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Commercial Connected Vehicle Test Procedure Development and Test Results – Forward Collision Warning

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16. Abstract

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

The prototype V2V equipment was observed to be capable of tracking potential FCW threats, but had some issues when vehicles were in a curve or when switching lanes. For the curve tests, the V2V equipment had trouble determining the lateral distance between the host vehicle (HV – test subject) and the remote vehicle (RV – collision threat) for certain scenarios.

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

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List of Acronyms

ASD – aftermarket safety device
BSW – blind spot warning
CAN – controller-area-network
CCV – commercial connected vehicles
DSRC – dedicated short-range communication
DGPS – differential global position system
DVI – driver-vehicle interface
EEBL – electronic emergency brake light
FCW – forward collision warning
GNSS – global navigation satellite system
GPS – global positioning system
GVWR – gross vehicle weight rating
GAWR – gross axle weight rating
HV – host vehicle
ICA – intersection collision avoidance
IMA – intersection movement assist
IMU – inertial measurement unit
ISS – integrated safety equipment
LCW – lane change warning
LCM – lane change-merge
OBE – on-board equipment
PCAP – packet capture
RSD – retrofit safety device
RV – remote vehicle
TTC – time-to-collision
TTC_{NA} – time-to-collision no acceleration
V2V – vehicle-to-vehicle
V2I – vehicle-to-infrastructure
V2X – V2V and/or V2I and/or other communication capabilities

VAD – vehicle awareness device

VRTC – Vehicle Research and Test Center

WSU – wireless safety unit

Executive Summary

The National Highway Traffic Safety Administration is developing test procedures to evaluate the safety applications of vehicle-to-vehicle equipped commercial vehicles. For this research, a commercial vehicle is defined as a medium or heavy truck (including tractor-trailer combinations) or bus with a gross vehicle weight rating of more than 10,000 pounds. The primary focus of this research was on developing the test procedures, with a secondary goal of evaluating the performance of the prototype V2V safety applications. Objective test procedures were developed to evaluate a range of safety applications including intersection movement assist, blind spot warning/lane change warning, forward collision warning, and emergency electronic brake light warning. This report documents the FCW test procedures and the results of testing commercial vehicles equipped 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 initially used in the model deployment study [1]. One was used as a host vehicle (HV – test subject) and the other was generally used as a remote vehicle (RV – collision threat). A 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 on the Cascadia trucks were observed to be capable of tracking potential FCW threats, but it had some issues when vehicles were in a curve or when switching lanes.

For the curve tests, the V2V equipment had trouble determining the lateral distance between the HV and the RV for certain scenarios (most notably in FCW-6: Stopped Vehicle Ahead in Adjacent Lane, Curved Road). This appeared to be more of an issue when the RV was to the outside of the HV in the curve.

For lane change scenarios, sometimes FCW false positives would occur after the HV would pass the RV (most notably in FCW-5: Stopped Vehicle Ahead in Same Lane, Curved Road). Also, the lateral range was not always well predicted when vehicles would make lane changes, which might delay when an alert was issued (most notably in FCW-9: Target Switch).

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

1 Introduction

This report documents NHTSA's test track research performed to support development of objective test procedures to evaluate the safety applications of V2V-equipped commercial vehicles. The tests were to be developed to evaluate the various safety applications available in V2V systems including IMA, BSW/LCW, FCW, and EEBL warning. This report documents the results of FCW testing.

2 Test Vehicles

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 both 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 Retrofit Safety Device (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].

Figure 1: Freightliner Cascadia and Mack CXU612

Vehicle data for the two Freightliner Cascadia and the Mack tractors 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 CXU612 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 were performed with a pair (primary and secondary) of Denso dedicated short-range communication radio/computer platforms called mini wireless safety units model 1.5, each of which has a single board computer and a two-channel 5.9 GHz DSRC radio. Vehicle positioning was performed with a differential global position system receiver (Novatel OEMV-1 FlexPak-G2-L1). The data acquisition system logger in the OBE was not used as part of this study. Instead, an extended version of the VRTC-owned data acquisition equipment was applied and is detailed in Chapter 3. For the driver vehicle interface, a wireless, dash-mounted tablet display with touchscreen (I-Pad) was used to input vehicle parameters (cab configuration and trailer length) and to provide visual driver notification of various alert types including IMA, BSW, EEBL, and FCW. The cab configuration and trailer length are selectable because the WSU broadcasts the vehicle size (length and width), which is represented as a single rigid body that is adjusted based on the vehicle configuration and trailer (or trailers – double 28' trailers are an option on the DVI) selected by the driver through the DVI. The rigid-body model was used because the trailers are not equipped with V2V systems and the WSU does not estimate the angle of articulation between the tractor and a towed semi-trailer. This study did not investigate how an articulated model representing the tractor and trailer as two bodies (or three bodies in the case of double trailers) would affect system performance or how it would affect the development of objective test procedures. The OBE system architecture is shown in Figure 2.

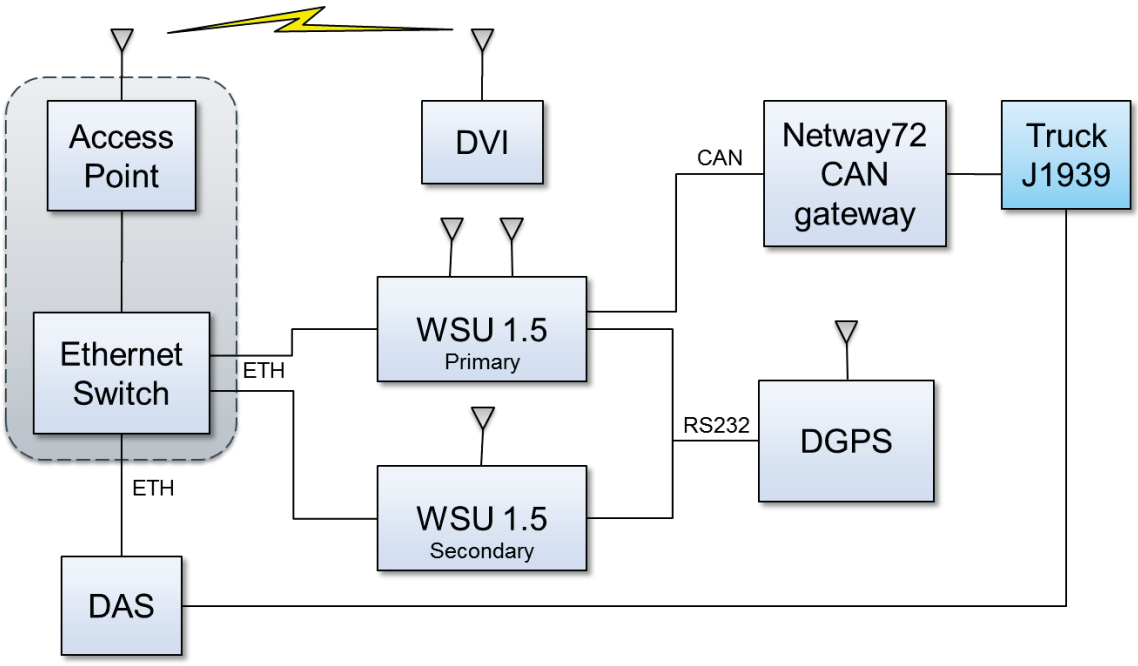


Figure 2: OBE System Architecture

Example FCW application Level 2 "Inform" and Level 3 "Warning" icons that are displayed on the tablet are shown in Figure 3. These icons show the rear view of the trailer approaching a slower moving remote vehicle from the rear.

Figure 3: "Inform" Level 2 Alert and "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. They are labeled RT, GPS, and WSU. The following sections briefly described how this data were collected.

3.1 RT Data Collected on UEI

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

3.2 GPS Data

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

3.3 WSU Data

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

4 Forward Collision Warning Results

There were nine Forward Collision Warning (FCW) test procedures evaluated.

- FCW-1: Stopped Vehicle Ahead in Same Lane, Straight Road
- FCW-2: Slower Vehicle Ahead in Same Lane, Straight Road
- FCW-3: Braking Vehicle Ahead in Same Lane, Straight Road
- FCW-4: Stopped Vehicles in Adjacent Lanes, Straight Road
- FCW-5: Stopped Vehicle Ahead in Same Lane, Curved Road
- FCW-6: Stopped Vehicle Ahead in Adjacent Lane, Curved Road
- FCW-7: Lane Change Reveal
- FCW-8: Tailgate
- FCW-9: Target Switch

The test procedures for these tests are documented in Appendix A- FCW 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 the V2V system types can be found in Appendix A, Section [1]) and is the test subject. An RV is a vehicle that carries a V2V system (ISS, RSD, ASD, or VAD), and represents a collision threat to the HV. The RV V2V system broadcasts many data elements including the RV's position, speed, direction of travel, and path history. The HV V2V system features an FCW application.

4.1 FCW-1: Stopped Vehicle Ahead in Same Lane, Straight Road

For the FCW-1 test procedure, two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The two vehicles are separated by a distance greater than the FCW application's alert range. The leading RV brakes to a stop in the lane of travel. The trailing HV drives in the same lane of travel toward the stopped RV and enters the FCW application's alert range. Details for this test procedure can be found in Appendix A, Section A.8. The HV speed was 45 mph for the tests conducted in this study.

The HV was the Red Cascadia and the RV was the Blue Cascadia. The trailer combinations evaluated are presented in Table 2 as well as the number of tests conducted for each combination. Some of the RV trailers are labeled as "Faux." For these tests the trailer was set on the I-Pad display, but the trailers were not actually attached. These tests were done in quick succession on one day of testing to see if the software was properly adjusting the trailer length for each trailer setting. Only four tests were run for some of these Faux trailer conditions because they were really only intended to be a quick check of the trailer length, but the data was later deemed useful and, therefore, included in this report. Two of the HV trailer combinations are labeled Faux due to the HV I-Pad display not being properly changed to the Bobtail setting. The display was left with the trailer length set to double 28' trailers. The doubles had been connected to the tractor for testing that had occurred earlier in the day, but were removed prior to the tests with the HV trailers labeled as "Faux."

Table 2: FCW-1 HV and RV Trailer Combinations Evaluated

HV Trailer	RV Trailer	Number of Tests Conducted
Bobtail	Bobtail	5
Bobtail	Single 28’ – Faux	4
Bobtail	Double 28’ - Faux	5
Bobtail	40’ Shipping Container - Faux	4
Bobtail	53’ Box - Faux	5
Double 28’ - Faux	53’ Box	5
Double 28’ - Faux	Double 28’	5
53’ Box	40’ Shipping Container	5

Example test results for an FCW-1 test are shown in Figure 4. The time-to-collision (TTC), longitudinal range, and lateral range from the HV to the RV and the HV Speed (RV speed 0 for this test) are shown. The FCW alert level is also shown. The FCW alert level rises from 0 to 1 near 17 seconds, 1 to 2 near 18 seconds and 2 to 3 near 18.5 seconds. It then drops to 0 near 20.5 seconds and back up to 3 for a brief period near 21.5 seconds. This occurs as the HV starts to go around the RV.

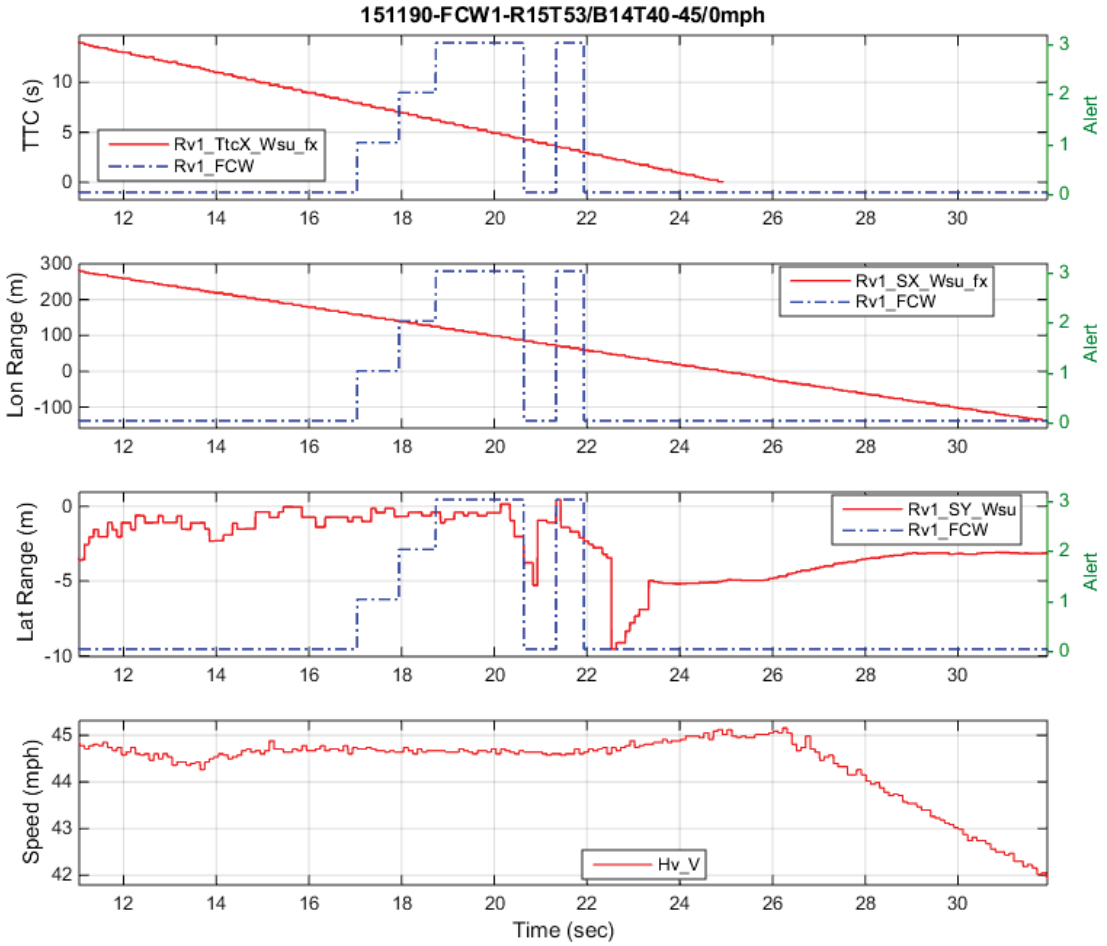


Figure 4: Example FCW-1 Test Results – TTC, Longitudinal Range, Lateral Range, and Speed – Test 1190

TTC and lateral range values as determined from the WSU data are presented in Table 3 for each HV and RV trailer combination evaluated. Mean, standard deviation, and coefficient of variation values are presented. More complete data for each individual test are presented in Appendix B, Section B.1. WSU, RT, and GPS data are presented for both Level 2 and Level 3 alert onsets in the appendix. The mean TTC values only ranged from 6.2 to 6.4 seconds for all the trailer combinations and the standard deviation was 0.1 seconds or less with coefficients of variation ranging from 0.4 percent to 1.1 percent. The mean longitudinal range varied from 124.2 to 129.2 meters, the standard deviations varied from 1.1 to 1.9 meters, and the coefficient of variation varied from 0.8 percent to 1.5 percent.

Table 3: FCW-1 WSU TTC and Longitudinal Range Values at FCW Level 3 Alert

HV Trailer	RV Trailer	TTC (s)			Longitudinal Range (m)		
		Mean	Std. Dev.	C. of V. (%)	Mean	Std. Dev.	C. Of V. (%)
Bobtail	Bobtail	6.3	0.0	0.7	126.2	1.2	0.9
Bobtail	Single 28’ - F	6.3	0.1	1.0	125.9	1.1	0.8
Bobtail	Doubles - F	6.3	0.1	1.1	125.1	1.5	1.2
Bobtail	40’ Ship. - F	6.3	0.0	0.7	125.7	1.3	1.1
Bobtail	53’ Box - F	6.3	0.1	0.9	124.7	1.1	0.9
Doubles - F	53’ Box	6.4	0.0	0.4	129.2	1.9	1.5
Doubles - F	Doubles	6.3	0.0	0.6	127.0	1.4	1.1
53’ Box	40’ Ship.	6.2	0.0	0.7	124.2	1.6	1.3

Comparing the results of the real and faux RV trailers, for the 53’ Box, the average TTC was 0.1 second greater (alerted a little earlier) for the real trailer case (6.4 versus 6.3 seconds). For the 28’ Doubles, the mean TTC was the same (6.3 seconds) and for the 40’ shipping container, the TTC was 0.1 second less for the real trailer cases (6.2 versus 6.3 seconds). These results suggest that the trailers had little or no influence on the performance of the WSUs under these test conditions.

Boxplots for the TTC values at the Level 2 and Level 3 FCW Alert onset are shown in Figure 5 and Figure 6. The box lengths represent the interquartile range, the horizontal line inside the box represents the group median, and the vertical lines (whiskers) extending beyond the box are the group minimum and maximum values. The first line of the label is the vehicle combination where R15 represents the Red Freightliner Cascadia and B14 represents the Blue Cascadia, the second line represents the HV/RV trailer lengths (“F” used to denote Faux trailer), the third line represents the HV/RV nominal speeds in mph, and the fourth line is the alert level and number of tests. There is a very narrow range of TTC values for both the Level 2 alerts (6.95 to 7.25 seconds with one outlier less than 6.8 seconds) and the Level 3 alerts (6.15 to 6.45 seconds).

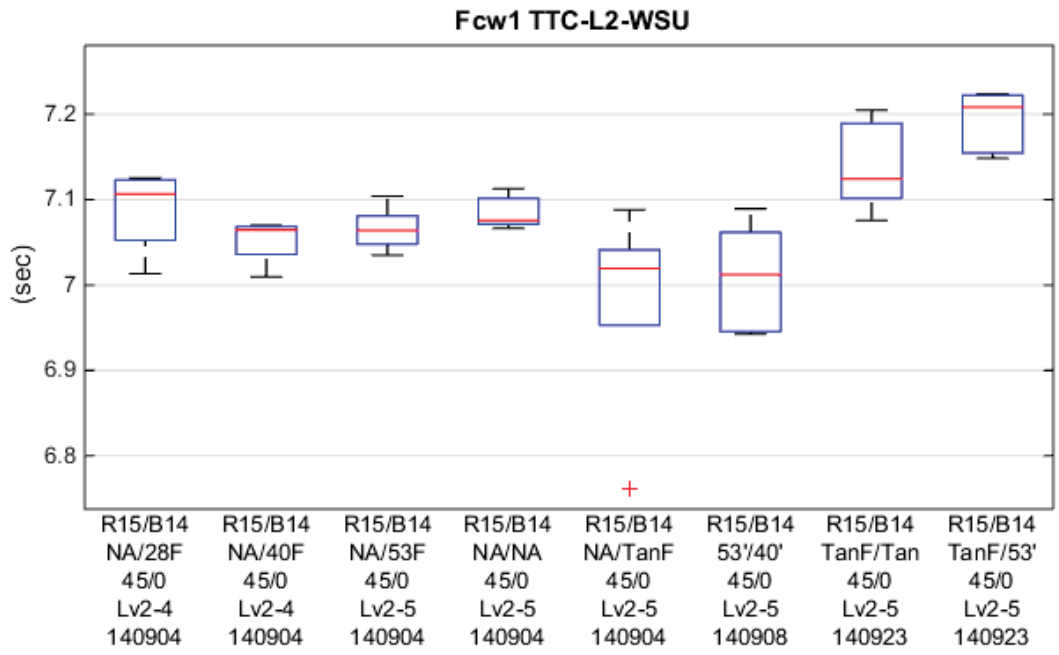


Figure 5: FCW-1 Boxplots of TTC at FCW Level 2 Alert – WSU Data

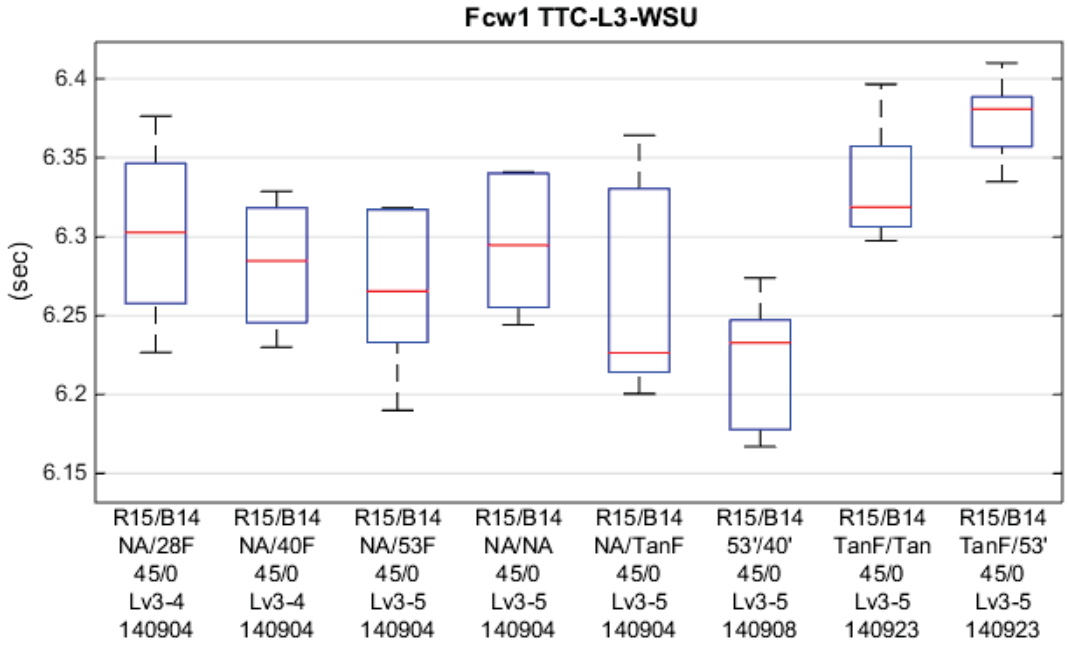


Figure 6: FCW-1 Boxplots of TTC at FCW Level 3 Alert – WSU Data

4.2 FCW-2: Slower Vehicle Ahead in Same Lane, Straight Road

For the FCW-2 test procedure, two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The two vehicles are separated by a distance greater than the FCW application's alert range. The velocity of the leading RV is steady but slower than that of the trailing HV. The HV drives in the same lane of travel toward the slower RV and enters the FCW application's alert range. Details for this test procedure can be found in Appendix A, Section A.9. For the FCW-2 tests conducted in this study the RV was at 25 mph and the HV approached at 45 mph.

The HV was always the Red Cascadia and the RV was generally the Blue Cascadia except for one test set which had the Honda Odyssey as the RV. The HV trailer and RV or RV Trailer combinations evaluated are presented in Table 4 as well as the number of tests conducted for each combination. Some of the RV trailers are labeled as "Faux." For these tests the trailer was set on the I-Pad display, but the trailers were not actually attached. These tests were done in quick succession on one day of testing to see if the software was properly adjusting the trailer length for each trailer setting. Two of the HV trailer combinations are labeled Faux. This occurred due to the HV I-Pad display not being changed to the Bobtail setting after the Double 28' trailers were disconnected after testing that occurred earlier in the day.

Table 4: FCW-2 HV and RV/RV Trailer Combinations Evaluated

HV Trailer	RV/RV Trailer	Number of Tests Conducted
Bobtail	Bobtail	5
Bobtail	Single 28' – Faux	5
Bobtail	Double 28' - Faux	5
Bobtail	40' Shipping Container - Faux	4
Bobtail	53' Box - Faux	5
Double 28' - Faux	53' Box	5
Double 28' - Faux	Double 28'	5
53' Box	40' Shipping Container	5
Bobtail	Honda Odyssey	5

Example test results for an FCW-2 test are shown in Figure 7. The TTC, longitudinal range, and lateral range from the HV to the RV and the HV and RV Speed are shown. The FCW alert level is also shown. The FCW alert level rises from 1 to 2 near 5 seconds and from 2 to 3 near 6 seconds. It then drops to 0 a little past 8 seconds. The drop to 0 occurs as the HV starts to move to the adjacent lane (noted by the change in lateral range in the third subplot).

