Cascadia Bobtail, RV2 = Mack With 53’ Box, and RV1 = Blue Cascadia With 53’ Box

Test No.	Long. Range at RV2 Brake (m)		Long. Range at Alert Onset (m)	
	WSU	GPS	WSU	GPS
1598	269	269	247.5	248.3
1599	268	266	248.6	248.0
1600	266	266		
1601	264	262	248.6	247.4
1602	265	265		
1603	265	264	245.7	244.4
Ave.	266	266	247.6	247.0
Std.	1.8	2.3	1.2	1.5
C. of V. (%)	0.7	0.9	0.5	0.6

Table B-11: EEBL Alert Delay From RV1 EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Red Cascadia Bobtail, RV2 = Mack With 53' Box, RV1 = Blue Cascadia With 53' Box

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1682	34.5	33.5	0.1	-0.6	0.5	1.0	-3.1
1683	34.7	33.6	0.1	1.1	0.7	0.6	-3.0
1684	34.6	33.3	0.1	1.3	0.5	1.0	-3.2
1685	34.8	33.8	0.1	-0.4	0.9	0.6	-3.3
1686	34.8	33.0	0.1	-0.1	0.9	0.6	-3.2
Ave.	34.7	33.4	0.1	0.3	0.7	0.8	-3.2
Std.	0.1	0.3	0.00	0.89	0.21	0.22	0.11

Table B-12: EEBL Alert Delay From RV1 EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Red Cascadia Bobtail, RV2 = Mack With 40' Ship. Cont., RV1 = Blue Cascadia With 53' Box

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1708	35.1	33.8	0.1	1.4	0.7	0.6	-3.0
1709	34.7	34.9					-3.2
1710	35.0	33.6	0.1	0.5	0.9	0.4	-3.9
1711	35.4	34.0					-3.3
1712	35.3	34.4	0.1	0.7	0.7	0.3	-3.3
1713	34.8	34.5					-4.0
1714	35.1	34.6	0.1	0.5	0.7	0.3	-3.3
1715*	35.8	35.3					
1716	34.8	33.2	0.1	0.3	0.8	0.4	-3.6
Ave.	35.1	34.2	0.1	0.7	0.8	0.4	-3.4
Std.	0.4	0.7	0.00	0.41	0.09	0.12	0.35

*-Late delay due to lateral offset

Table B-13: EEBL Alert Delay From RV1 EEBL Brake Threshold of 0.4 g and HV and RV Speeds for HV = Red Cascadia Bobtail, RV2 = Mack With 28’ Doubles, RV1 = Blue Cascadia With 53’ Box

Test No.	Speeds at RV2 Brake (mph)		Alert Delay from RV2 Brake Decel.= 0.4g (sec)			Alert Delay from Hard Brake (s)	Decel at Hard Brake Event (m/s/s)
	HV	RV	WSU	RT	GPS		
1729	35.5	34.6	0.2	-0.7	0.8	0.6	-3.0
1730	34.8	34.1	0.1	0.5	0.7	0.3	-3.6
1731	34.4	34.7	0.1	-0.9	0.7	0.3	-3.6
1732	35.2	34.9	0.2	0.9	1.0	0.6	-3.3
1733	35.3	34.3	0.2		0.7	0.4	-3.4
Ave.	35.0	34.5	0.2	-0.1	0.8	0.4	-3.4
Std.	0.5	0.3	0.06	0.88	0.21	0.15	0.2

DOT HS 812 327
September 2016

U.S. Department
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National Highway
Traffic Safety
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12384-092116-v2