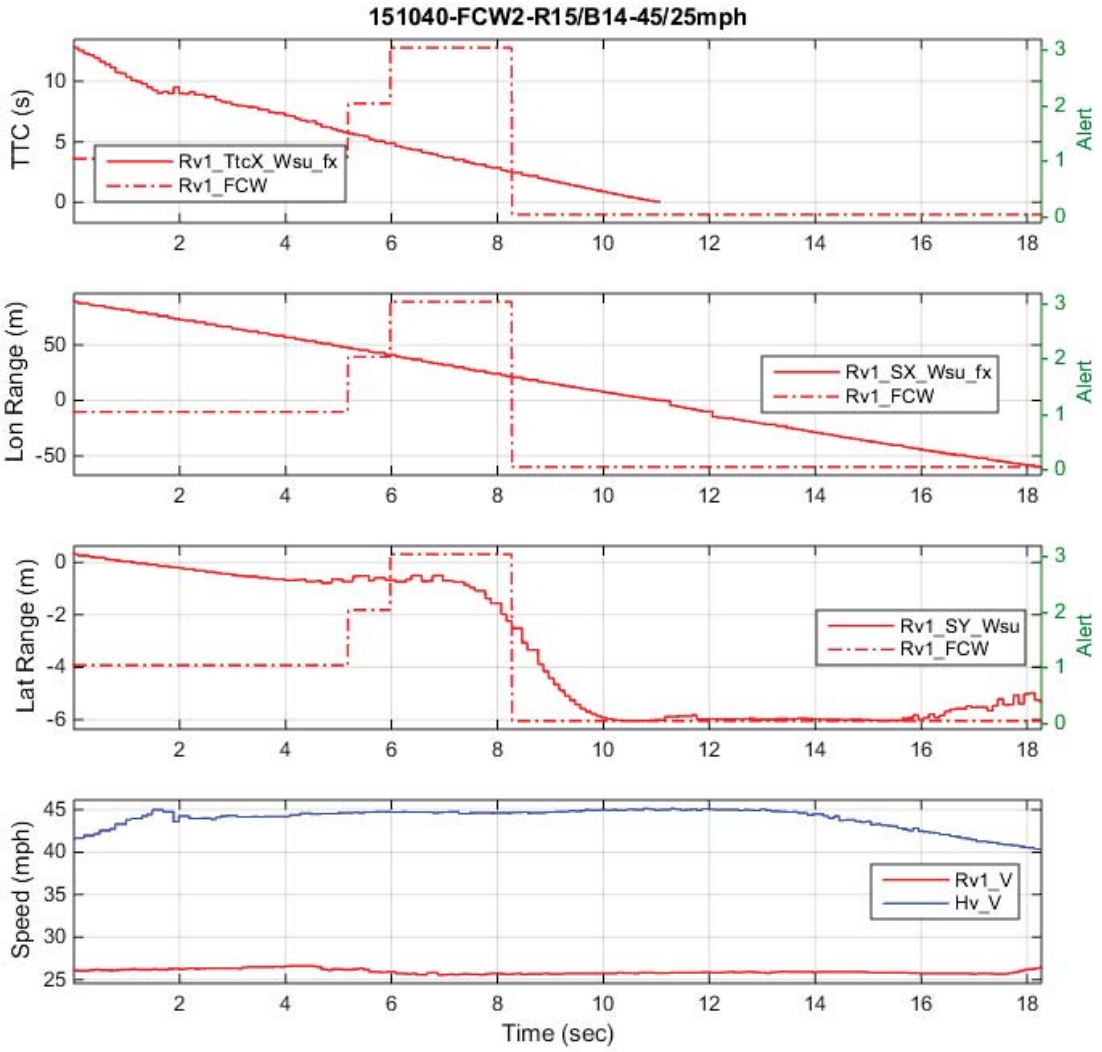


Figure 7: Example FCW-2 Test Results – TTC, Longitudinal Range, Lateral Range, and Speed – Test 1040

TTC and lateral range values as determined from the WSU data are presented in Table 5 for each HV trailer and RV or RV trailer combination evaluated. Mean, standard deviation, and coefficient of variation values are presented. More complete data for each individual test are presented in Appendix B, Section B.2. WSU, RT, and GPS data are presented for both Level 2 and Level 3 alert onsets in the appendix. The mean TTC values ranged from 4.8 to 5.1 seconds for all the trailer combinations and the standard deviation was 0.1 seconds or less with coefficients of variation ranging from 0.9 percent to 2.8 percent. The mean longitudinal range varied from 40.7 to 47.5 meters, the standard deviations varied from 0.6 to 3.5 meters, and the coefficient of variation varied from 1.3 percent to 7.9 percent. The HV/RV trailer combination of 53'Box/40' Shipping container had the most variability primarily due to one test (Test 1221) that alerted earlier than the other tests for this combination.

Table 5: FCW-2 WSU TTC and Longitudinal Range Values at FCW Level 3 Alert

HV Trailer	RV/RV Trailer	TTC (s)			Longitudinal Range (m)		
		Mean	Std. Dev.	C. of V. (%)	Mean	Std. Dev.	C. Of V. (%)
Bobtail	Bobtail	4.8	0.1	1.2	41.5	1.1	2.6
Bobtail	Single 28’ - F	5.0	0.1	1.1	42.4	0.9	2.2
Bobtail	Double 28’ - F	4.9	0.1	1.4	43.0	0.6	1.3
Bobtail	40’ Ship. - F	4.8	0.0	0.9	40.7	0.9	2.2
Bobtail	53’ Box - F	5.0	0.0	0.9	43.5	1.4	3.2
Double 28’ - F	53’ Box	5.1	0.1	1.0	47.5	2.4	5.1
Double 28’ - F	Double 28’	4.9	0.1	1.3	42.0	0.9	2.1
53’ Box	40’ Ship.	5.0	0.1	2.8	44.2	3.5	7.9
Bobtail	Honda Odyssey	4.9	0.1	1.2	44.3	2.1	4.7

Comparing the results of the real and faux RV trailers, for the 53’ Box trailer the average TTC was 0.1 second greater (alerted a little earlier) for the real trailer case, for the Double 28’ trailers the average TTC values were the same (4.9 seconds) and for the 40’ shipping container the average TTC was 0.2 second greater for the real trailer cases (5.0 versus 4.8 seconds). These results suggest that the trailers had little or no influence on the performance of the WSUs under these test conditions.

Boxplots for the TTC values at the Level 2 and Level 3 FCW Alert onset are shown in Figure 8 and Figure 9. There is a very narrow range of TTC values for both the Level 2 alerts (5.55 to 6.05 seconds) and the Level 3 alerts (4.75 to 5.25 seconds). As was noted above, the HV/RV 53’Box/40’ Shipping Container combination had the most variability primarily due to one test (Test 1221).

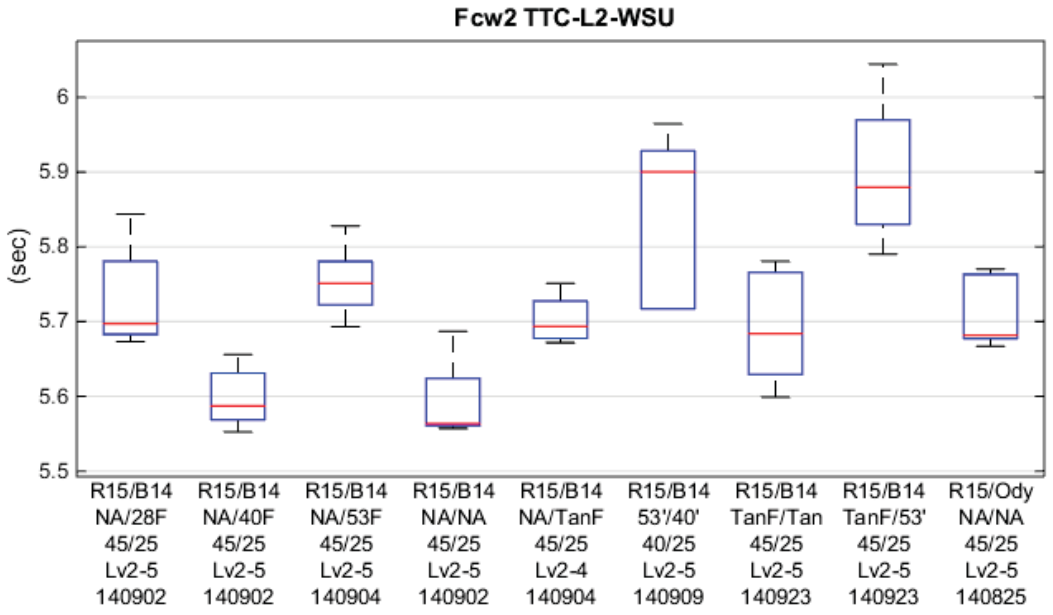


Figure 8: FCW-2 Boxplots of TTC at FCW Level 2 Alert – WSU Data

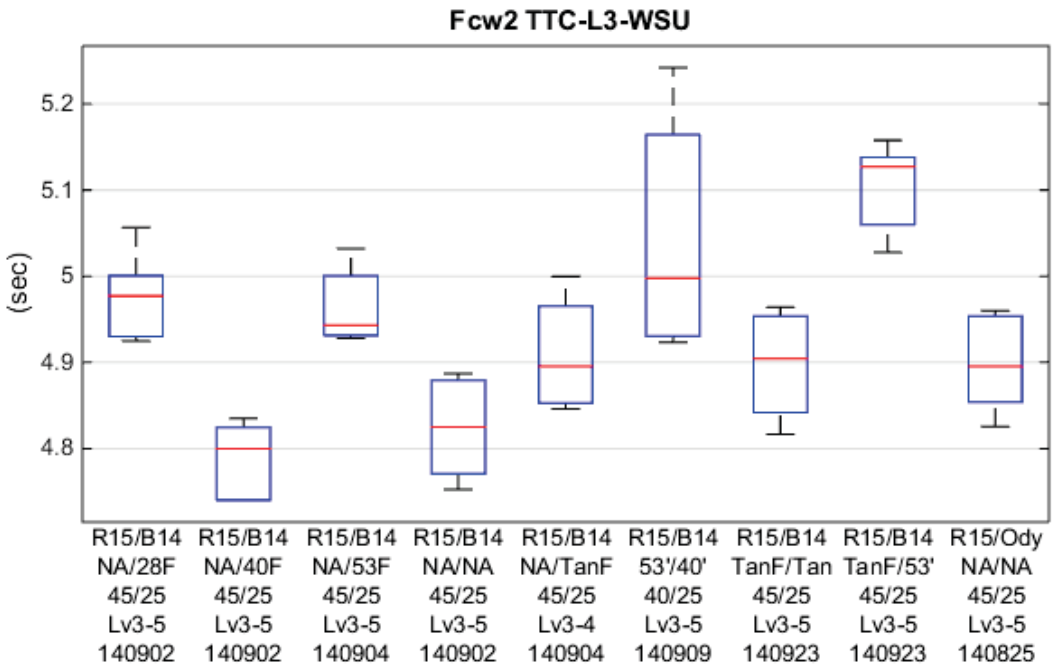


Figure 9: FCW-2 Boxplots of TTC at FCW Level 3 Alert – WSU Data

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

For the FCW-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 are separated by a specified distance or headway and travel at the same velocity. The leading RV then brakes at a level below the EEBL threshold of 0.4 g, while the trailing HV maintains the specified velocity. Details for this test procedure can be found in Appendix A, Section A.10. For the tests conducted in this study the RV and HV are initially traveling in the same lane at 45 mph.

The HV was always the Red Cascadia and the RV was generally the Blue Cascadia except for one test set which had the Honda Odyssey as the RV. The HV trailer and RV or RV trailer combinations evaluated are presented in Table 6 as well as the number of tests conducted for each combination. Two of the HV trailer combinations are labeled Faux. This occurred due to the HV I-Pad display not being changed to the Bobtail setting after the Double 28’ trailers were disconnected after testing that occurred earlier in the day.

Table 6: FCW-3 HV and RV/RV Trailer Combinations Evaluated

HV Trailer	RV/RV Trailer	Number of Tests Conducted
Double 28’ - Faux	53’ Box	5
Double 28’ - Faux	Double 28’	5
53’ Box	40’ Shipping Container	5
Bobtail	Honda Odyssey	6

Example test results for an FCW-3 test are shown in Figure 10. The TTC, longitudinal range, and lateral range from the HV to the RV and the HV and RV Speed are shown. The FCW alert level is also shown. The FCW alert level rises from 1 to 3 near 7 seconds when the RV speed starts to reduce (fourth subplot) due to the brake application and then drops to 0 a little past 10 seconds. The drop to 0 occurs as the HV starts to move to the adjacent lane (noted by the change in lateral range in the third subplot).

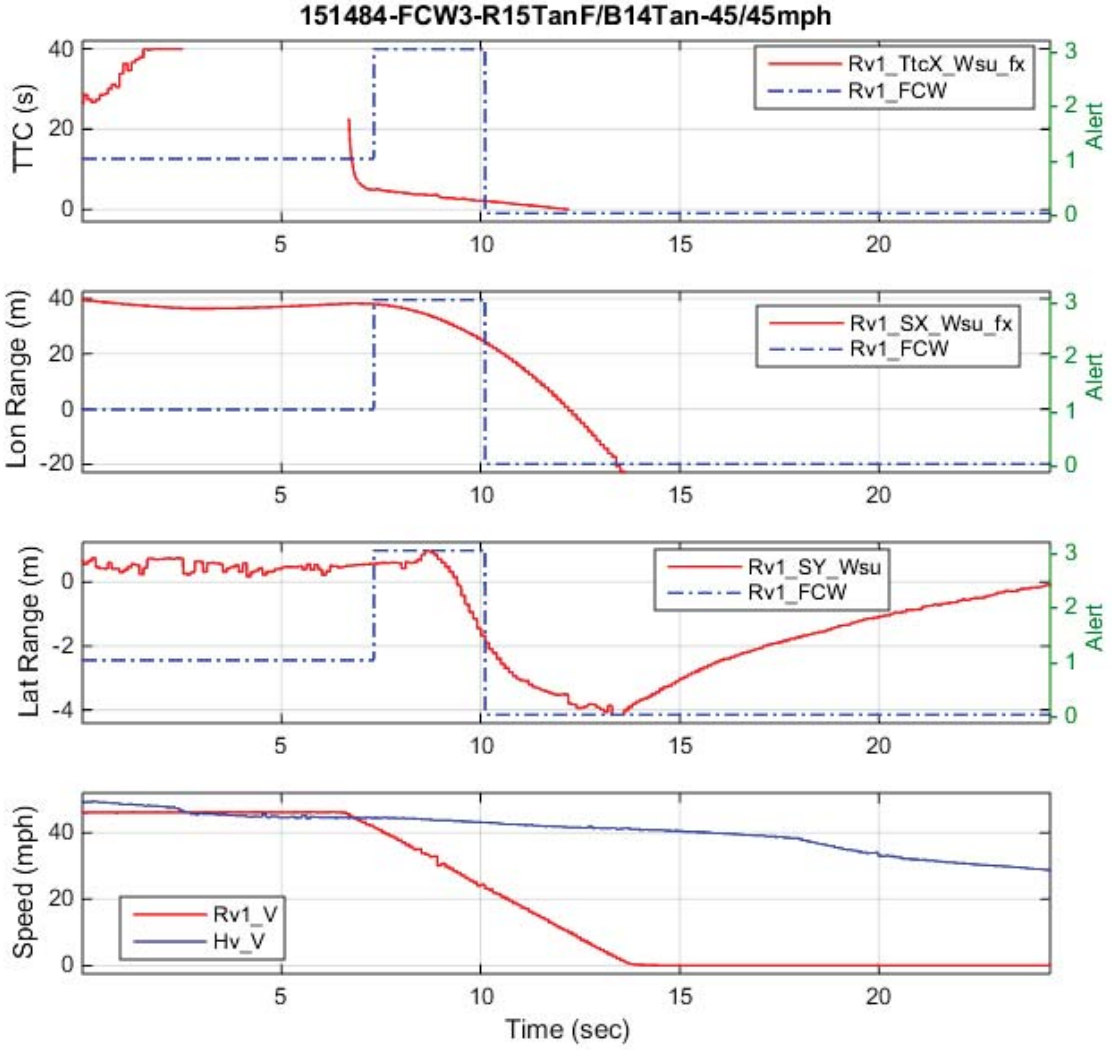


Figure 10: Example FCW-3 Test Results – TTC, Longitudinal Range, Lateral Range, and Speed – Test 1484

TTC and lateral range values as determined from the WSU data are presented in Table 7 for each HV trailer and RV or RV trailer combination evaluated. Mean, standard deviation, and coefficient of variation values are presented. More complete data for each individual test are presented in Appendix B, Section B.3. WSU, RT, and GPS data are presented for both Level 2 and Level 3 alert onset in the appendix. The mean TTC values ranged from 3.8 to 5.9 seconds (more than a 2 second range). Most of this variability is due to the HV generally being close

enough to the RV that when the RV starts to brake the HV issues an alert very shortly thereafter. This occurs in part due to alerts being issued very early by the WSUs on the Cascadia trucks. For most of the trials the HV went from a Level 1 tracking to a Level 3 alert shortly after the application of the brakes (as shown in example plots in Figure 10). The major exception to this was the HV/RV trailer combination of 53' Box/40' Shipping Container that had a much larger longitudinal distance between the HV and RV at the Level 3 alert (112.6 meters on average versus average values of 26.8 to 42.8 meters for other combinations).

Table 7: FCW-3 WSU TTC and Longitudinal Range Values at FCW Level 3 Alert

HV Trailer	RV/RV Trailer	TTC (s)			Longitudinal Range (m)		
		Mean	Std. Dev.	C. of V. (%)	Mean	Std. Dev.	C. Of V. (%)
Double 28' - F	53' Box	3.8	0.3	9.1	32.3	0.8	2.5
Double 28' - F	Double 28'	4.9	0.3	6.4	42.8	3.5	8.1
53' Box	40' Ship.	5.9	0.3	4.7	112.6	3.0	2.7
Bobtail	Honda Odyssey	3.4	0.4	12.7	26.8	2.4	8.8

Boxplots for the TTC values at the Level 2 and Level 3 FCW Alert onset are shown in Figure 11 and Figure 12. The HV/RV trailer combination of Double 28' – Faux/Double 28' only had one test with a Level 2 alert. The 53'/40' combination had Level 2 alerts for all five tests. The range in TTC values for the Level 3 alerts was more than 3 seconds for the various combinations (a little under 3 seconds to over 6 seconds).

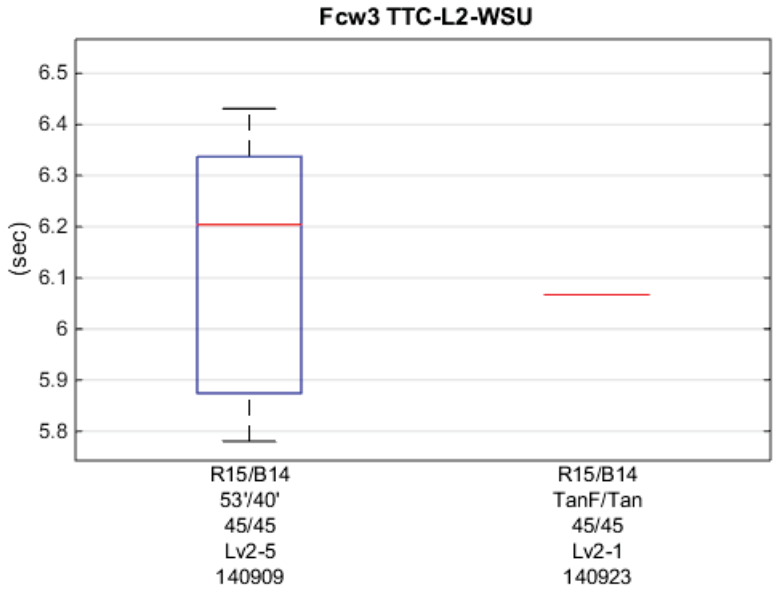


Figure 11: FCW-3 Boxplots of TTC at FCW Level 2 Alert – WSU Data

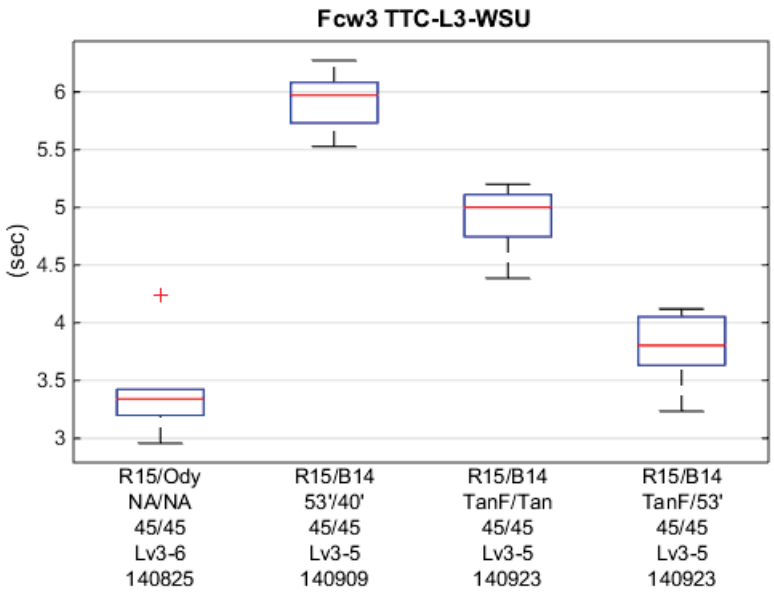


Figure 12: FCW-3 Boxplots of TTC at FCW Level 3 Alert – WSU Data

The mean, standard deviation, and coefficient of variation for the longitudinal range at RV brake onset and the average RV deceleration are given in Table 8. The average RV deceleration fell within a fairly tight window of -2.6 to -2.9 m/s/s. As was also seen above for the longitudinal range at FCW Level 3 Alert, the average longitudinal range at RV brake onset had a very wide range (29.4 to 130.1 meters).

Table 8: FCW-3 WSU Longitudinal Range at RV Brake Onset and Average RV Deceleration

HV Trailer	RV/RV Trailer	Longitudinal Range at Brake Onset (m)			Average RV Deceleration (m/s/s)		
		Mean	Std. Dev.	C. of V. (%)	Mean	Std. Dev.	C. Of V. (%)
Double 28' - F	53' Box	32.9	1.0	2.9	-2.7	0.2	10.6
Double 28' - F	Double 28'	43.4	3.9	8.9	-2.7	0.1	5.3
53' Box	40' Ship.	130.1	1.4	1.1	-2.9	0.3	11.2
Bobtail	Honda Odyssey	29.4	2.5	8.3	-2.6	0.3	11.5

The average TTC at Level 3 FCW Alert is plotted as a function of average longitudinal range at brake onset for the various HV/RV combinations in Figure 13. There are only a few data points, but it appears that the TTC increases with longitudinal range up to a point where it would start to plateau. This makes sense from an operational standpoint of the system as well. If the HV/RV longitudinal range is such that a TTC lower than the threshold for a Level 3 alert is achieved very shortly after the onset of braking, then the system will issue an alert very soon after braking. If the longitudinal range is such that the HV is outside the range of a TTC that initiates an FCW alert, then the alert will be delayed until the HV gets close enough to reach the TTC threshold.

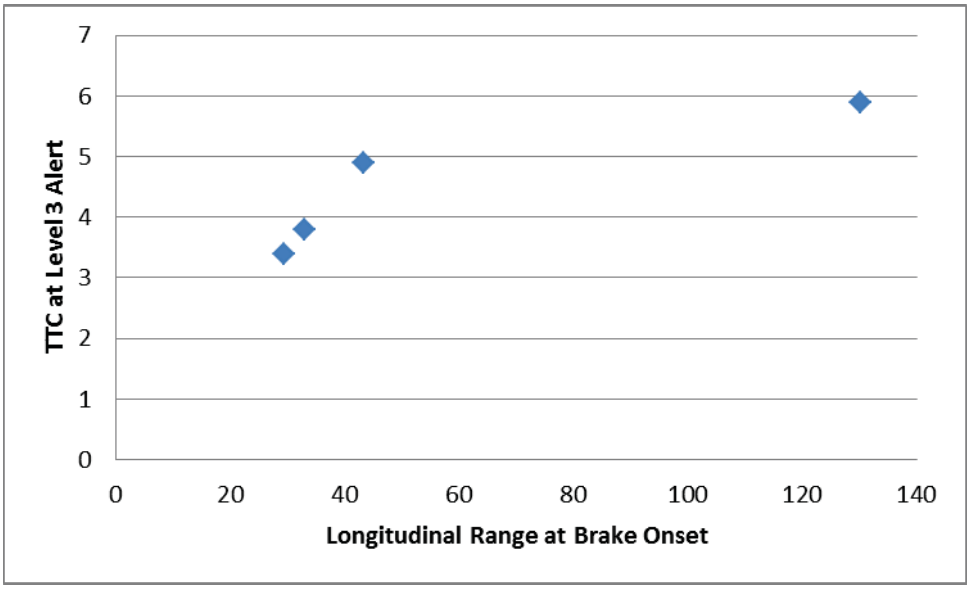


Figure 13: Average TTC at Level 3 Alert as a Function of Average Longitudinal Range at Brake Onset

Given the results presented above, it is important to determine what the main metric/result from this test procedure should be. If the main result is to determine when an FCW-3 alert is issued by the system, then preliminary tests that determine how far the HV and RV need to be separated to guarantee that the HV does not alert shortly upon RV brake onset must be conducted. If a TTC threshold for warning is the main result, i.e, the V2V system must issue an alert by a TTC of XX seconds, then it is only important to select a longitudinal range and RV deceleration rate that will guarantee an initial TTC greater than the threshold. Another potential result/metric could be how quickly does the V2V system issue an alert given that the HV is below a certain TTC threshold almost immediately upon braking onset.

4.4 FCW-4: Stopped Vehicles in Adjacent Lanes, Straight Road

For the FCW-4 test procedure two leading RVs are driven along a straight roadway in the same direction but in separate lanes such that there is one open lane between the two vehicles. Each leading vehicle is decelerated by brake application to a stop such that the trailing edges of the two leading vehicles are aligned laterally across the travel lanes. The HV is driven behind and in the same direction as the leading RVs in the open lane. Initially, the HV is separated from the leading vehicles by a distance greater than the FCW application's alert range. The HV is driven in the open lane of travel toward, between, and past the stopped leading vehicles. No FCW alerts should occur. Details for this test procedure can be found in Appendix A, Section A.11. For the tests conducted in this study the HV speed was 45 mph.

The HV and RV combinations evaluated with the FCW-4 test procedure are listed in Table 9. There were two combinations of vehicles evaluated. The Red Cascadia Bobtail was the HV for both cases. The Honda Odyssey was RV1 for one combination with no RV2. These tests were done in conjunction with other testing and were just a quick check of how the WSU on the Red Cascadia would perform in the test procedure. The second combination had the Mack and the Blue Cascadia both with 53' Box Trailers attached. There were 10 trials with the first

combination of vehicles and five trials with the second combination of vehicles. No alerts occurred in any of the tests.

Table 9: FCW-4 HV/RV Combinations Evaluated and Results

HV	RV1	RV2	No. of Trials	No. of Alerts
Red Cascadia Bobtail	Honda Odyssey	-	10	0
Red Cascadia Bobtail	Mack w/ 53' Box	Blue Cascadia w/ 53' Box	5	0

4.5 FCW-5: Stopped Vehicle Ahead in Same Lane, Curved Road

For the FCW-5 test procedure, two vehicles travel along a curved roadway in the same lane of travel and in the same direction. The two vehicles are separated by a distance greater than the FCW application's alert range. The leading RV brakes to a stop in the lane of travel. The trailing HV drives in the same lane of travel toward the stopped RV and enters the FCW application's alert range. Details for this test procedure can be found in Appendix A, Section A.12. The FCW-5 test procedure is very similar to the FCW-1 test procedure except that the stopped RV is on a curved roadway. Details for the curved roadway used in this study can be found in Appendix A - Section A.7. For the tests conducted in this study, the HV initial speed was 45 mph.

The HV was the Red Cascadia and the RV was the Blue Cascadia. The HV trailer and RV Trailer combinations evaluated are presented in Table 10 as well as the number of tests conducted for each combination.

Table 10: FCW-5 HV and RV Trailer Combinations Evaluated

HV Trailer	RV Trailer	Number of Tests Conducted
Bobtail	Double 28'	5
Bobtail	40' Shipping Container	Two sets of 5
53' Box	40' Shipping Container	5

Example test results for an FCW-5 test are shown in Figure 14. The TTC, longitudinal range, and lateral range from the HV to the RV and the HV and RV Speed are shown. The FCW alert level is also shown. The FCW alert level rises from 0 to 1 near 6.5 seconds, 1 to 2 near 7.75 seconds, and 2 to 3 near 8.5 seconds. The drop to 0 occurs near 10.75 seconds as the HV starts to move to the adjacent lane (noted by the change in lateral range in the third subplot). There is a spike up in the WSU determined lateral range from roughly -5 meter to nearly 0 meters between 13 and 14 seconds that causes the system to issue a secondary FCW Level 3 alert as the Red Cascadia passes the Blue Cascadia. This spike is not real, but does explain the secondary alert. The spike up in the lateral range occurred fairly frequently and the level of the spike was high enough to cause the second Level 3 alert to occur 4 times out of the 20 tests conducted. The WSU lateral range is quite oscillatory which is not real, but must be an artifact of the calculation due to the vehicles being on a curve. Even though the RV is stationary for this test, the path history is for the curve.

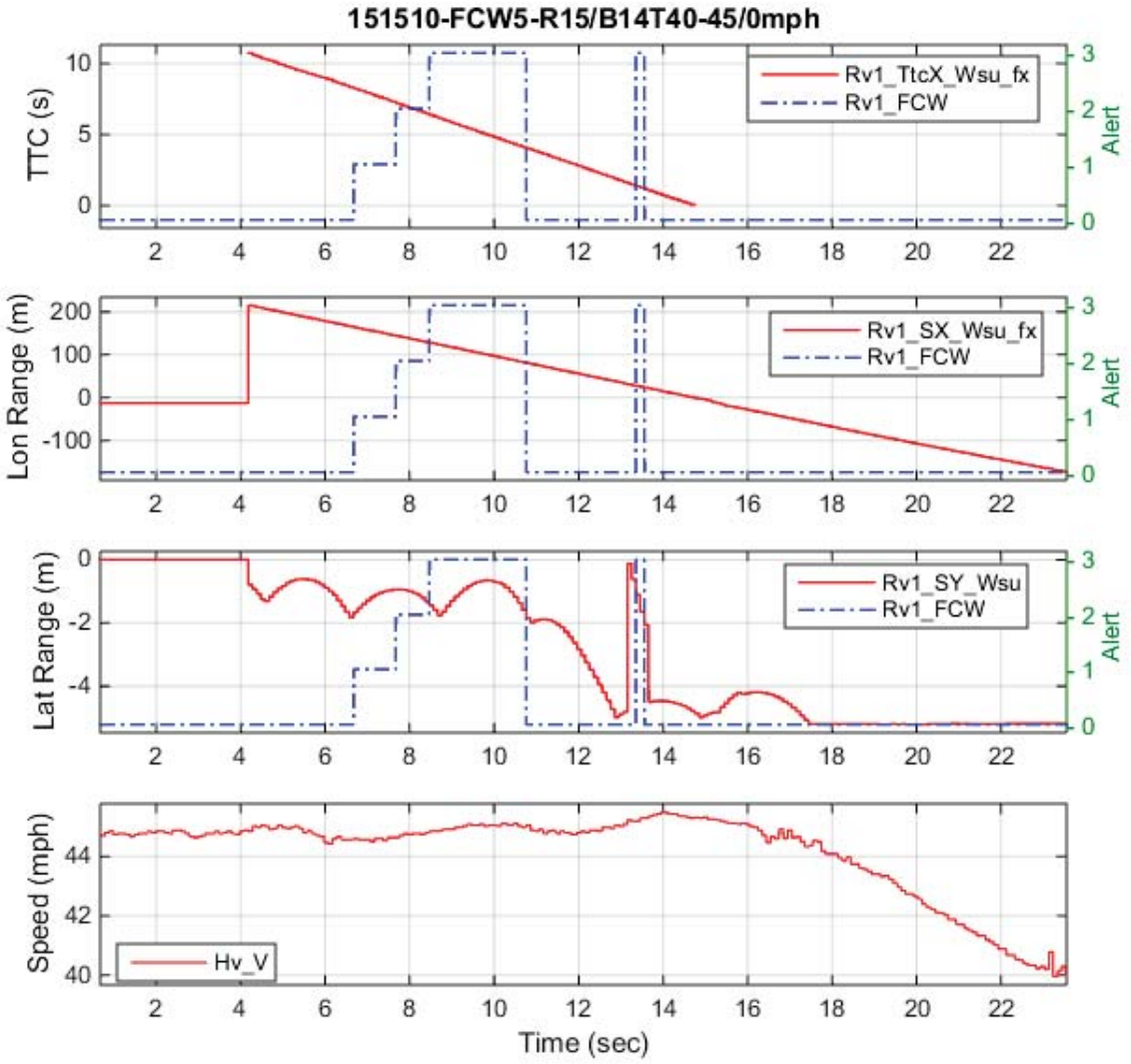


Figure 14: Example FCW-5 Test Results – TTC, Longitudinal Range, Lateral Range, and Speed – Test 1510

TTC and lateral range values as determined from the WSU data are presented in Table 11 for each HV trailer and RV trailer combination evaluated. Mean, standard deviation, and coefficient of variation values are presented. More complete data for each individual test are presented in Appendix B, Section B.4. WSU, RT, and GPS data are presented for both Level 2 and Level 3 alert onsets in the appendix. The mean TTC values ranged from only 6.3 to 6.4 seconds. The standard deviations were 0.1 seconds and the coefficients of variation ranged from 0.3 percent to 0.9 percent. The mean longitudinal range varied from only 126 to 128 meters with standard deviation of 2 meters or less and coefficients of variation of 2 percent or less.

Table 11: FCW-5 WSU TTC and Longitudinal Range Values at FCW Level 3 Alert

HV Trailer	RV Trailer	TTC (s)			Longitudinal Range (m)		
		Mean	Std. Dev.	C. of V. (%)	Mean	Std. Dev.	C. of V. (%)
Bobtail	Double 28’	6.3	0.0	0.8	126	2	2
Bobtail	40’ Shipping Container	6.4	0.0	0.3	128	0	0
Bobtail	40’ Shipping Container	6.3	0.0	0.8	125	2	1
53’ Box	40’ Shipping Container	6.3	0.1	0.9	127	1	1

Comparing the results for the tests with the RV 40’ Shipping Container, the two sets of test with the HV bobtail have only a 0.1 second difference in the mean TTC values and a 3 meter difference in the mean longitudinal range. Adding the 53’ Box trailer to the HV did not influence results with the mean TTC value being the same as one of the two sets for the HV bobtail condition and the mean longitudinal range (127 meters) falling between the values for the two sets (128 and 125 meters).

Boxplots for the TTC values at the Level 2 and Level 3 FCW Alert onset are shown in Figure 15 and Figure 16. There was a very narrow range of TTC values for both the Level 2 alerts (6.95 to 7.22 seconds with one outlier less than 6.9 seconds) and the Level 3 alerts (6.23 to 6.4 seconds with one outlier around 6.42 seconds).

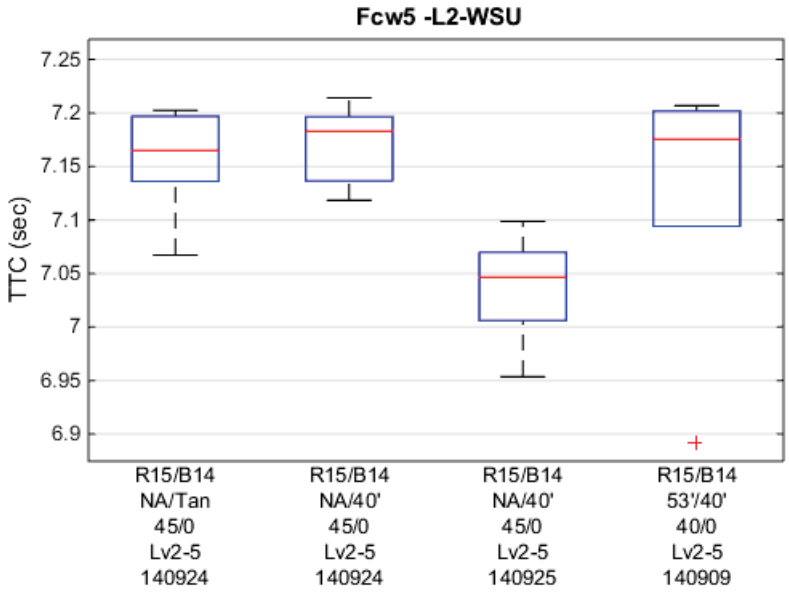


Figure 15: FCW-5 Boxplots of TTC at FCW Level 2 Alert – WSU Data

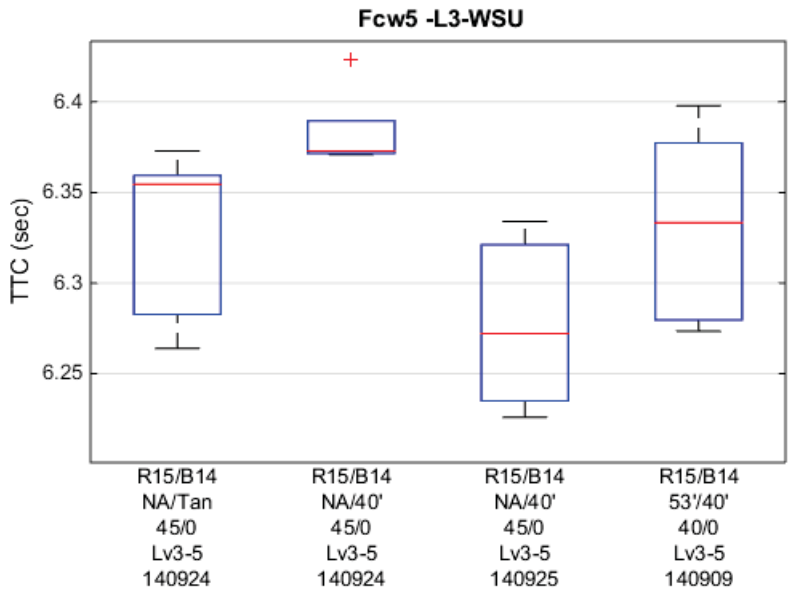


Figure 16: FCW-5 Boxplots of TTC at FCW Level 3 Alert – WSU Data

In summary, the WSU on the Red Cascadia gave a consistent alert (Level 2 and Level 3) for all the test conditions evaluated with the FCW-5 test procedure, but in 4 out of 20 tests gave a Level 3 alert as the Red Cascadia, in an adjacent lane, passed the various RV combinations.

4.6 FCW-6: Stopped Vehicle Ahead in Adjacent Lane, Curved Road

For the FCW-6 test procedure a leading RV is driven along a curved roadway and is decelerated by brake application to a stop. The HV is driven behind and in the same direction as the leading vehicle but in an adjacent lane. Initially, the HV is separated from the leading vehicle by a distance greater than the FCW application's alert range. The HV is driven in the adjacent lane toward and past the stopped RV. Details for this test procedure can be found in Appendix A, Section A.13. The FCW-6 test procedure is very similar to the FCW-4 test procedure except that the stopped RV is on a curved roadway. Details for the curved roadway used in this study can be found in Appendix A - Section A.7. For the tests conducted in this study the HV speed was 45 mph.

The HV was the Red Cascadia and the RV was the Blue Cascadia. The HV trailer and RV trailer combinations evaluated are presented in Table 12 as well as the number of tests conducted for each combination. The test procedure currently calls for the RV to be on the inner lane of the curve with the HV passing on the outer lane, but tests were conducted with the RV on both the inner and outer lane for most combinations.

Table 12: FCW-6 HV and RV Trailer Combinations Evaluated

HV Trailer	RV Trailer	Number of Tests Conducted	
		RV Outer	RV Inner
Bobtail	Double 28’	6	5
Bobtail	40’ Shipping Container	Two sets of 5	Two sets of 5
53’ Box	40’ Shipping Container	-	5

None of the FCW-6 tests with the RV on the inner lane produced alerts on the HV WSU. Tests with the RV in the outer lane were observed to produce FCW Level 3 alerts on the HV WSU in 10 out of 16 tests performed. A false positive FCW alert is an FCW alert that is given when no imminent crash threat is present. A summary of the number of tests with false positive alerts is given in Table 13.

Table 13: FCW-6 Number of Tests With False Positive Alerts

HV Trailer	RV Trailer	Number of Tests with FCW Alerts	
		RV Outer	RV Inner
Bobtail	Double 28’	2 of 6	0 of 5
Bobtail	40’ Shipping Container	4 of 5	0 of 5
Bobtail	40’ Shipping Container	4 of 5	0 of 5
53’ Box	40’ Shipping Container	-	0 of 5

TTC and lateral range values as determined from the WSU data are presented in Table 14 for each HV trailer and RV trailer combination evaluated that had false positive alerts. Mean, standard deviation, and coefficient of variation values are presented. These values are obviously only calculated for the tests that had alerts. More complete data for each individual test are presented in Appendix B, Section B.5. WSU, RT, and GPS data are presented for Level 3 alert onset in the appendix. The mean TTC values ranged from 0.9 to 1.3 seconds and the mean longitudinal range values were 18 to 25 meters. These values show that the alerts for this test procedure were much later (HV closer to RV) than what occurred with the FCW-5 tests (stopped vehicle in same lane).

Table 14: FCW-6 WSU TTC and Longitudinal Range Values at FCW Level 3 Alert

HV Trailer	RV Trailer	TTC (s)			Longitudinal Range (m)		
		Mean	Std. Dev.	C. of V. (%)	Mean	Std. Dev.	C. Of V. (%)
Bobtail	Double 28’	1.3	0.0	0.0	25	0	1
Bobtail	40’ Shipping Container	1.3	0.1	5.6	25	1	6
Bobtail	40’ Shipping Container	0.9	0.2	22.7	18	4	23

An example HV path map for an RV on the Inner Lane test is shown in Figure 17 and example longitudinal and lateral range traces are shown in Figure 18. Both the WSU determined ranges (red) and ranges determined using GPS data (dashed blue) are presented. The WSU and GPS longitudinal range traces are in very good agreement, but the WSU lateral range has a scalloped oscillating shape that as the HV approaches the RV has a mean value that is close to what was determined using the GPS data (oscillates around the GPS mean), but deviates dramatically after

the HV has passed the RV (near 16 seconds and later). No alert was issued even though the WSU lateral range goes to zero because the HV has passed the RV at this point.

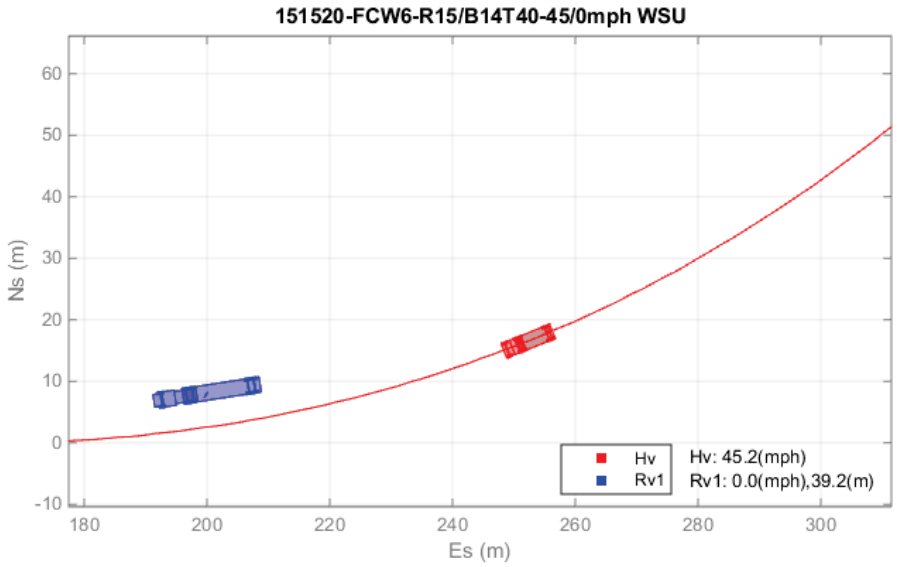


Figure 17: Example HV Path for FCW-6 Test With RV in Inner Lane

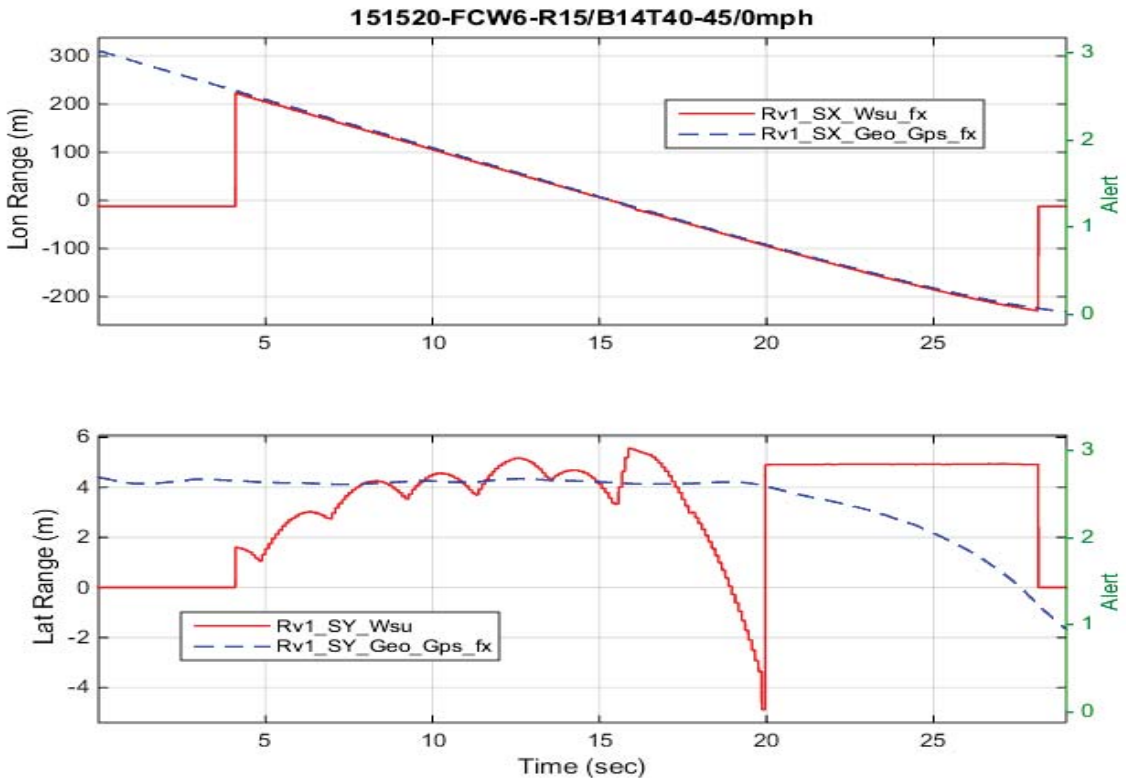


Figure 18: Example FCW-6 HV to RV Longitudinal and Lateral Range Traces for RV in Inner Lane – No Alert Case

An example HV path map for an RV on the Outer Lane test is shown in Figure 19 and example longitudinal and lateral range traces are shown in Figure 20. Both the WSU and GPS determined ranges are presented. The WSU and GPS longitudinal range traces are in good agreement with some deviation as the HV passes the RV. The WSU lateral range has a scalloped oscillating shape that as the HV approaches the RV has a mean value that is close to what was determined using the GPS data, but then deviates dramatically in the 13 to 14 second range. The spike up in the lateral range would suggest that the HV jumped from being to the inside of the RV to it being on the outside (negative values jumping to positive values). As the WSU determined lateral range "returns" to the HV being back to the inside of the RV, an FCW Level 3 alert is issued for a brief period of time as the WSU lateral range passes through 0 (just before 14 seconds).

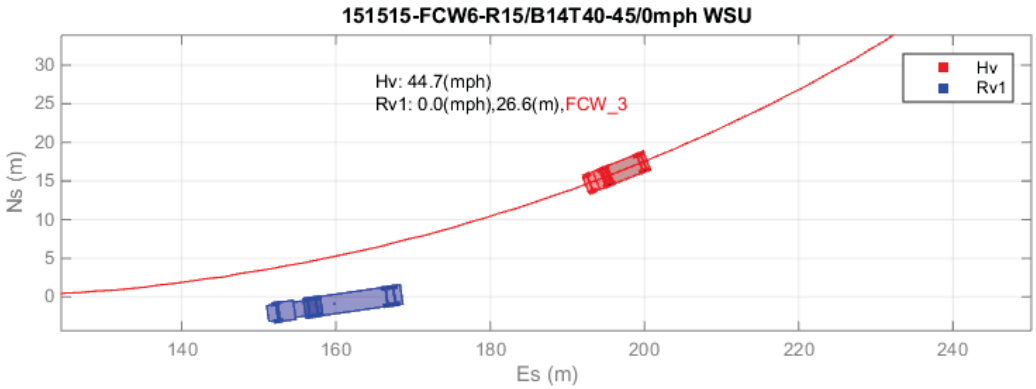


Figure 19: Example HV Path for FCW-6 Test With RV in Outer Lane

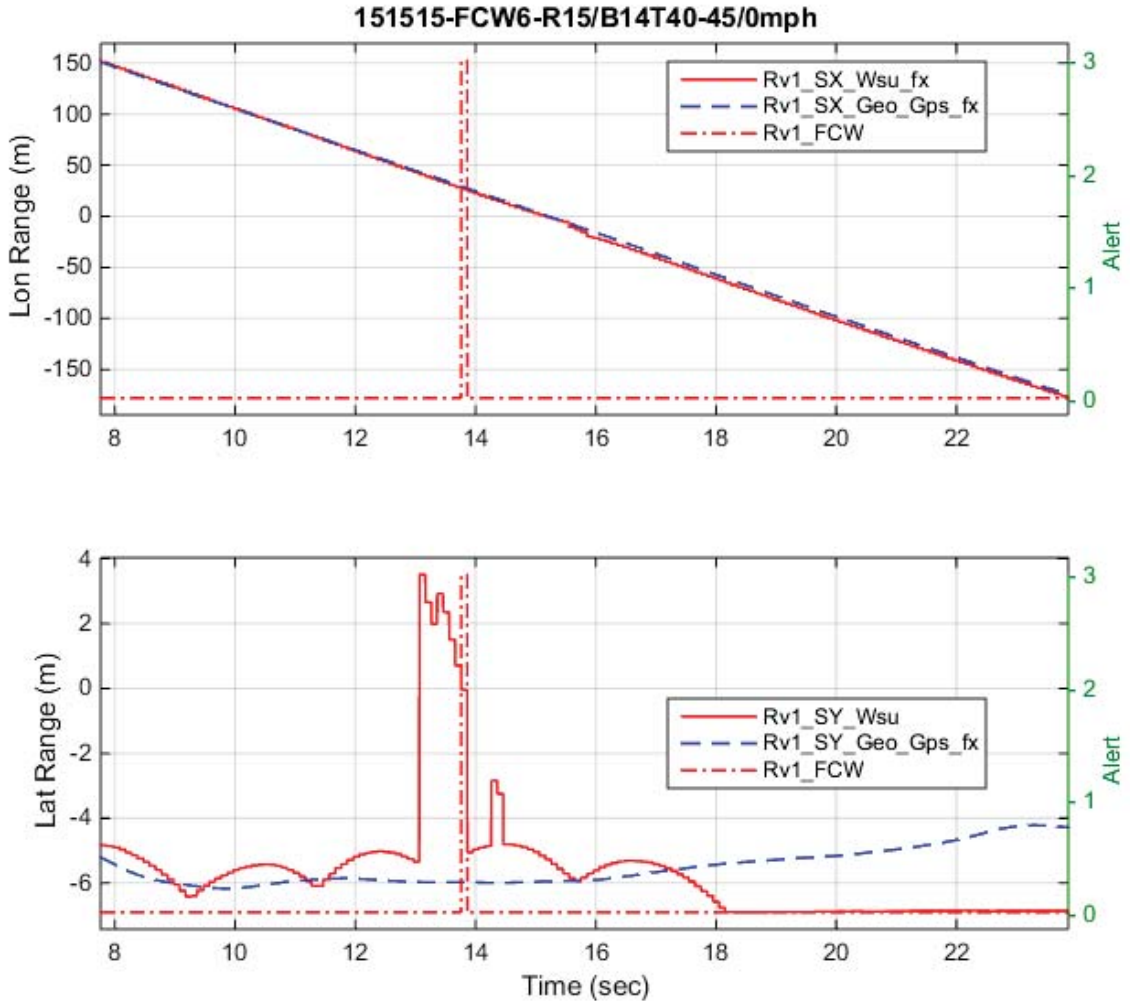


Figure 20: Example FCW-6 HV to RV Longitudinal and Lateral Range Traces for RV in Outer Lane – False Positive Alert Case – Test 1515

4.7 FCW-7: Lane Change Reveal

For the FCW-7 test procedure, three vehicles travel along a straight roadway in the same lane of travel and in the same direction. The driver of the leading vehicle, RV2, applies the vehicle service brakes and stops the vehicle in the lane of travel. The driver of the intermediate vehicle, RV1, steers the vehicle into an adjacent lane to avoid the stopped leading vehicle. Thus, the stopped RV2 is revealed to the moving trailing HV. Details for this test procedure can be found in Appendix A, Section A.14. For the tests conducted in this study, the initial speed for the RV1 and HV was 45 mph.

The HV was the Red Cascadia, the RV1 was the Mack and the RV2 was the Blue Cascadia. The HV was always run Bobtail. The RV trailer combinations evaluated are presented in Table 15 as well as the number of tests conducted for each combination.

Table 15: FCW-7 HV and RV Trailer Combinations Evaluated

RV1 Trailer	RV2 Trailer	Number of Tests Conducted
53’ Box	53’ Box	5
40’ Shipping Container	53’ Box	6
Double 28’	53’ Box	5

Example test results for an FCW-7 test are shown in Figure 21. The TTC, longitudinal range, and lateral range from the HV to the RVs and the HV and RV2 Speed (RV1 speed 0 for this test) are shown. The FCW alert level is also shown in the first three subplots. The FCW alert level rises from 0 to 1 near 17.5 seconds, 1 to 2 near 18.5 seconds and 2 to 3 near 19.5 seconds. It then drops to 0 near 22 seconds and back up to 3 for a brief period near 23 seconds. This occurs as the HV starts to go around the RV (as noted by the change in the lateral range.

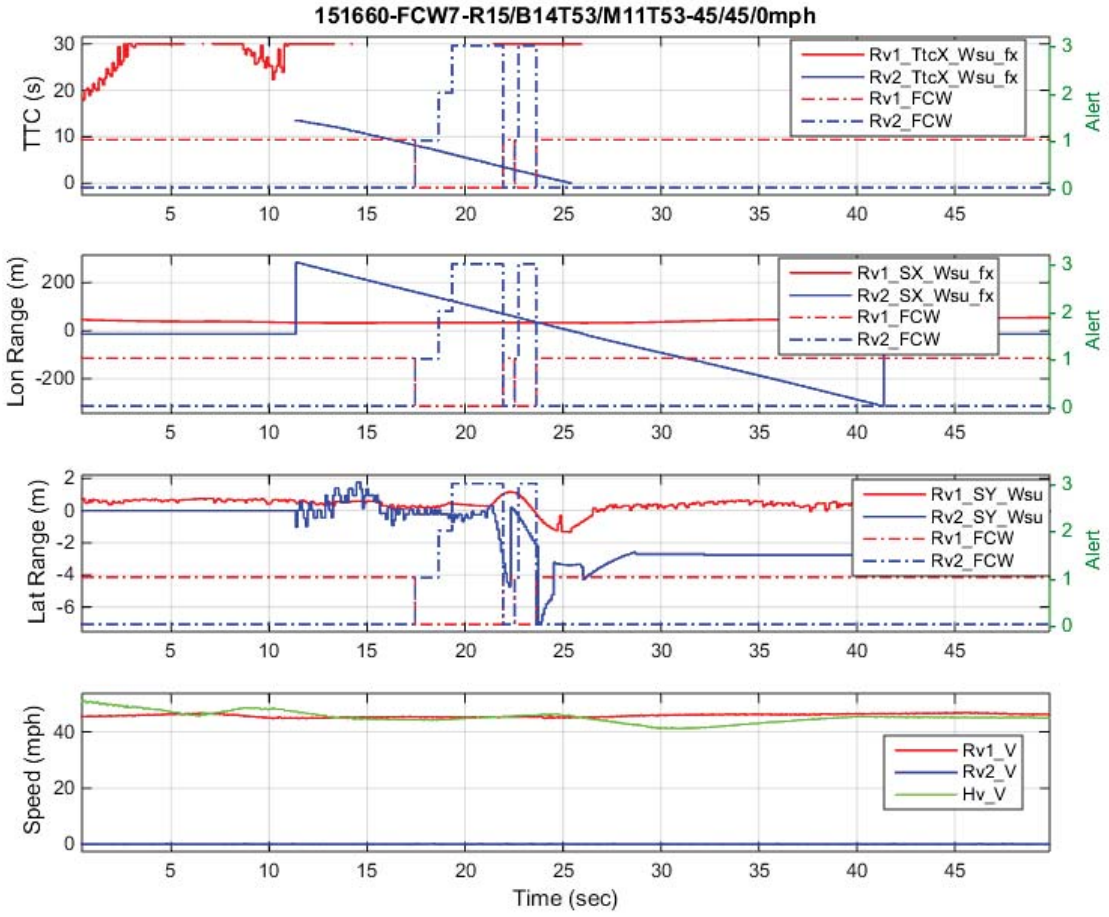
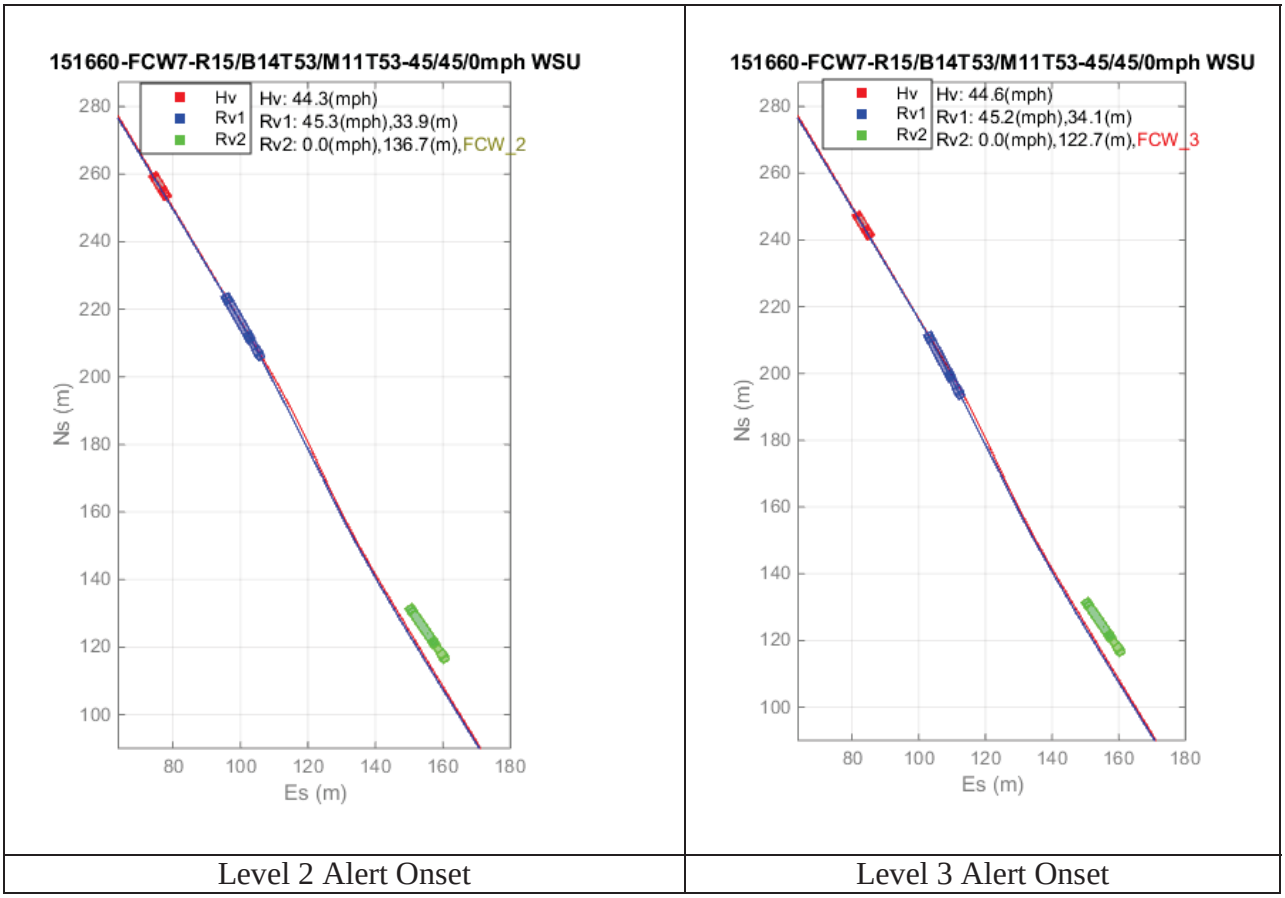


Figure 21: FCW 7 – TTC, Long. Range, Lat. Range, and Speeds – Test 1660

Example path maps for the HV, RV1, and RV2 are shown in Figure 22. The vehicle positions at FCW Level 2 and Level 3 Alert onsets are shown. The HV gets the alert before the RV1 "blocking" vehicle makes significant movement out of the initial lane.



Level 2 Alert Onset	Level 3 Alert Onset

Figure 22: FCW-7 Vehicle Path and Position at Alert Onsets - WSU Data

TTC and lateral range values as determined from the WSU data are presented in Table 16 for each RV1 and RV2 trailer combination evaluated. Mean, standard deviation, and coefficient of variation values are presented. More complete data for each individual test are presented in Appendix B, Section B.6. WSU, RT, and GPS data are presented for both Level 2 and Level 3 alert onset in the appendix. The mean TTC values ranged from 6.2 to 6.3 seconds for all the trailer combinations and the standard deviation was 0.1 seconds or less with coefficients of variation ranging from 0.6 percent to 1.0 percent. The mean longitudinal range varied from 125 to 126 meters, the standard deviations varied from 1 to 2 meters, and the coefficients of variation were 1 percent.

Table 16: FCW-7 WSU TTC and Longitudinal Range Values at FCW Level 3 Alert

RV1 Trailer	RV2 Trailer	TTC (s)			Longitudinal Range (m)		
		Mean	Std. Dev.	C. of V. (%)	Mean	Std. Dev.	C. Of V. (%)
53’ Box	53’ Box	6.3	0.0	0.6	126	1	1
40’ Ship. Container	53’ Box	6.3	0.0	0.8	125	2	1
Double 28’	53’ Box	6.2	0.1	1.0	126	2	1

Boxplots for the TTC values at the Level 2 and Level 3 FCW Alert onset are shown in Figure 23 and Figure 24. The first line of the label is the vehicle combination where R15 represents the Red Freightliner Cascadia and Vr11 represents the Mack, the second line represents the HV/RV2 trailer lengths, the third line represents the HV/RV2 nominal speeds in mph, and the fourth line is the alert level and number of tests. There is a very narrow range of TTC values for both the Level 2 alerts (roughly 6.95 to 7.25 seconds including one outlier) and the Level 3 alerts (6.18 to 6.34 seconds including two outliers) for the various RV trailer combinations evaluated.

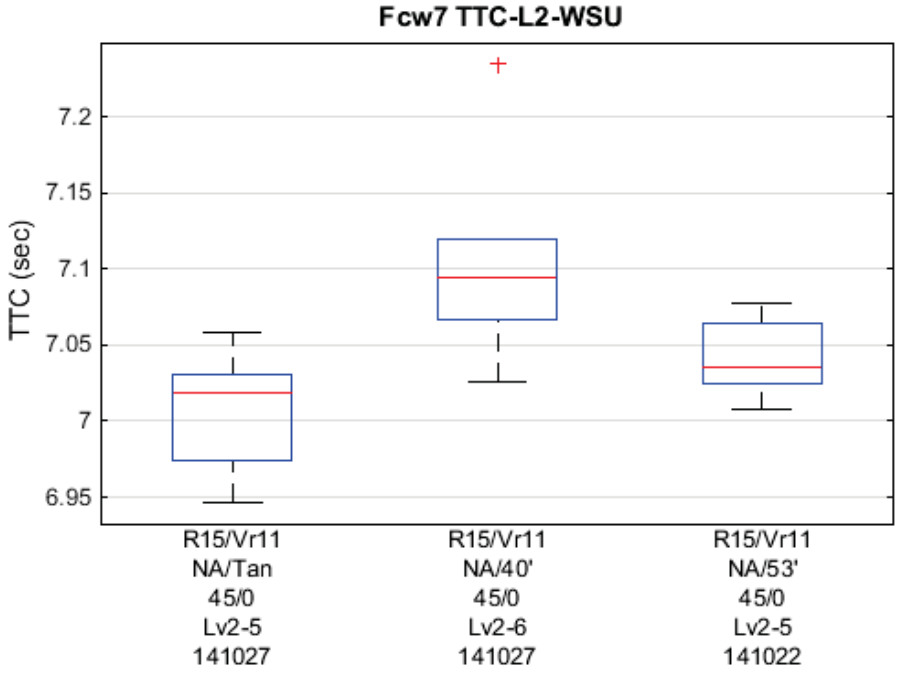


Figure 23: FCW-7 Boxplots of TTC at FCW Level 2 Alert – WSU Data

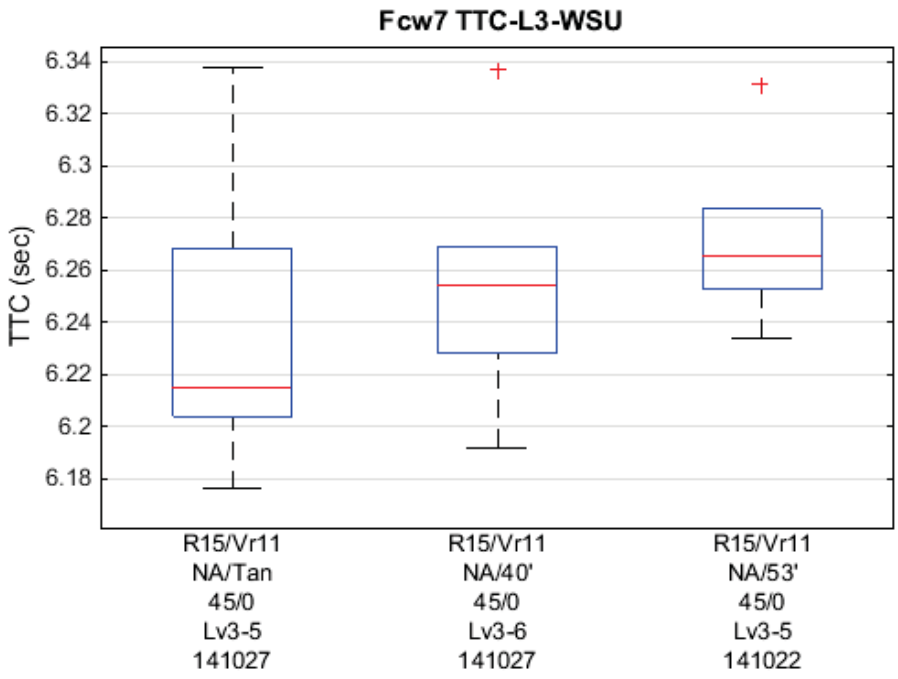


Figure 24: FCW-7 Boxplots of TTC at FCW Level 3 Alert – WSU Data

The only difference between the FCW-7 test procedure and the FCW-1 test procedure is the addition of the blocking vehicle (RV1). The mean, standard deviation, and range of TTC values for the FCW-7 tests are very comparable to the results from the FCW-1 tests. The TTC value ranged from 6.15 to 6.45 seconds for the Level 3 alerts for the FCW-1 tests and from 6.18 to 6.34 seconds for Level 3 alerts for the FCW-7 tests (there were more combinations evaluated for the FCW-1 test procedure). Adding the blocking vehicle to the test procedure appears to have little or no effect on the alert timing.

4.8 FCW-8: Tailgate

For the FCW-8 test procedure two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The two vehicles travel at the same velocity and are separated by a minimal distance such that the trailing HV tailgates the leading RV. Details for this test procedure can be found in Appendix A, Section A.15. For the testing conducted in this research the HV and RV speeds were both either 25 or 55 mph.

The HV was the Red Cascadia (bobtail) and the RV was the Blue Cascadia. The RV trailer combinations evaluated are presented in Table 17 along with the number of tests for each speed evaluated. The RV was either run bobtail or with a faux 53’ trailer, which means the trailer setting on the I-Pad display was set to 53’, but the trailer was not physically in place. This allowed the HV to get closer to the RV while reducing the chance of contact with the actual trailer. Two sets of runs were conducted because after analyzing the first set of data it was determined that the I-Pad display was showing FCW Level 2 warnings even though the data being broadcast in the Basic Safety Message (BSM data from the WSU) did not show a warning being issued. For the second set of runs, the HV was driven closer to the RV to verify that the

BSM was broadcasting an alert. For the second set of runs, the 55 mph RV Bobtail combination was deemed unsafe to perform given the lack of an FCW Level 3 alert being obtained for the 25 mph Bobtail tests during the second set of runs.

Table 17: FCW-8 RV Trailer Combinations and HV/RV Speeds Evaluated

RV Trailer	HV and RV Speed	
	25 mph	55 mph
Bobtail	2 sets of 5	1 sets of 5
Faux 53’	2 sets of 5	2 sets of 5

The purpose of the FCW-8 test procedure is to determine the ability of the commercial vehicle’s V2V system to avoid presenting an alert when closely following another vehicle while both vehicles are maintaining the same velocity. The WSU system did not suppress the alert.

The number of I-Pad displayed warnings and the number of warnings broadcast in the BSM data for each combination of tests from the first round of testing are given in Table 18. Even though the I-Pad display showed an FCW Level 2 warning for each test conducted, the BSM only had an alert in 2 of 5 or 1 of 5 tests.

Table 18: FCW-8 Number of I-Pad and BSM Warnings for First Set of Tests

RV Trailer	I-Pad Warning		BSM Warning	
	25 mph	55 mph	25 mph	55 mph
Bobtail	5 of 5 Level 2	5 of 5 Level 2	2 of 5 Level 2	2 of 5 Level 2
Faux 53’	5 of 5 Level 2	5 of 5 Level 2	2 of 5 Level 2	1 of 5 Level 2

Included in the BSM warning/alert data is a “Threat Level” channel. The FCW Level 2 warning is issued when the FCW Threat Level channel is above 50. Example BSM FCW Alert and Threat Level data for tests without and with BSM Level 2 warnings being issued are shown in Figure 25 and Figure 26 respectively. The Threat Level threshold of 50 is shown as a horizontal line in the bottom subplot of each figure. The Threat Level stays below the 50 threshold during the first test and no FCW alert is issued for the data presented in Figure 25. The Threat Level goes above the 50 threshold for a period during the second test and an FCW alert (Level 2) is issued for the data presented in Figure 26. Both tests presented in the figure below were observed to result in FCW Level 2 alerts issued on the I-Pad display.

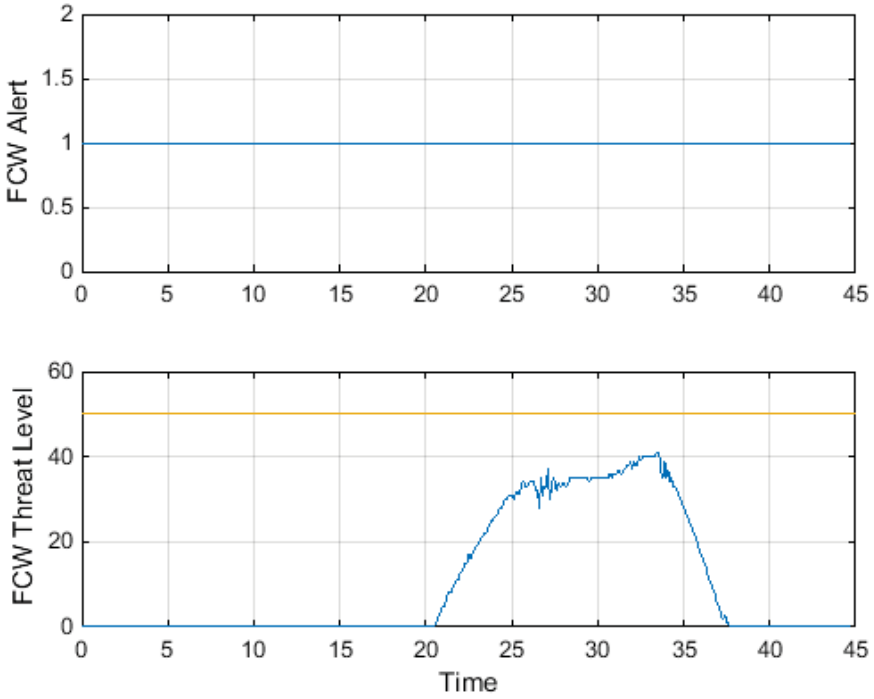


Figure 25: FCW Alert and Threat Level for Test With I-Pad Warning but No BSM Warning (Test 628_3)

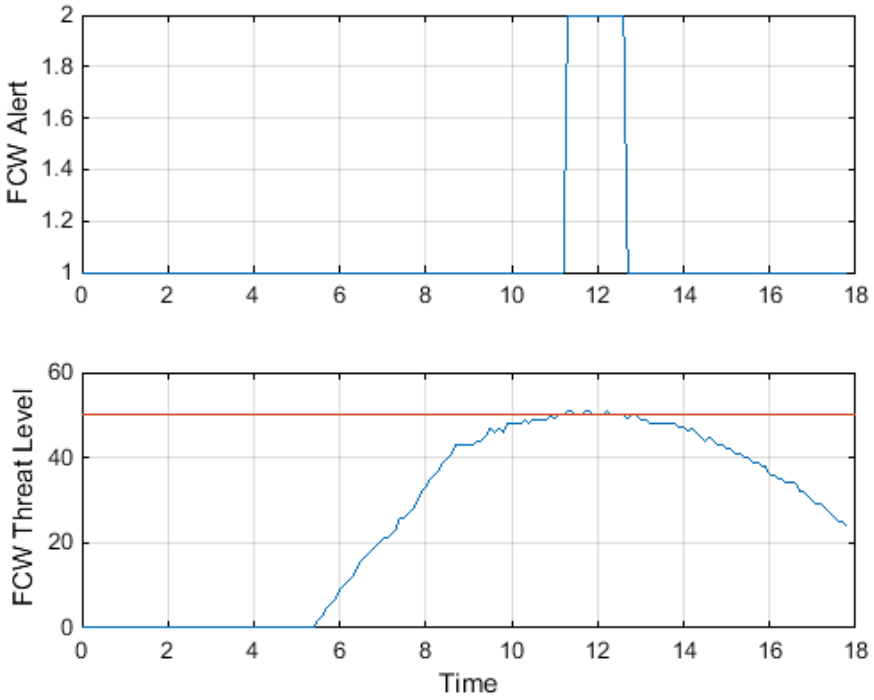


Figure 26: FCW Alert and Threat Level for Test With I-Pad Warning and BSM Warning (Test 628_10)

Given these results, a second set of tests were conducted in which the HV was driven closer to the RV to observe if the BSM data contained the FCW Level 2 Alert. The HV driver was then told to drive even closer to observe if an FCW Level 3 Alert would be issued. For the test with the Faux 53' trailer, FCW Level 3 alerts were observed. For the 25 mph Bobtail tests, the HV driver did not get close enough for an FCW Level 3 alert to occur. It was not felt safe to try and attempt to get an FCW Level 3 alert at 55 mph for the Bobtail RV and therefore testing was not conducted for this condition. The numbers of FCW Level 2 and Level 3 warnings are listed for this second set of tests in Table 19.

Table 19: FCW-8 Number of I-Pad and BSM Warnings for Second Set of Tests

RV Trailer	I-Pad Warning		BSM Warning	
	25 mph	55 mph	25 mph	55 mph
Bobtail	5 of 5 Level 2	NA	5 of 5 Level 2	NA
Faux 53'	5 of 5 Level 2 5 of 5 Level 3	5 of 5 Level 2 5 of 5 Level 3	5 of 5 Level 2 5 of 5 Level 3	5 of 5 Level 2 5 of 5 Level 3

The average and standard deviation for the longitudinal range between the HV and RV for the FCW Level 2 warnings are listed in Table 20. Similar values for the FCW Level 3 warnings are given in Table 21. The average values for the 25 mph Bobtail and Faux 53' Box Trailer were within 1 meter of each other for the FCW Level 2 warning (8.5 and 9.4 meters). The average value for the 55 mph Faux 53' Box Trailer tests was higher at 16.3 meters. The difference in the 25 and 55 mph Faux 53' Box Trailer longitudinal range at FCW Level 3 warning were closer in value than the values for the Level 2 warning with the 55 mph average value being less than 1 meter greater (6.4 and 7.3 meters respectively). Tabulated WSU data for each individual test is given in Appendix B, Section B.7.

Table 20: FCW-8 HV to RV Longitudinal Range at FCW Level 2 Warning – WSU Data

RV Trailer	Speed (mph)	HV to RV Longitudinal Range (m)	
		Average	Std. Dev.
Bobtail	25	8.5	0.7
Faux 53' Box	25	9.4	0.8
	55	16.3	1.0

Table 21: FCW-8 HV to RV Longitudinal Range at FCW Level 3 Warning – WSU Data

RV Trailer	Speed (mph)	HV to RV Longitudinal Range (m)	
		Average	Std. Dev.
Faux 53' Box	25	6.4	1.2
	55	7.3	0.8

4.9 FCW-9: Target Switch

For the FCW-9 test procedure three vehicles travel along a straight, multi-lane roadway in the same direction. The trailing HV approaches the intermediate vehicle, RV2, which is traveling in the same lane ahead of but slower than the HV. The leading vehicle, RV1, is traveling a short distance ahead of the RV2 in one of the adjacent lanes at a velocity slower than the RV2. As the three vehicles converge, RV1 moves to the lane occupied by the other two vehicles. Then RV2

moves to one of the adjacent lanes to avoid RV1 and the HV approaches the slower RV1. Details for this test procedure can be found in Appendix A, Section A.16. For the testing conducted in this research the HV speed was 45 mph, RV2 speed was 30 mph, and the RV1 speed was 20 mph.

The HV was the Red Cascadia, the RV1 (lead vehicle) was the Mack, and the RV2 (intermediate vehicle) was the Blue Cascadia. The HV was always run Bobtail. The RV trailer combinations evaluated are presented in Table 22 as well as the number of tests conducted for each combination.

Table 22: FCW-9 HV and RV Trailer Combinations Evaluated

RV1 Trailer	RV2 Trailer	Number of Tests Conducted
Double 28’	40’ Shipping Container	6
40’ Shipping Container	Double 28’	5

Example test results for a test with alerts that occur as intended for the test procedure are shown in Figure 27 (Test 1817). Longitudinal and lateral range traces are shown in the top and bottom subplot respectively. The data shown is from the HV WSU. The range traces show the range from the HV to the RV1 (blue) and from the HV to RV2 (green). In addition to the range traces, the FCW alert channels are also shown. For the longitudinal range traces (top subplot), the HV, RV1, and RV2 are at the respective test speeds at around 20 seconds as noted by the steadily decreasing longitudinal range values until approximately 42 seconds when the HV has moved out of lane to go around the RV1. The RV longitudinal range is initially larger and has a higher slope (decreases faster), which is consistent with the RV1 being the lead vehicle and only going 20 mph while RV2 is the intermediate vehicle and is going 30 mph. The HV initially gets FCW alerts for RV2 (Level 2 at roughly 34 seconds and Level 3 at roughly 35 seconds) and then an FCW Level 3 alert for RV1. The switch from Level 3 on RV2 to Level 3 on RV1 is instantaneous. The lateral range traces are shown in the lower subplot. The HV to RV2 lateral range is approximately -1 meter as the HV approaches RV2 and the HV to RV1 lateral range is approximately -5 meters. There is some jumping around in the data. Later figures show GPS data and the amount of chatter is much less for the GPS data. When the HV gets the initial alert for the RV2, RV1 and RV2 start to switch lanes as evidenced by the increase in the lateral range for both RV2 and RV1. There is a spike down in the RV2 range near 36 seconds, but then it continues to increase. When the lateral range for RV2 increases to about 2 meters, the FCW alert switches from RV2 to RV1. The RV1 lateral range at this point is approximately -1.5 meters. The FCW RV1 alert stays on until the RV1 lateral range increases to a little over +2 meters at approximately 42 seconds. The initial changes in the lateral ranges are due to the RV2 and RV1 switching lanes (from approximately 34 to 41 seconds), while the second change in lateral range is due to the HV switching lanes to avoid RV1. This is more evident in the following figure where the GPS lateral range data is also presented (GPS data was not available for Test 1817).

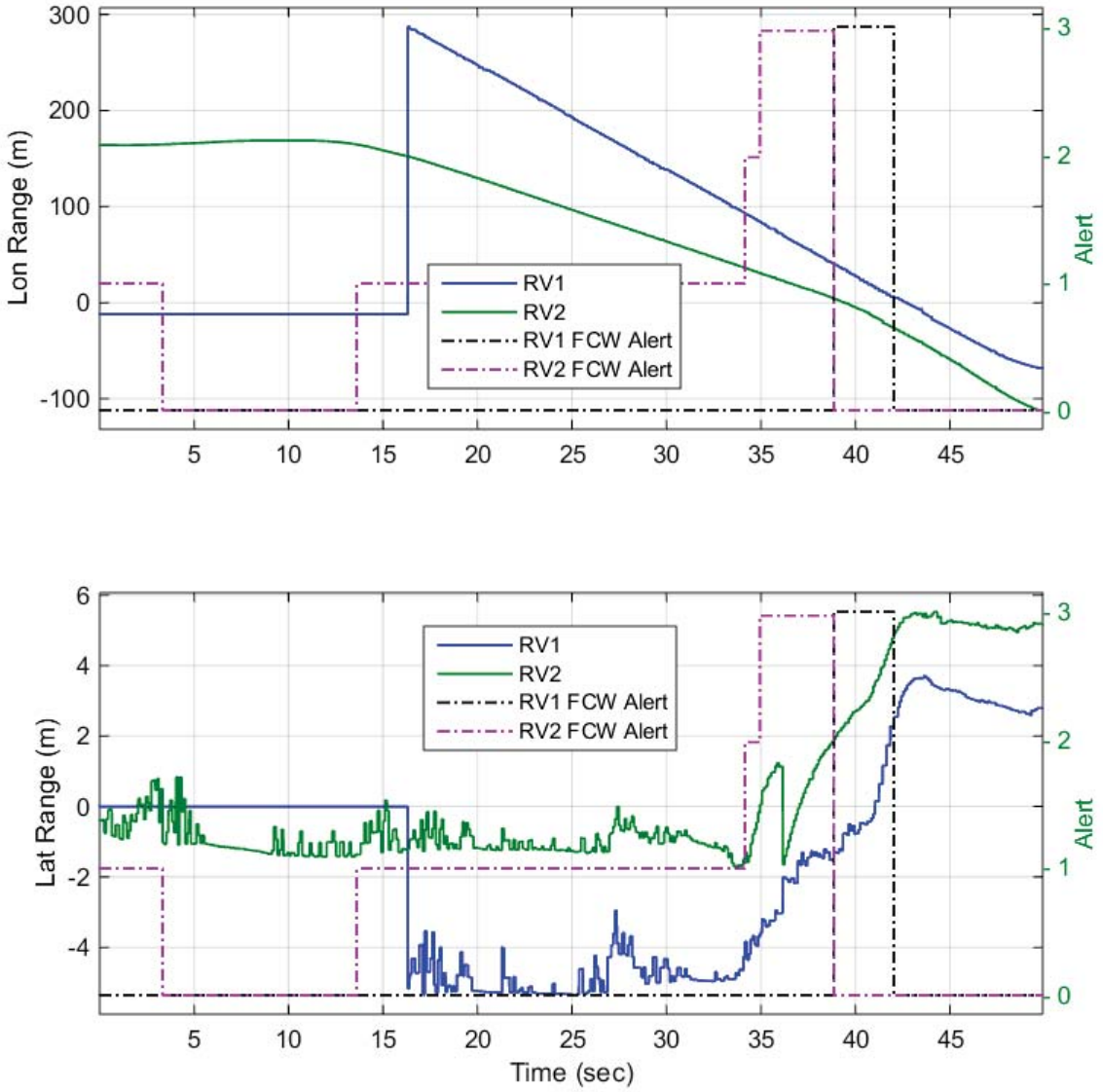


Figure 27: Example FCW-9 Test Results – Longitudinal and Lateral Range for Test 1817

Another example set of longitudinal and lateral range traces are shown in Figure 28 (Test 1814). The major difference between this figure and the previous is the addition of GPS data for the ranges. The GPS longitudinal range data (dashed lines) for both RV2 and RV1 are in good agreement with the WSU data (solid lines). The GPS lateral range data (lower subplot) has the same basic shape as the WSU data but there are some differences. The GPS data "leads" the WSU data for the initial lane change (RV1 and RV2 switching lanes starting around 30 seconds), but the GPS and WSU data have similar timing when the HV switches lanes (around 40 seconds). Why does this occur? One potential explanation is that the GPS and WSU data are representing different things especially for the vehicles with trailers. The GPS data is for a single GPS antenna roughly centered on the tractor for each vehicle combination (there were no GPS

antenna on the shipping container or the Double trailers – some 53’ trailer data had GPS antennas, but it was not used in the FCW-9 tests reported here). The lateral range for the WSU data is for the center of the tractor/trailer combination and therefore the RV2 and RV1 WSU range for the initial lane changes (RV1 and RV2 changing lanes) may appear delayed and slower relative to the GPS range data. The WSU and GPS ranges have a much more similar timing for the HV lane change (again at roughly 40 seconds) because the HV does not have a trailer and therefore the WSU data is only accounting for a box the size of the tractor, which is the same as the GPS data. Testing with only bobtail vehicles or light vehicles and eliminating any issues that may be caused by the trailers in the RV positions would help determine if this explanation is correct or plausible.

As was the case with the test in the previous figure, the FCW alert switches from the RV2 to RV1 when the RV2 lateral range increases to approximately +2 meters (WSU data) and the FCW alert for RV1 extinguishes when the RV1 lateral range is a little greater than +2 meters. Another difference between Test 1814 and 1817 (previous figure) is that the FCW alert for RV1 has a very brief period of Level 2 alert before going to Level 3.

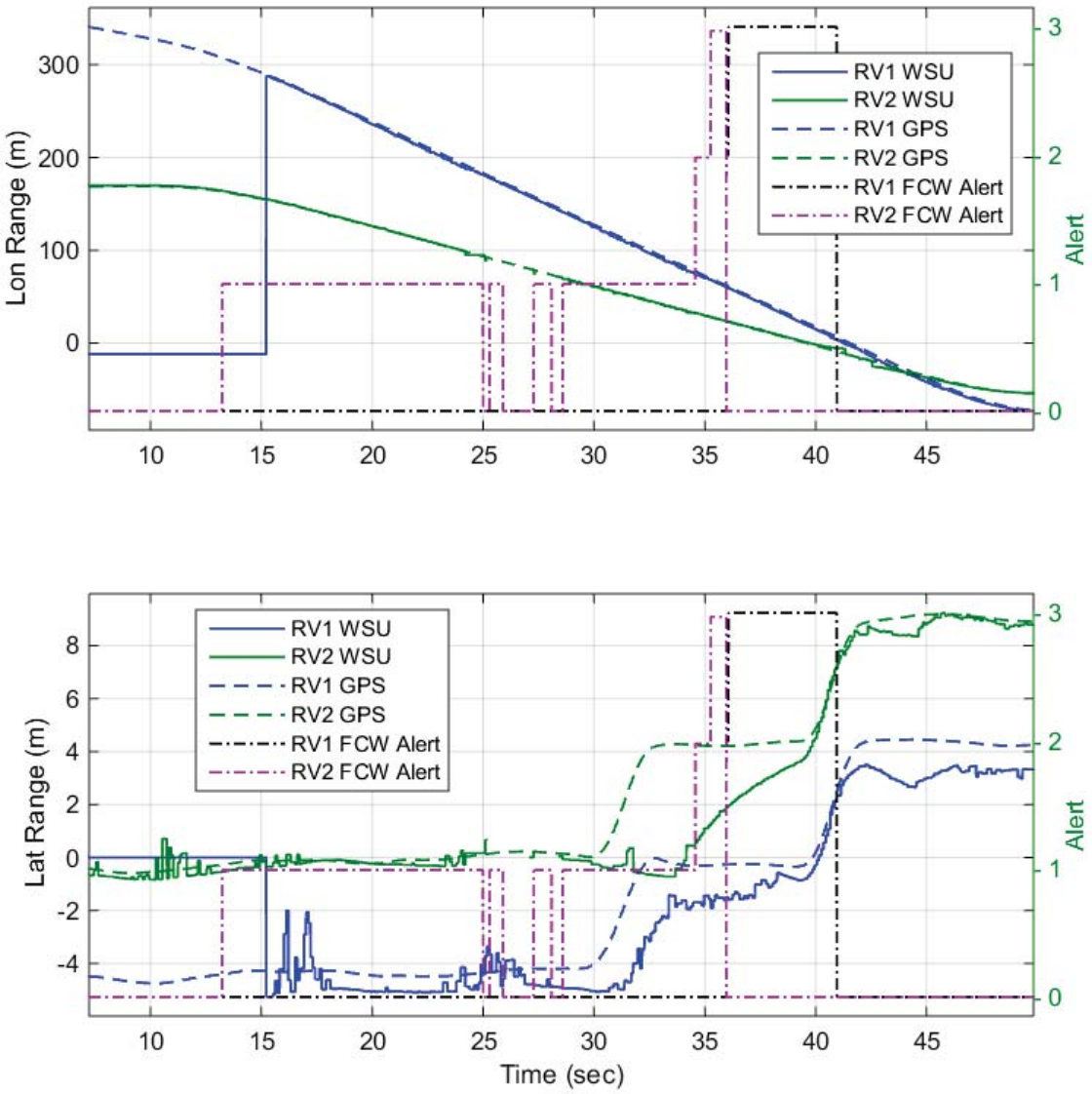


Figure 28: Example FCW-9 Test Results – Longitudinal and Lateral Range for Test 1814

An example of longitudinal and lateral range data for an FCW-9 test that had a delay between the RV2 and RV1 alerts is shown in Figure 29. The FCW Level 3 alert for RV2 extinguishes at approximately 44.5 seconds and the FCW Level 3 alert for RV1 comes on at roughly 47 seconds. Why did this delay between the offset of the RV2 and onset of the RV1 alert occur? The FCW alert for the RV2 extinguishes as the RV2 lateral range increases to over +2 meters (WSU data), which is similar to what happened in the results presented in the previous figures. The WSU data for the RV1 lateral range is less than -2 meters (WSU data) at this point and stays less than -2 meters until shortly before the RV1 FCW alert comes on. The RV1 GPS lateral range data shows that the RV1 tractor at a minimum is in the lane well before this and reaches the -2 meter range at around 42 seconds, well before the FCW alert for the RV2 extinguishes.

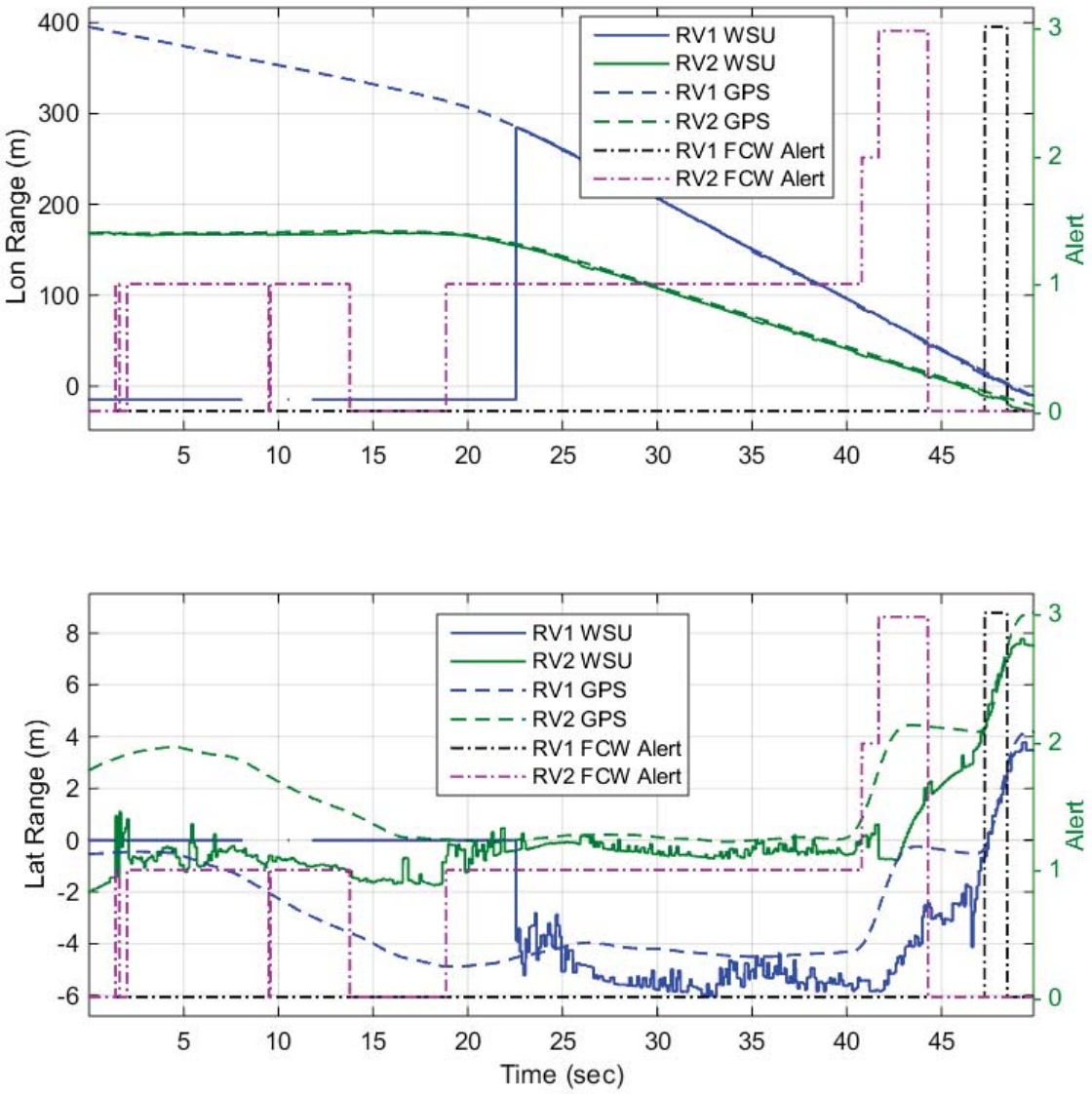


Figure 29: Example FCW-9 Test Results – Longitudinal and Lateral Range for Test 1809

An example of longitudinal and lateral range data for a test that has a "drop out" in the FCW alert for RV1 are shown in Figure 30. For this test the FCW alert for RV1 drops to zero around 34 seconds and stays off until a little past 35 seconds. This appears to occur due to a drop in the WSU determined lateral range between the HV and RV1 (solid blue trace) that occurs in this same time frame. The GPS determined lateral range has no such drop and there is no physical way for such a sudden drop in lateral range to occur. This sudden change in lateral range

coincides with the HV starting to make the lane change after the RV1 and RV2 have completed the initial lane change.

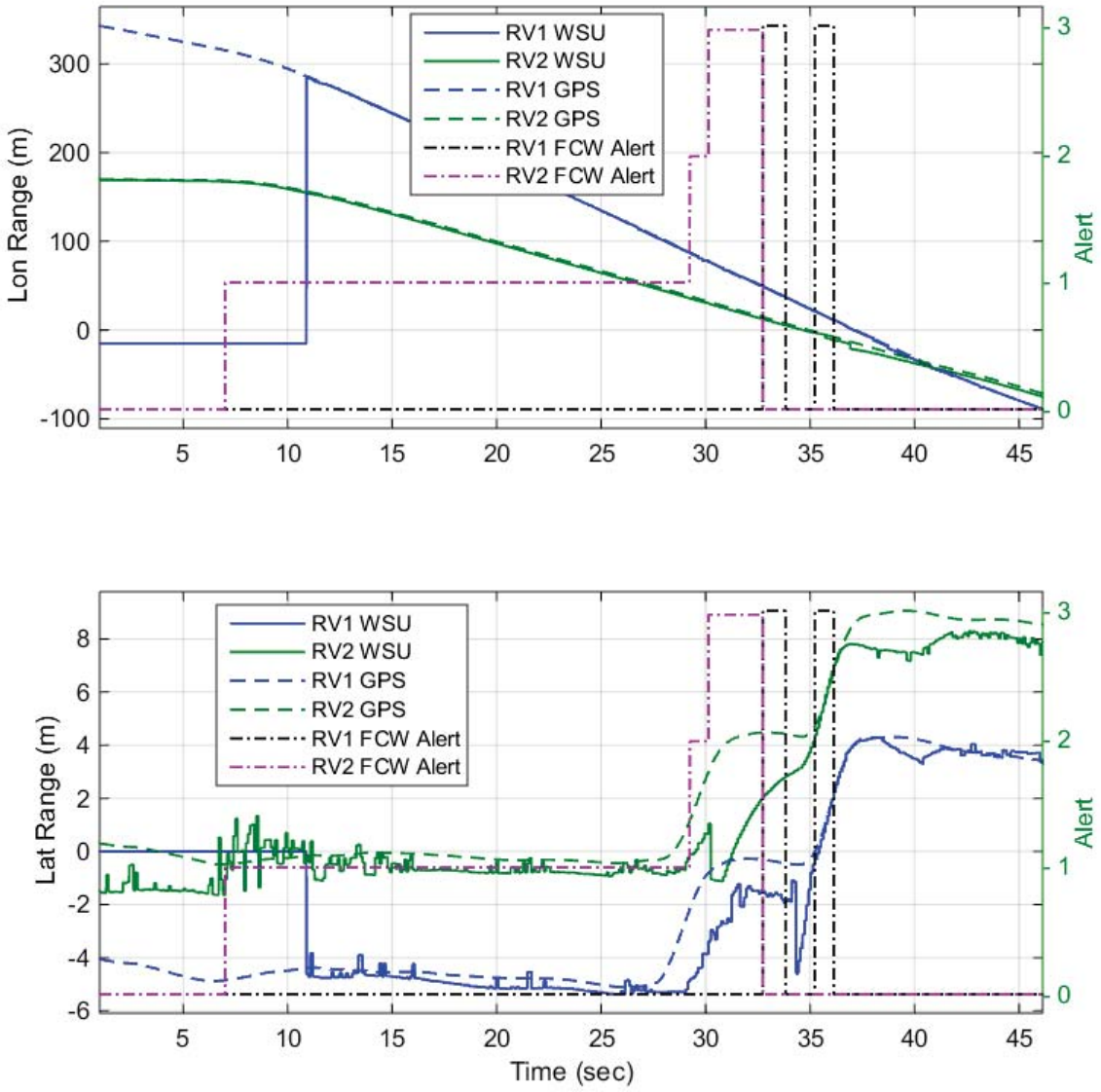


Figure 30: Example FCW-9 Test Results – Longitudinal and Lateral Range for Test 1811

The results presented above show that a lot is happening in a short period of time during this testing. Other notes and observations from the testing also provide some insight into how difficult this test is to conduct. The test engineer that rides with the HV driver calls out over the radio telling the RV drivers when to "switch" lanes. The switch time is based on a target distance that would occur before FCW alerts on the RV2 (intermediate vehicle) would occur. This is evident in the lateral range data plots shown above. The GPS data in particular shows that the RVs are starting to switch lanes before the FCW alert on the RV2 occurs. Another issue is how long the trailers take to get out of lane. There were several tests where the HV came very close to

the RV2 trailer because it would take so long to leave the initial lane, in fact the HV driver had several preliminary tests where he had to do a partial lane change to avoid the RV2 trailer and then come back into the original lane to pick up RV1. The lack of a good trailer model or a WSU strictly for the trailer leaves the HV without enough information to truly predict when the RVs are fully out of the HV "lane." If FCW-9 testing is to be pursued further, the authors would recommend that the testing be done with bobtail tractors or light vehicles in the RV positions until such time that tractor-trailer articulation angle (general position, speed, heading etc. of the trailer) are properly predicted and communicated through the Basic Safety Message (BSM) and that the BSM can be properly interpreted by other V2V equipped vehicles.

TTC and lateral range values for the FCW Level 3 Alert on RV2 (intermediate vehicle) as determined from the WSU data are presented in Table 23 for each RV2/RV1 trailer combination evaluated. Mean, standard deviation, and coefficient of variation values are presented. More complete data for each individual test are presented in Appendix B, Section B.8. WSU, RT, and GPS data are presented for both Level 2 and Level 3 alert onset in the appendix. The mean TTC value was 4.5 seconds for both combinations evaluated with very small standard deviations (0.1 seconds or less). The longitudinal range mean value ranged from 28.9 to 29.8 meters with standard deviations ranging from 0.8 to 1.1 meters and coefficients of variation ranging from 2.8 to 3.7 percent.

Table 23: FCW-9 WSU TTC and Longitudinal Range Values at FCW Level 3 Alert on RV2

RV2 Trailer	RV1 Trailer	TTC (s)			Longitudinal Range (m)		
		Mean	Std. Dev.	C. of V. (%)	Mean	Std. Dev.	C. Of V. (%)
40' Ship.	Double 28'	4.5	0.1	1.2	29.8	0.8	2.8
Double 28'	40' Ship.	4.5	0.0	1.1	28.9	1.1	3.7

Similar data for the first FCW alert on RV1 after the RV2 Level 3 Alert are presented in Table 24. Most often the first alert on RV1 was a Level 3 alert, but each group of tests had one Level 2 alert. The standard deviations and coefficients of variation are much larger for this alert than those for RV2. This variation is due to a variety of reasons including the relative spacing of the vehicles at the lane switch, the length of time of the switch, and most importantly how long it takes the WSU system to recognize that the RV1 has entered the lane with the HV. The tests with time gaps between alerts like that shown above in Figure 29 had much lower TTC and longitudinal range values at alert.

Table 24: FCW-9 WSU TTC and Longitudinal Range Values at First FCW Level 2 or 3 Alert on RV1 after RV2 Alert Extinguishes

RV2 Trailer	RV1 Trailer	TTC (s)			Longitudinal Range (m)		
		Mean	Std. Dev.	C. of V. (%)	Mean	Std. Dev.	C. Of V. (%)
40' Ship.	Double 28'	3.6	1.5	43.4	39.5	17.0	42.9
Double 28'	40' Ship.	4.3	0.9	20.5	46.9	9.6	20.5

The time gap between the FCW alert offset from RV2 to the FCW alert onset from RV1 for each RV1/RV2 trailer combination are presented in Table 25 and Table 26. For the RV2 with 40' Shipping Container and the RV1 with 28' Doubles combination, 3 out of 6 tests had no time gap

between alerts. For the tests with time gaps, the time gaps ranged from 0.4 to 3.0 seconds. For the RV2 with 28’ Doubles and the RV1 with 40’ Shipping Container combination, 4 out of 5 tests had no time gap between alerts. The time gap was 1.2 seconds for the one test with a time gap (Test 1815).

Table 25: Time Gap between FCW Alert Offset from RV2 to FCW Alert Onset from RV1 for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 40’ Shipping Container, RV1 = Mack /w 28’ Doubles

Test	Previous Alert			
	RV	Name	Level	Time Gap (sec)
1805	2	FCW	3	0.4
1806*	2	FCW	3	0.0
1807	2	FCW	3	0.0
1808	2	FCW	3	2.7
1809	2	FCW	3	3.0
1811	2	FCW	3	0.0

Table 26: Time Gap between FCW Alert Offset from RV2 to FCW Alert Onset from RV1 for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 28’ Doubles Container, RV1 = Mack /w 40’ Shipping

Test	Previous Alert			
	RV	Name	Level	Time Gap (sec)
1813	2	FCW	3	0.0
1814*	2	FCW	3	0.0
1815	2	FCW	3	1.2
1817	2	FCW	3	0.0
1818	2	FCW	3	0.0

Another interesting metric is the lateral range at alert offset. The lateral range from the HV to RV2 at the FCW Level 3 Alert offset for RV2 are shown in Table 27 and Table 28 for two RV2 trailers evaluated. The average lateral range values were fairly similar for the two trailers (1.9 and 1.8 meters) with standard deviations ranges from 0.2 meters to below 0.1 meters.

Table 27: HV to RV2 Lateral Range at FCW Level 3 Alert Offset for RV2 – WSU Data for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 40' Shipping Container

Test	Lat. Range (m)
1805	1.9
1806	2.1
1807	1.8
1808	2.2
1809	1.5
1811	2.0
Ave.	1.9
Std.	0.2
C. of V. (%)	11.6

Table 28: HV to RV2 Lateral Range at FCW Level 3 Alert Offset for RV2 – WSU Data for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 28' Doubles

Test	Lat. Range (m)
1813	1.9
1814	1.8
1815	1.8
1817	1.8
1818	1.8
Ave.	1.8
Std.	0.0
C. of V. (%)	1.0

5 Conclusions and Recommendations

A series of FCW 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 FCW threats, but had some issues when vehicles were in a curve or when switching lanes.

For the curve tests, the V2V equipment had trouble determining the lateral distance between the Host Vehicle (HV – test subject) and the Remote Vehicle (RV – collision threat) for certain scenarios (most notably in FCW-6: Stopped Vehicle Ahead in Adjacent Lane, Curved Road). This appeared to be more of an issue when the RV was to the outside of the HV in the curve.

For lane change scenarios, sometimes FCW false positives would occur after the HV would pass the RV (most notably in FCW-5: Stopped Vehicle Ahead in Same Lane, Curved Road). Also, the lateral range was not always well predicted when vehicles would make lane changes, which might delay when an alert was issued (most notably in FCW-9: Target Switch).

Future testing with commercial vehicles equipped with V2V technology that has advanced with respect to lateral position/lane prediction accuracy will be required to fully develop the FCW objective test track procedures and performance metrics.

References

1. LeBlanc, D., Bogard, S., and Gilbert, M. (2014, January 31). *Connected Commercial Vehicle—Integrated Truck Project: Vehicle build and build test plan final technical report* (Report Number FHWA-JPO-13-103). 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, final report* (Report No. FHWA-JPO-13-112). Washington, DC: Federal Highway Administration. Available at http://ntl.bts.gov/lib/51000/51700/51726/13-112.pdf

Appendix A - FCW 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 Forward Collision Warning (FCW) 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] National Highway Traffic Safety Administration. (2013, February). Forward Collision Warning System Confirmation Test. Washington, DC: Author. Available at www.safercar.gov/staticfiles/safercar/NCAP/FCW_NCAP_Test_Procedure_2-7-2013.pdf

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

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

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

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

A.3 Definitions

A.3.1 On-Board Equipment

On-board equipment (OBE) packages are the vehicle platform-mounted elements of V2V-based collision avoidance systems. Variants of V2V-based OBE are the integrated safety system (ISS), the retrofit safety device (RSD), the aftermarket safety device (ASD), and the vehicle awareness device (VAD).

A.3.2 Integrated Safety System

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

A.3.3 Retrofit Safety Device

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

A.3.4 Aftermarket Safety Device

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

A.3.5 Vehicle Awareness Device

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

A.4 Vehicle Platforms

A.4.1 Host Vehicle

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

A.4.2 Remote Vehicle

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

A.5 Vehicle and V2V System Roles

A.5.1 Host Vehicle and On-Board Equipment

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

A.5.2 Remote Vehicle and On-Board Equipment

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

A.6 General Procedures

A.6.1 Ambient Conditions

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

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

A.6.2 Personnel

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

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

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

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

A.6.3 Zero Position Measurement

The in-lane longitudinal position of the HV at the point of impact with the RV—the zero position—is required to determine the longitudinal position of the HV in relation to the RV during the execution of each trial. The zero position defines the distance between the range

measuring instrumentation's reference points for the HV and RV when the front of the HV contacts the rear of the RV.

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

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

A.6.4 Path History (Breadcrumbs or Breadcrumb Trail)

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

A.7 Test Facility

For FCW tests, the test facility is a straight, flat, and level roadway which includes two or more 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 FCW tests where the roadway is curved instead of straight (discussed in more detail below). 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 FCW alert range or equal to 150 m, whichever is greater.

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.

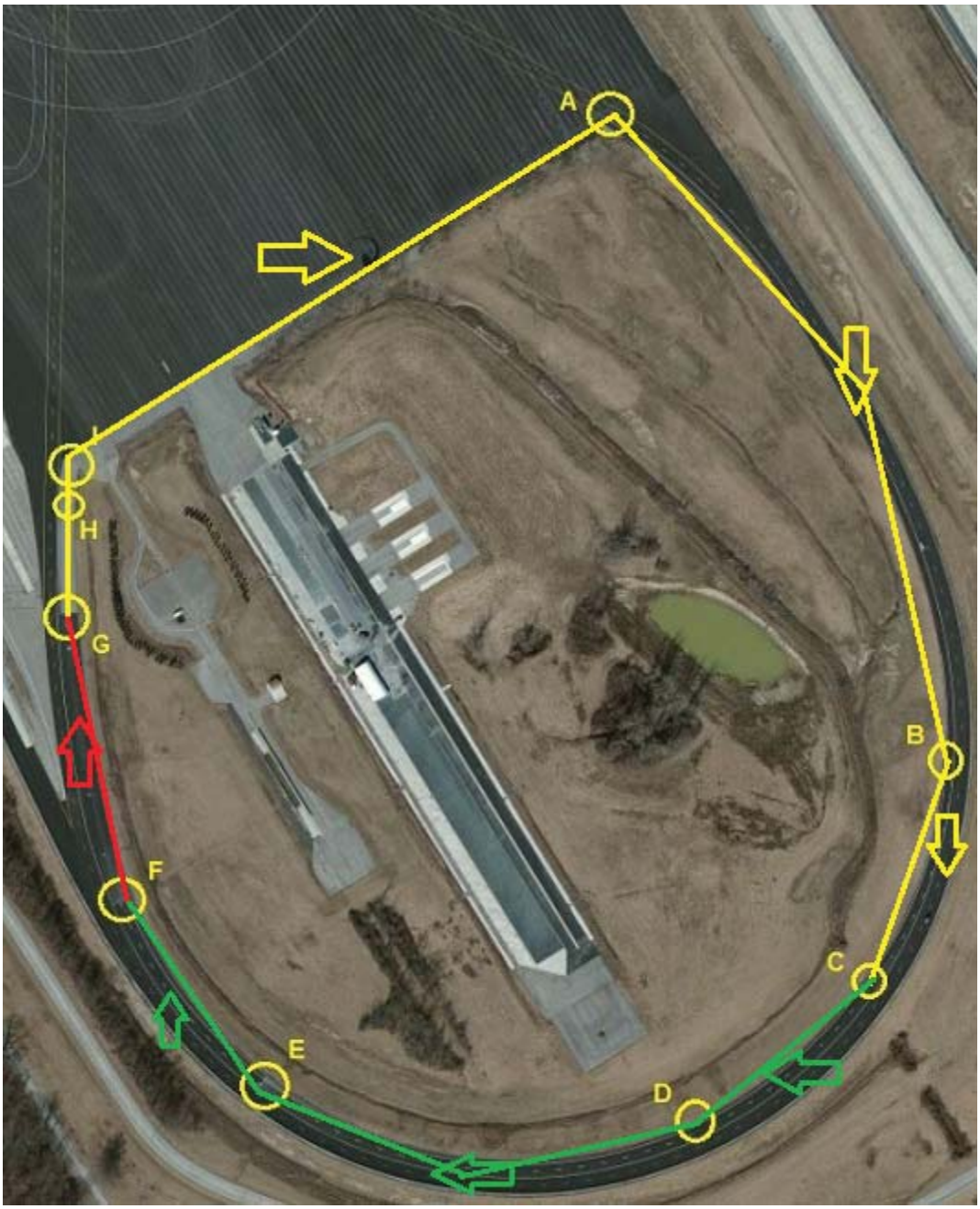


Figure A-1: Curved Road Testing on South Loop Berms Lanes of the Vehicle Dynamics Area at the Transportation Research Center Inc.

A.8 FCW-1 - Stopped 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 FCW 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

Two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The trailing vehicle is a commercial truck equipped with a V2V system that features a FCW application. The two vehicles are separated by a distance greater than the FCW application's alert range. The leading vehicle brakes to a stop in the lane of travel. The trailing vehicle drives in the same lane of travel toward the stopped leading vehicle and enters the FCW application's alert range.

A.8.2 Test Subject and Purpose

The subject of this test is the V2V-based FCW system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to identify the stopped leading vehicle as a collision threat and alert the trailing vehicle's driver of the threat in a timely manner.

A.8.3 Initial Condition

A.8.3.1 Test Velocities

For tests of V2V-based FCW systems where the RV is driven along the test course to establish a path history, the RV is driven at a velocity above the minimum velocity at which the RV's OBE will establish and broadcast the RV's path history.

The velocity of the HV as it enters the test course is specified for each trial or set of trials. A minimum velocity may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity—not necessarily a minimum velocity—may be specified at which an ISS or RSD would issue an alert to produce a successful trial. A range of test velocities may be specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress FCW alerts, and to determine the performance of the subject ISS or RSD from a minimum velocity to a maximum velocity.

A.8.4 Metric

A.8.4.1 Collision Alert

Time-to-collision (TTC) is a measure of the time interval between a pre-crash state and a potential collision of the HV with the RV. A minimum time-to-collision (TTCmin) for alert activation is specified for each trial or set of trials. A collision alert must be presented to the driver before the TTC falls below TTCmin.

A.8.5 Execution of Procedure

Because application of the HV's service brakes will typically suppress FCW alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the lane change has been completed at the end of the trial. 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.

The test procedure is depicted in Figure A-2.

1. To establish a path history, the RV is driven down the center of the primary test lane from the beginning of the test course toward the end of the course.
2. As the RV approaches the end of the course the driver slows the RV and, at a specified distance from the beginning of the course, stops the RV in the center of the primary lane. A traffic cone or other suitable marker may be used to mark the parking location.
3. When the RV is stopped, the driver places the RV's transmission in park or neutral, sets the parking brake, and releases the service brake. The RV's OBE remains on. The RV driver may exit the vehicle and move to a location away from the test course.
4. The RV driver informs the experimenter that the RV is parked.
5. The experimenter arms the data acquisition system and directs the HV driver to begin the trial.
6. The HV driver begins driving toward the beginning of the test course while establishing and maintaining the HV at a specified speed.
7. The driver drives the HV onto the course in the primary test lane. The trial begins when the HV is on the test course. A traffic cone or other suitable marker may be used to indicate the beginning of the test course.
8. The driver drives the HV toward the RV while maintaining the HV at the specified speed and while maintaining the HV's lateral position in the center of the lane.
9. Each trial ends when the required FCW alert occurs or, if the required FCW alert does not occur, when the TTC falls to less than 90 percent of TTCmin.
10. After the end of the trial, the HV driver steers the HV into the secondary lane, passes the RV, and exits the course. A traffic cone or other suitable marker may be used to indicate to the HV driver where the trial ends and the lane change is to be initiated.

A.8.6 Execution of Alternative Procedure

The alternative CCV FCW-1 procedure allows the HV and RV to be operated in separate, but adjacent lanes such that, during trials, the HV does not approach the RV in the same lane and does not change lanes. The alternative procedure requires that the lateral position offset of the RV's OBE (ISS, RSD, ASD, or VAD) is reliably configurable to a magnitude of one lane width, and that the one lane width lateral offset configuration does not affect the ability of the RV's OBE to broadcast the RV's true longitudinal position.

Prior to executing CCV FCW-1 alternative procedure trials, the RV's OBE is configured to broadcast a simulated position and path history equal to one lane width laterally from the RV's true position and path such that the RV appears to the HV's OBE to have traveled and appears to be stopped in the same lane as the HV when the HV is operated in a lane adjacent to the RV. The magnitude of the configured lateral offset is equal to the width of the test facility's driving lanes.

Because application of the HV's service brakes will typically suppress FCW 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 the trial. 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.

The alternative test procedure is depicted in Figure A-3.

1. To establish a path history, the RV is driven down the center of its assigned lane from the beginning of the test course toward the end of the course.
2. As the RV approaches the end of the course the driver slows the RV and, at a specified distance from the beginning of the course, stops the RV in the center of its assigned lane. A traffic cone or other suitable marker may be used to mark the parking location.
3. When the RV is stopped, the driver places the RV's transmission in park or neutral, sets the parking brake, and releases the service brake. The RV's OBE remains on. The RV driver may exit the vehicle and move to a location away from the test course.
4. The RV driver informs the experimenter that the RV is parked.
5. The experimenter arms the data acquisition system and directs the HV driver to begin the trial.
6. The HV driver begins driving toward the beginning of the test course while establishing and maintaining the HV at a specified speed.
7. The driver drives the HV onto the course in its assigned lane, which is adjacent to the RV's assigned lane. The trial begins when the HV is on the test course. A traffic cone or other suitable marker may be used to indicate the beginning of the test course.
8. The driver drives the HV toward the end of the test course while maintaining the HV at the specified speed and while maintaining the HV's lateral position in the center of its assigned lane.
9. Each trial ends when the required FCW alert occurs or, if the required FCW alert does not occur, when the TTC falls to less than 90 percent of TTCmin.
10. After the end of the trial, the HV passes the RV and exits the course.

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 FCW alert or, if no alert is presented, for a period of three seconds before the TTC falls to less than 90 percent of TTCmin.
2. The HV's service brakes were not applied prior to the required FCW alert or, if no alert is presented, for a period of three seconds before the TTC falls to less than 90 percent of TTCmin.
3. The lateral deviation requirements for the primary and alternative procedures follow:
    a. When the primary procedure is executed, the lateral distance between the longitudinal centerline of the HV and the longitudinal centerline of the RV did not exceed 2.0 feet from the time the HV enters the test course until the TTC falls to less than 90 percent of TTCmin.
    b. When the alternative procedure is executed, the lateral distance between the longitudinal centerline of the HV and the longitudinal centerline of the RV did not deviate more than 2.0 feet from the magnitude of the configured lateral offset of the RV's V2V device from the time the HV enters the test course until the TTC falls to less than 90 percent of TTCmin.
4. The yaw rate of the HV did not exceed ±1 degree/second.

Developmental 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 if the HV OBE initiates a high-level FCW alert before the TTC falls below TTCmin. A trial is unsuccessful if the HV OBE initiates a high-level FCW alert after the TTC falls below TTCmin, or if no high-level FCW alert is initiated during the trial. Low-level FCW alerts are not considered.

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

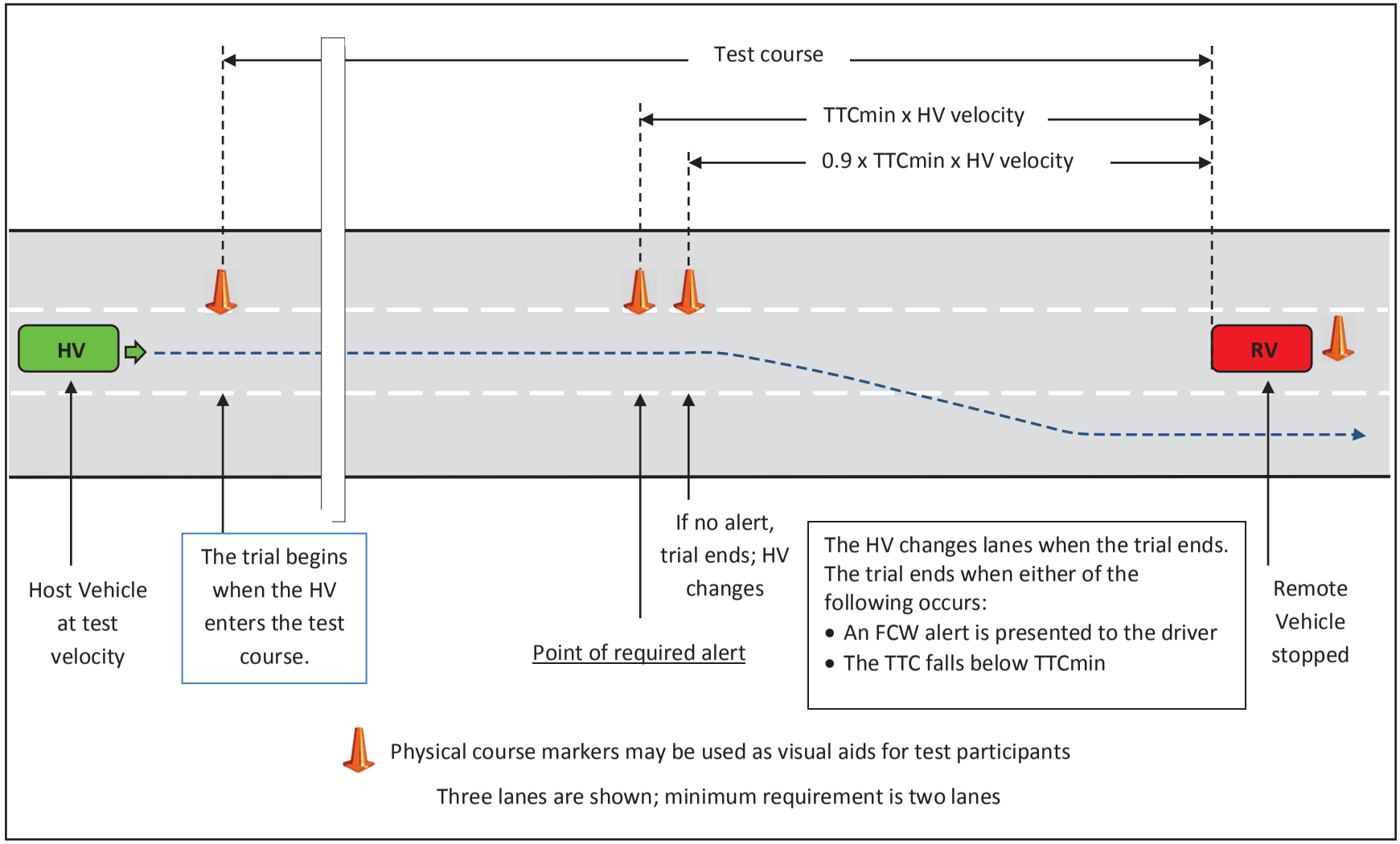


Figure A-2: FCW-1 Test Course Graphic for Primary Procedure [not to scale]

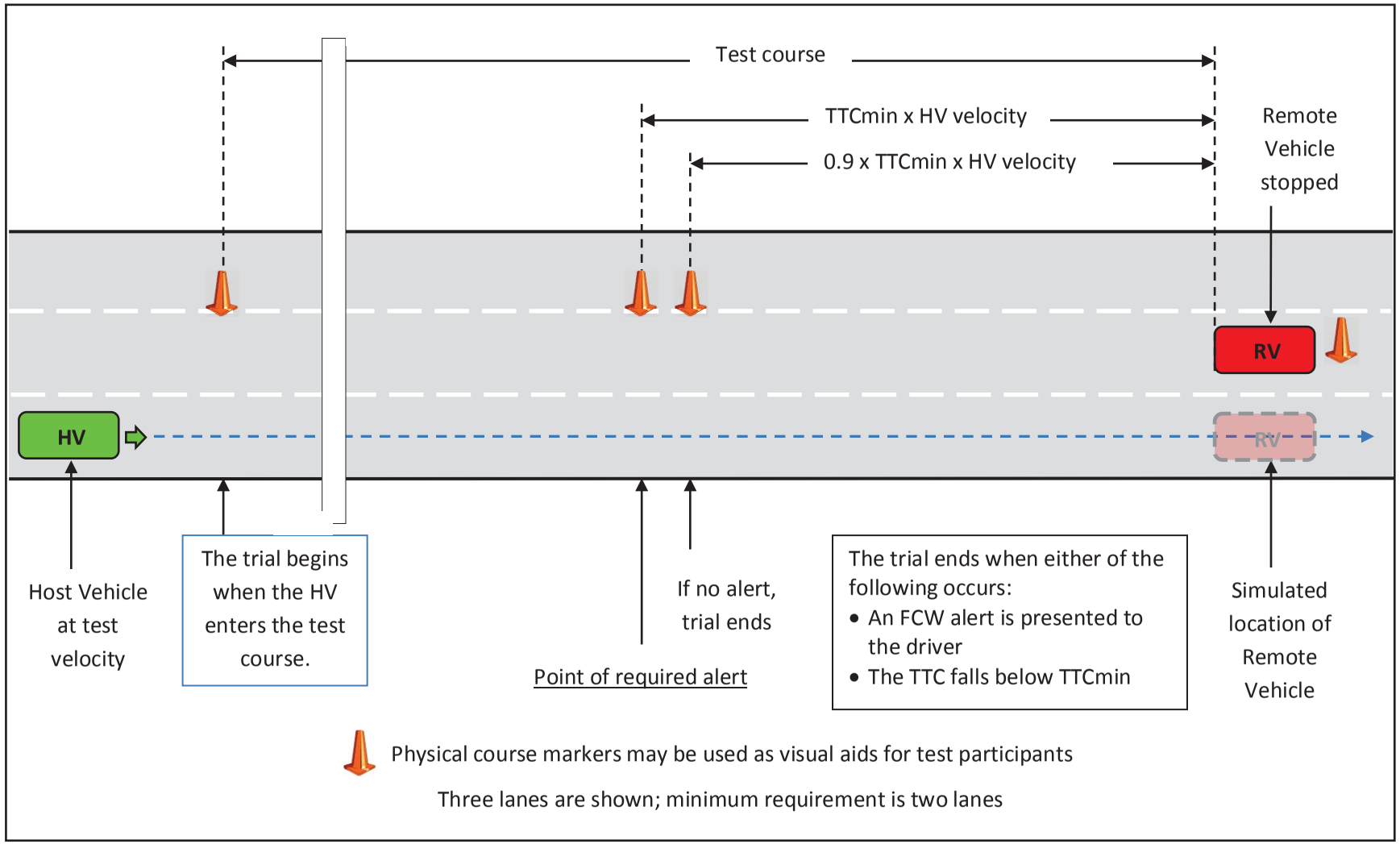


Figure A-3: FCW-1 Test Course Graphic for Alternative Procedure [not to scale]

A.9 FCW-2 - Slower 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 FCW 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.9.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The trailing vehicle is a commercial truck equipped with a V2V system that features a FCW application. The two vehicles are separated by a distance greater than the FCW application's alert range. The velocity of the leading vehicle is steady but lower than that of the trailing vehicle. The trailing vehicle drives in the same lane of travel toward the slower leading vehicle and enters the FCW application's alert range.

A.9.2 Test Subject and Purpose

The subject of this test is the V2V-based FCW system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to identify the slower, leading vehicle as a collision threat and alert the trailing vehicle's driver of the threat in a timely manner.

A.9.3 Initial Condition

A.9.3.1 Test Velocities

The velocities of the HV and the RV are specified for each trial or set of trials. A RV minimum velocity may be specified above which the RV's OBE will broadcast the RV's location, velocity, direction of travel, and path history. Similarly, a HV minimum velocity may be specified that is greater than the specified RV velocity, and above which the HV's ISS or RSD would issue an alert to produce a successful trial. Standard velocities for the RV and HV—not necessarily minimum velocities—may be specified. A range of RV/HV velocity combinations may be specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress FCW alerts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum RV and HV velocity combinations.

A.9.3.2 Initial Headway

An initial headway is specified for each trial or set of trials and determines the point at which each trial begins. The initial headway is greater than the range within which an FCW alert would occur, and might be dependent on the initial test velocities. Each trial begins when the dynamic headway is reduced to the specified initial headway. 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.9.4 Metric

A.9.4.1 Collision Alert

Time-to-collision (TTC) is a measure of the time interval between a pre-crash state and a potential collision of the HV with the RV. A minimum time-to-collision (TTCmin) for alert activation is specified for each trial or set of trials. A collision alert must be presented to the driver before the TTC falls below TTCmin.

A.9.5 Execution of Procedure

Because application of the HV's service brakes will typically suppress FCW alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the lane change has been completed at the end of the trial. 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 velocities, and the headway between the HV and the RV closes to the specified initial headway. There may be a variety of methods for establishing these initial conditions. Steps 1 through 5 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 6, 7, and 8 comprise the specified procedure.

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

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.
2. The experimenter arms the HV's data acquisition system and directs the RV driver to begin driving.
3. The RV driver begins driving and establishes and maintains the velocity specified for the RV. The RV driver informs the experimenter that the RV is at the specified velocity.
4. When the headway between the two vehicles opens to the specified initial headway, the experimenter directs the HV driver to begin driving.
5. The HV driver begins driving and establishes the velocity specified for the HV before the headway between the two vehicles closes to the specified initial headway.
6. When the headway closes to the specified initial headway, the trial begins. As the headway decreases from the specified initial headway, the drivers maintain the specified velocities for the two vehicles and maintain the lateral position of the vehicles in the center of the primary test lane.
7. Each trial ends when the required FCW alert occurs or, if the required FCW alert does not occur, when the TTC falls to less than 90 percent of the required minimum TTC.
8. After the end of the trial, the HV driver steers the HV into the secondary lane and passes the RV.
9. Both vehicles exit the test course.

A.9.6 Execution of Alternative Procedure

The alternative CCV FCW-2 procedure allows the HV and RV to be operated in separate, but adjacent lanes such that, during trials, the HV does not approach the RV in the same lane and does not change lanes. The alternative procedure requires that the lateral position offset of the RV's OBE (ISS, RSD, ASD, or VAD) is reliably configurable to a magnitude of one lane width, and that the one lane width lateral offset configuration does not affect the ability of the RV's OBE to broadcast the RV's true longitudinal position.

Prior to executing CCV FCW-2 alternative procedure trials, the RV's OBE is configured to broadcast a simulated position and path history equal to one lane width laterally from the RV's true position and path such that the RV appears to the HV's OBE to be traveling in the same lane as the HV when the HV is operated in a lane adjacent to the RV. The magnitude of the configured lateral offset is equal to the width of the test facility's driving lanes.

Because application of the HV's service brakes will typically suppress FCW 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 the trial. 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 velocities, and the headway between the HV and the RV closes to the specified initial headway. There may be a variety of methods for establishing these initial conditions. Steps 1 through 5 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 6, 7, and 8 comprise the specified procedure.

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

1. The RV and the HV are staged at one end of the straight road test facility. The HV is staged behind the RV in a lane adjacent to the RV and both vehicles are oriented to travel toward the opposite end of the test facility.
2. The experimenter arms the HV's data acquisition system and directs the RV driver to begin driving.
3. The RV driver begins driving and establishes and maintains the velocity specified for the RV. The RV driver informs the experimenter that the RV is at the specified velocity.
4. When the headway between the two vehicles opens to the specified initial headway, the experimenter directs the HV driver to begin driving.
5. The HV driver begins driving and establishes the velocity specified for the HV before the headway between the two vehicles closes to the specified initial headway.
6. When the headway closes to the specified initial headway, the trial begins. As the headway decreases from the specified initial headway, the drivers maintain the specified velocities for the two vehicles and maintain the lateral position of each vehicle in the center of its assigned test lane.
7. Each trial ends when the required FCW alert occurs or, if the required FCW alert does not occur, when the TTC falls to less than 90 percent of the required minimum TTC.
8. After the end of the trial, the HV passes the RV and both vehicles exit the course.

A.9.7 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 FCW alert or, if no alert was presented, for a period of three seconds before the TTC falls to less than 90 percent of TTCmin.
2. The RV's velocity did not deviate from the specified velocity by more than 1.0 mph during the trial.
3. The HV's service brakes were not applied prior to the required FCW alert or, if no alert was presented, for a period of three seconds before the TTC falls to less than 90 percent of TTCmin.
4. The lateral deviation requirements for the primary and alternative procedures follow:
    a. When the primary procedure is executed, the lateral distance between the longitudinal centerline of the HV and the longitudinal centerline of the RV did not exceed 2.0 feet from the time the HV enters the test course until the TTC falls to less than 90 percent of TTCmin.
    b. When the alternative procedure is executed, the lateral distance between the longitudinal centerline of the HV and the longitudinal centerline of the RV did not deviate more than 2.0 feet from the magnitude of the configured lateral offset of the RV's V2V device from the time the HV enters the test course until the TTC falls to less than 90 percent of TTCmin.
5. The yaw rates of the HV and the RV did not exceed ±1 degree/second.

Developmental 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)

A trial is successful if the HV OBE initiates a high-level FCW alert before the TTC falls below TTCmin. A trial is unsuccessful if the HV OBE initiates a high-level FCW alert after the TTC falls below TTCmin, or if no high-level FCW alert is initiated during the trial. Low-level FCW alerts are not considered.

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

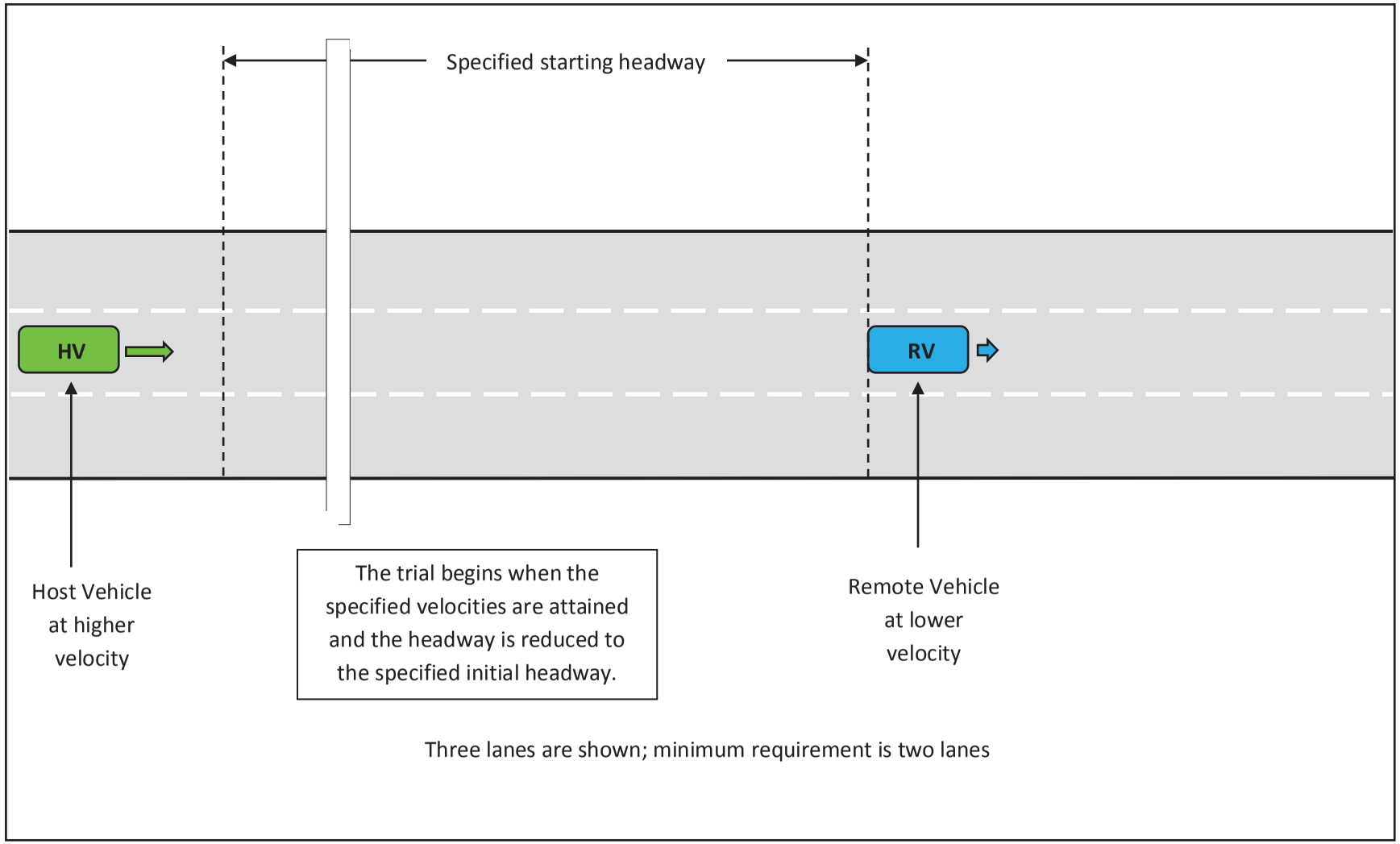


Figure A-4: FCW-2 Test Course Graphic, Initial Conditions for Primary Test Procedure [not to scale]

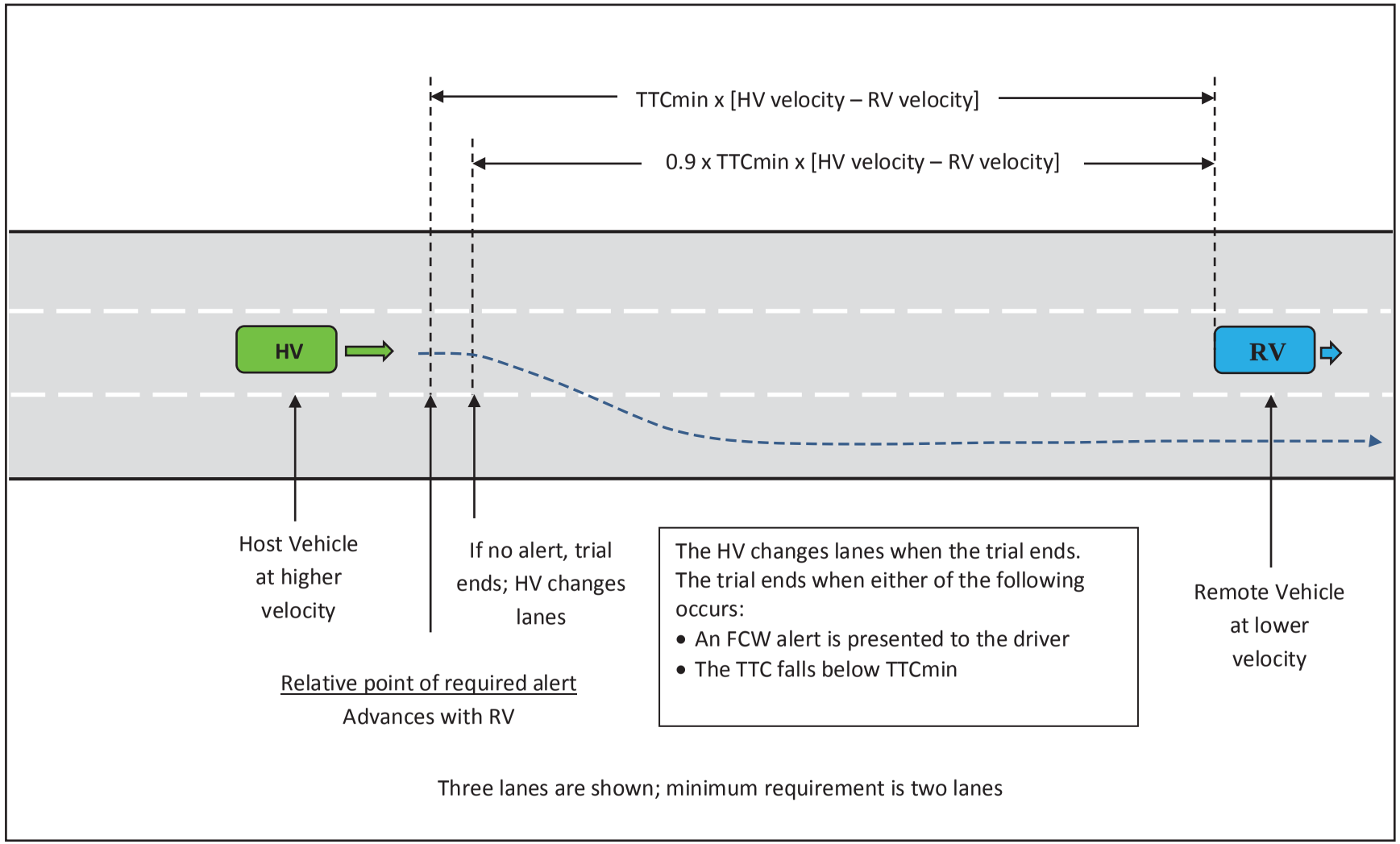


Figure A-5: FCW-2 Test Course Graphic, Primary Test Procedure End of Trial [not to scale]

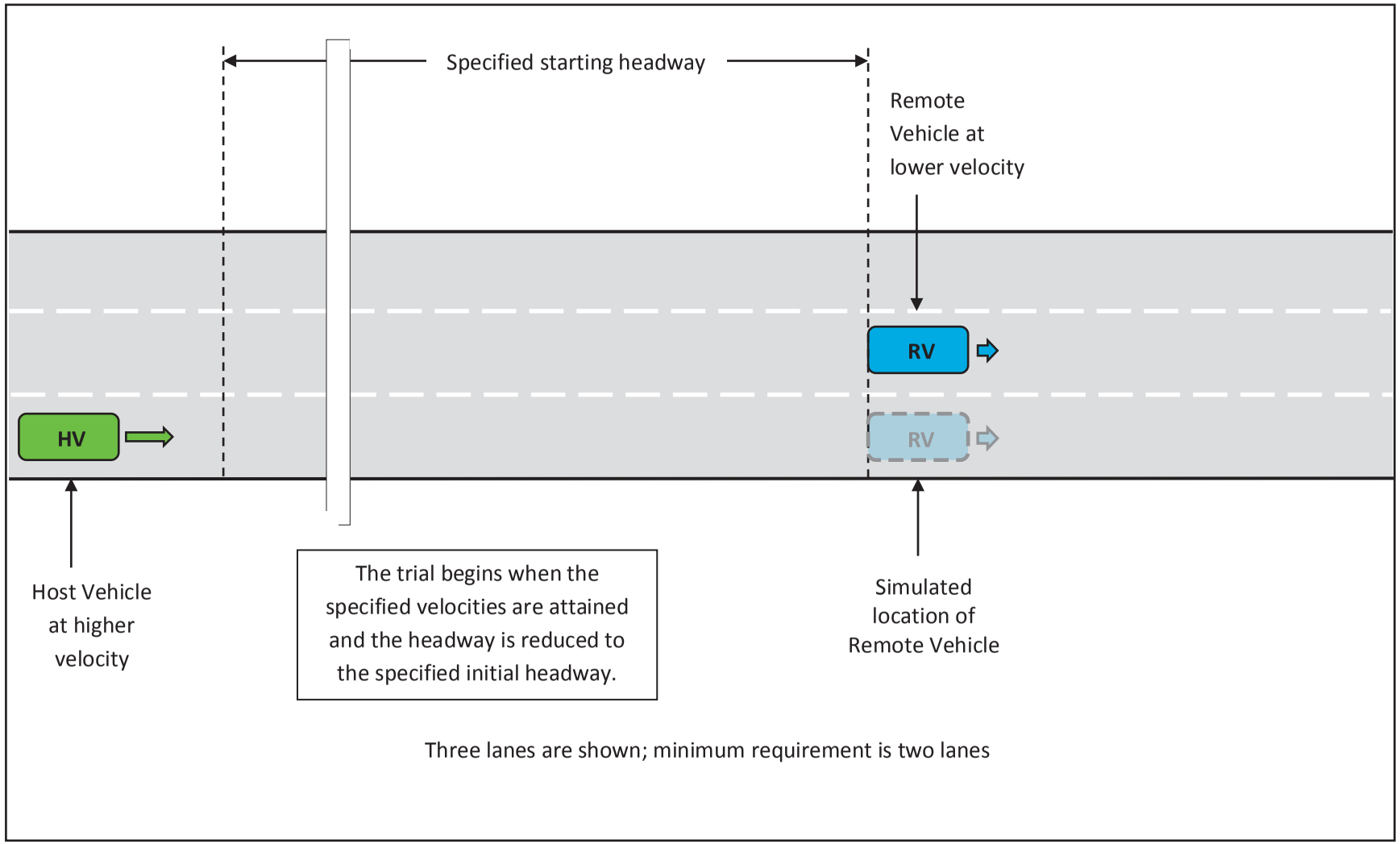


Figure A-6: FCW-2 Test Course Graphic, Initial Conditions for Alternative Test Procedure [not to scale]

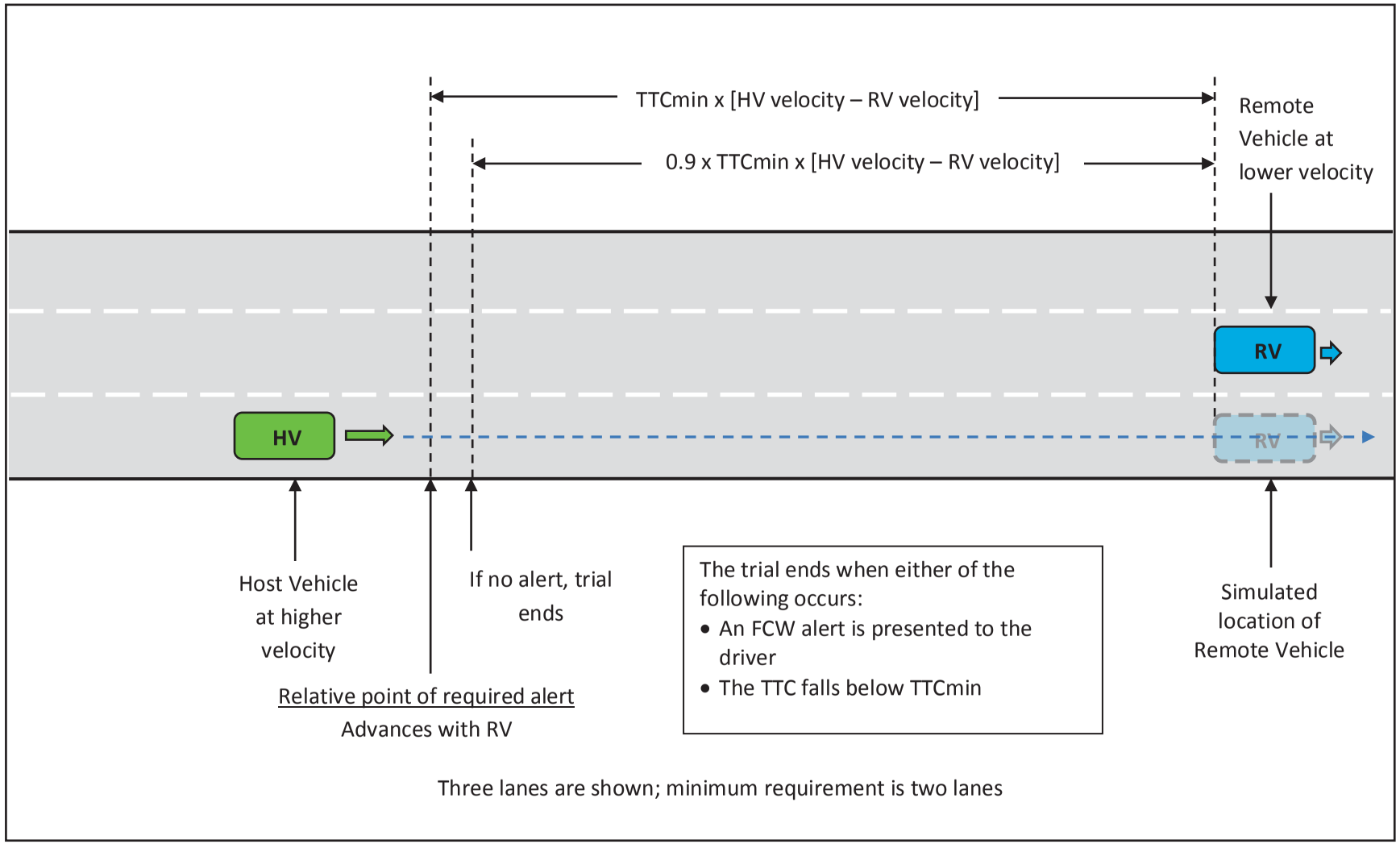


Figure A-7: FCW-2 Test Course Graphic, Alternative Test Procedure End of Trial [not to scale]

A.10 FCW-3 - 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 FCW 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.10.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The trailing vehicle is a commercial truck equipped with a V2V system that features a FCW application. Initially, the two vehicles are separated by a specified distance or headway and travel at the same velocity. The leading vehicle then brakes while the trailing vehicle maintains the specified velocity.

A.10.2 Test Subject and Purpose

The subject of this test is the V2V-based FCW system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to identify the decelerating lead vehicle as a collision threat and alert the trailing vehicle's driver of the threat in a timely manner.

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, and direction of travel, 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 FCW alerts, and to determine the performance of the subject ISS or RSD across a range of minimum to maximum velocities.

A.10.3.2 Initial Headway

An initial headway is specified for each trial or set of trials. The specified headway is large enough to prevent the activation of collision avoidance alerts prior to the initiation of RV braking, and small enough for the FCW alert mode to have priority over the EEBL mode. 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 HV have established the specified test velocity and headway. 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 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.10.5 Metric

A.10.5.1 Collision Alert

Time-to-collision (TTC) is a measure of the time interval between a pre-crash state and a potential collision of the HV with the RV. A minimum time-to-collision (TTCmin) for alert activation is specified for each trial or set of trials. A collision alert must be presented to the driver before the TTC falls below TTCmin.

A.10.6 Execution of Procedure

Because application of the HV's service brakes will typically suppress FCW alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the lane change has been completed at the end of the trial. If unsafe conditions or events are encountered during any trial, the HV driver should abort the trial and brake and/or control the HV 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, 5, and 6 comprise the specified procedure.

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

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 at a distance equivalent to the specified initial headway and both vehicles are oriented to travel toward the opposite end of the test facility.
2. The experimenter arms the HV's data acquisition system and directs the drivers of the RV and HV to begin driving.
3. The drivers begin driving to establish the specified test velocity and headway.
4. The drivers maintain the specified test velocity and headway for the duration of the specified steady-state interval.

5. At the end of the steady-state interval, the RV driver applies the RV's service brakes to decelerate the RV as specified while the HV driver maintains the HV at the specified test velocity.
6. Each trial ends when the required FCW alert occurs or, if the required FCW alert does not occur, when the TTC falls to less than 90 percent of TTCmin.
7. After the end of the trial, the HV driver steers the HV into the secondary lane and passes the RV.
8. Both vehicles exit the test course.

A.10.7 Execution of Alternative Procedure

The alternative CCV FCW-3 procedure allows the HV and RV to be operated in separate, but adjacent lanes such that, during trials, the HV does not approach the RV in the same lane and does not change lanes. The alternative procedure requires that the lateral position offset of the RV's OBE (ISS, RSD, ASD, or VAD) is reliably configurable to a magnitude of one lane width, and that the one lane width lateral offset configuration does not affect the ability of the RV's OBE to broadcast the RV's true longitudinal position.

Prior to executing CCV FCW-3 alternative procedure trials, the RV's OBE is configured to broadcast a simulated position and path history equal to one lane width laterally from the RV's true position and path such that the RV appears to the HV's OBE to be traveling in the same lane as the HV when the HV is operated in a lane adjacent to the RV. The magnitude of the configured lateral offset is equal to the width of the test facility's driving lanes.

Because application of the HV's service brakes will typically suppress FCW 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 the trial. If unsafe conditions or events are encountered during any trial, the HV driver should abort the trial and brake and/or control the HV 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, 5, and 6 comprise the specified procedure.

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

1. The RV and the HV are staged at one end of the straight road test facility. The HV is staged behind the RV in a lane adjacent to the RV's lane at a distance equivalent to the specified initial headway, and both vehicles are oriented to travel toward the opposite end of the test facility.
2. The experimenter arms the HV's data acquisition system and directs the drivers of the RV and HV to begin driving.
3. The drivers begin driving to establish the specified test velocity and headway.
4. The drivers maintain the specified test velocity and headway for the duration of the specified steady-state interval.
5. At the end of the steady-state interval, the RV driver applies the RV's service brakes to decelerate the RV as specified while the HV driver maintains the HV at the specified test velocity.

6. Each trial ends when the required FCW alert occurs or, if the required FCW alert does not occur, when the TTC falls to less than 90 percent of TTCmin.
7. After the end of the trial, the HV passes the RV and both vehicles exit the test course.

A.10.8 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 FCW alert or before the TTC falls to less than 90 percent of TTCmin.
2. The 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 RV braking.
3. The HV's service brakes were not applied prior to the required FCW alert or before the TTC falls to less than 90 percent of TTCmin.
4. The lateral deviation requirements for the primary and alternative procedures follow:
    a. When the primary procedure is executed, the lateral distance between the longitudinal centerline of the HV and the longitudinal centerline of the RV did not exceed 2.0 feet from the time the HV enters the test course until the TTC falls to less than 90 percent of TTCmin.
    b. When the alternative procedure is executed, the lateral distance between the longitudinal centerline of the HV and the longitudinal centerline of the RV did not deviate more than 2.0 feet from the magnitude of the configured lateral offset of the RV's V2V device from the time the HV enters the test course until the TTC falls to less than 90 percent of TTCmin.
5. The yaw rates of the HV and the RV did not exceed ±1 degree/second.
6. The deceleration of the RV conforms to the specified deceleration profile.
7. The deviation of the headway does 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.

Developmental 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.10.9 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful if the HV OBE initiates a high-level FCW alert before the TTC falls below TTCmin. A trial is unsuccessful if the HV OBE initiates a high-level FCW alert after the TTC falls below TTCmin, or if no high-level FCW alert is initiated during the trial. Low-level FCW alerts are not considered.

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

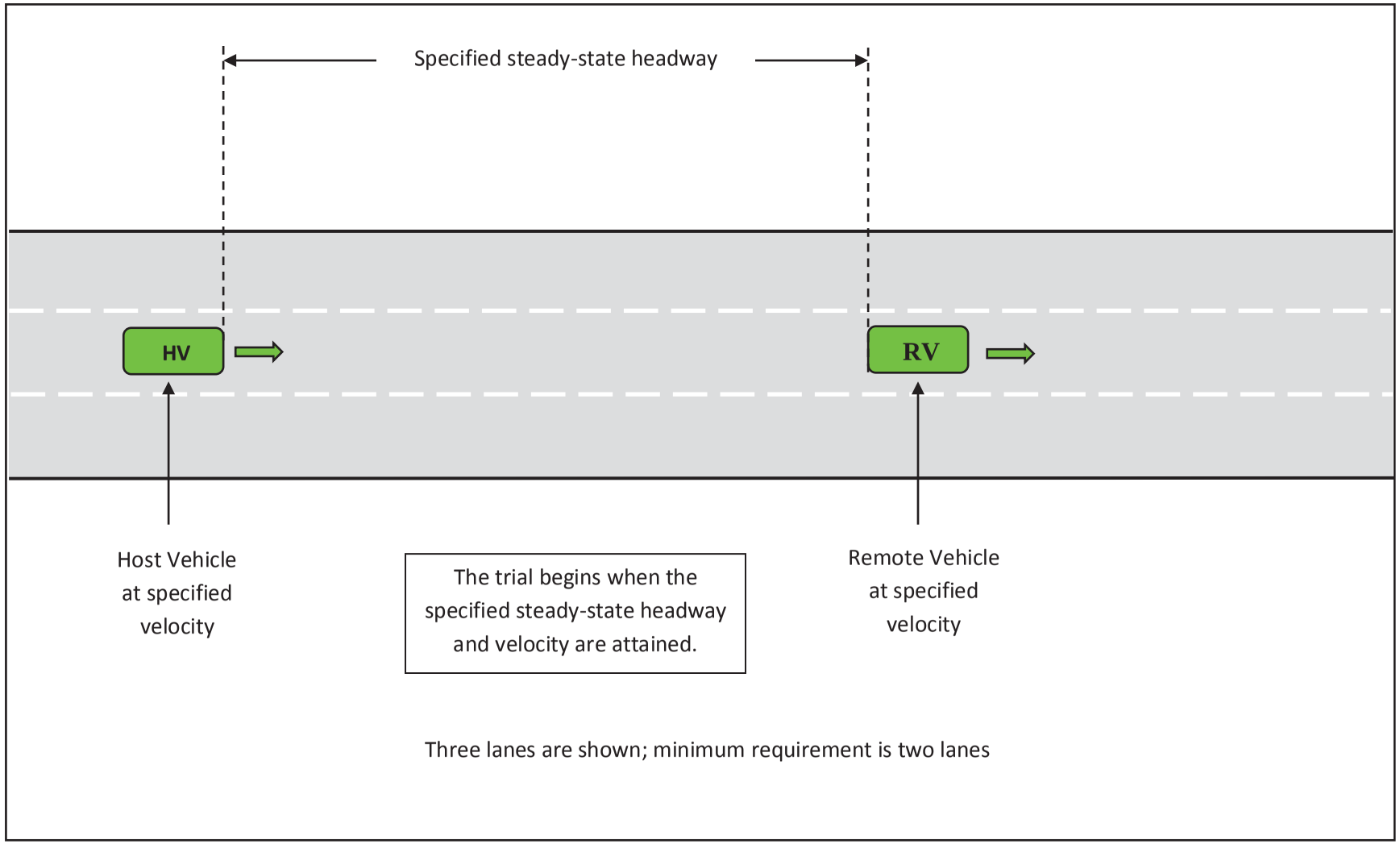


Figure A-8: FCW-3 Test Course Graphic, Initial Conditions for Primary Test Procedure [not to scale]

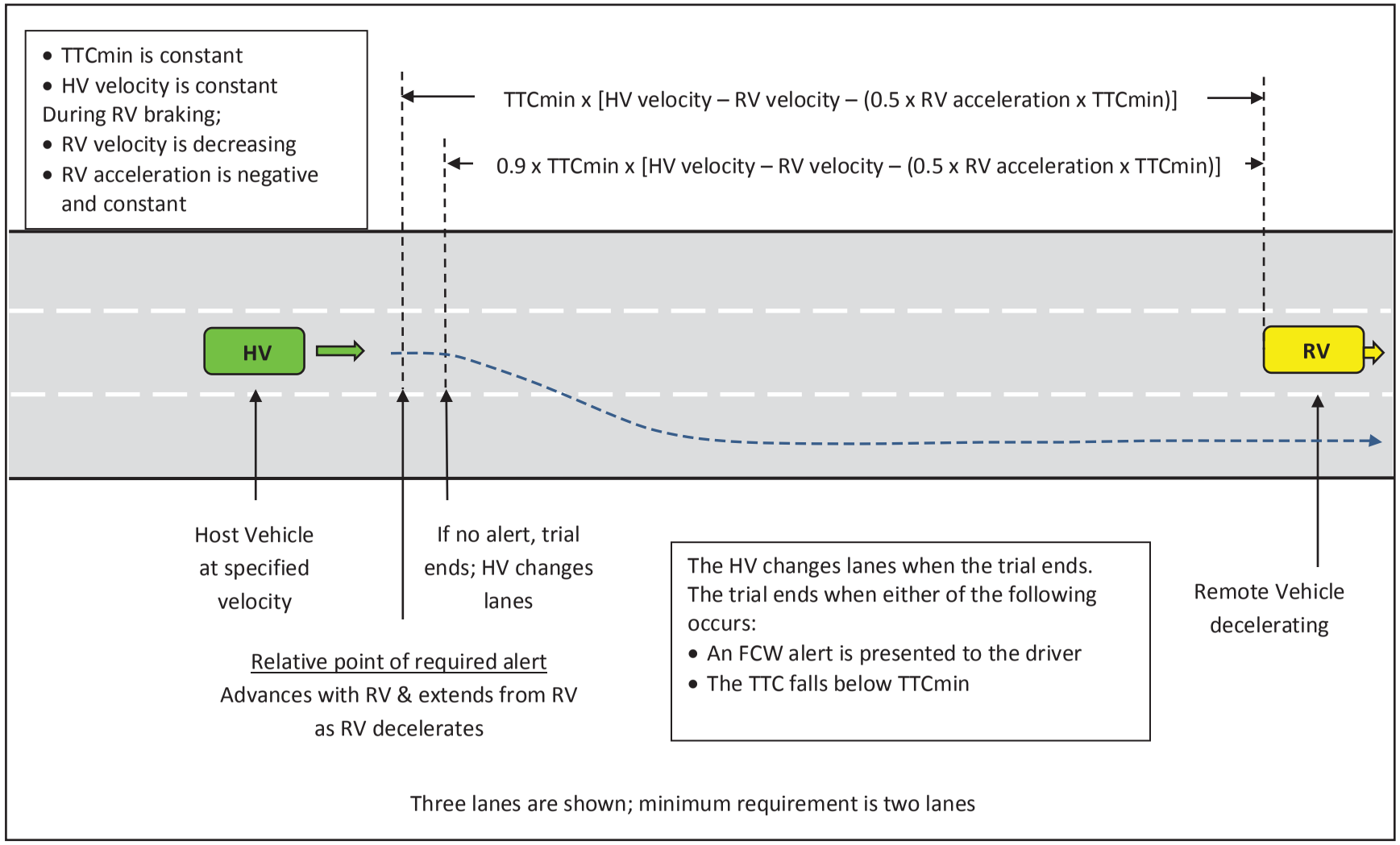


Figure A-9: FCW-3 Test Course Graphic, Primary Test Procedure End of Trial [not to scale]

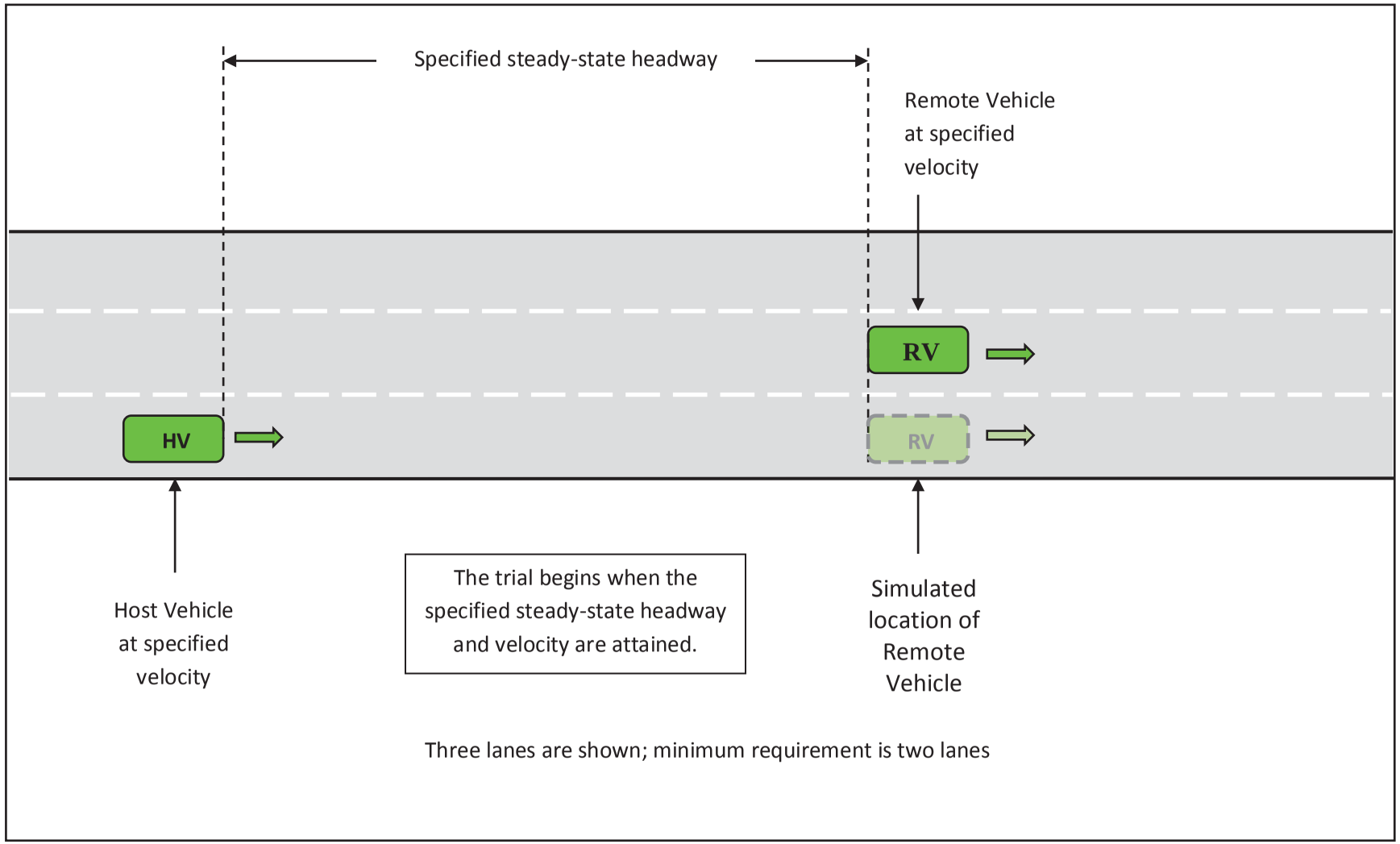


Figure A-10: FCW-3 Test Course Graphic, Initial Conditions for Alternative Test Procedure [not to scale]

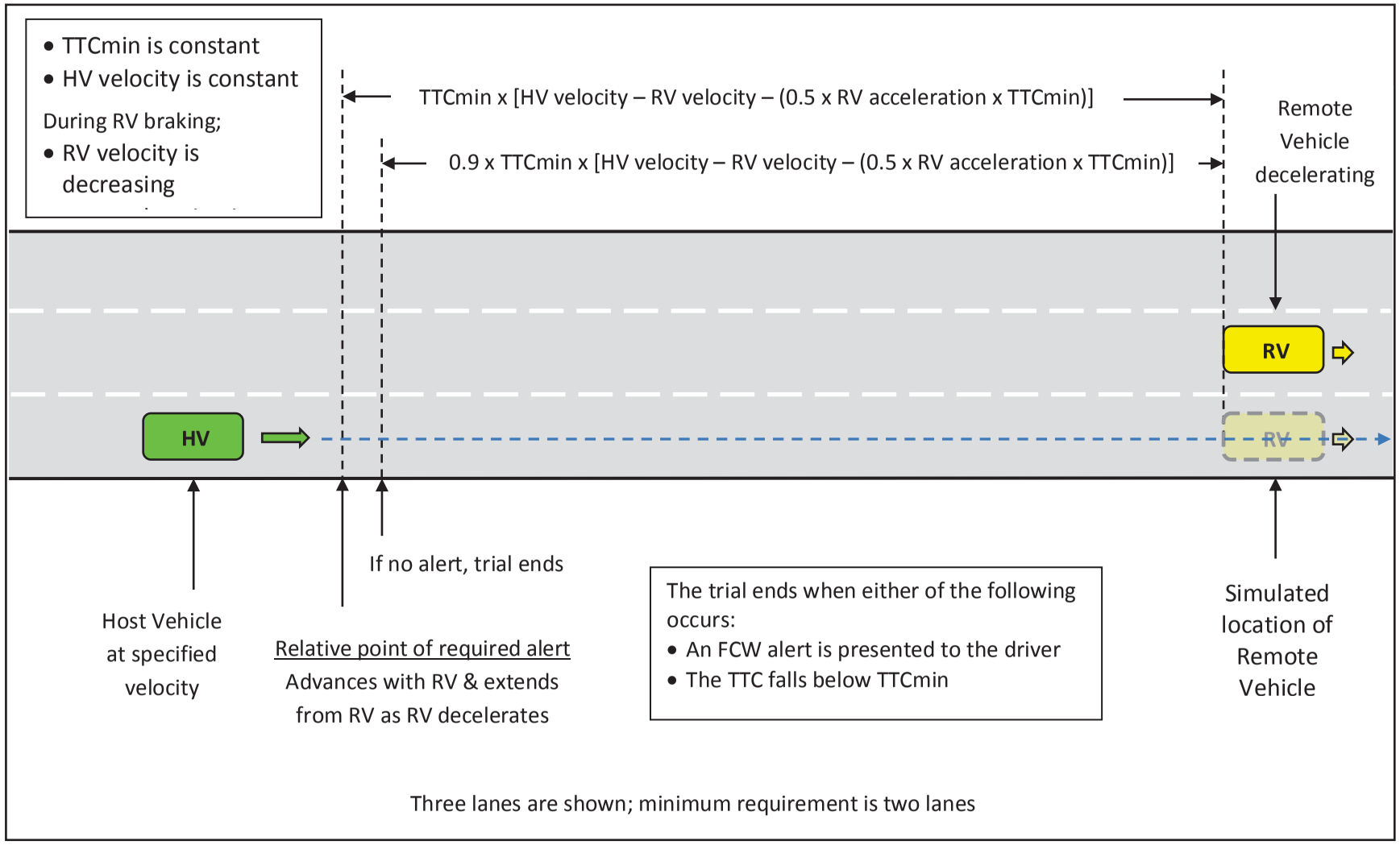


Figure A-11: FCW-3 Test Course Graphic, Alternative Test Procedure End of Trial [not to scale]

A.11 FCW-4 - Stopped Vehicles in Adjacent Lanes, Straight Road

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific FCW 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

Two leading vehicles are driven along a straight roadway in the same direction but in separate lanes such that there is one open lane between the two vehicles. Each leading vehicle is decelerated by brake application to a stop such that the trailing edges of the two leading vehicles are aligned laterally across the travel lanes. The leading vehicles are equipped with V2V systems that broadcast each leading vehicle's position, speed, direction of travel, and path history. A commercial vehicle equipped with a V2V system that features a FCW application is driven behind and in the same direction as the leading vehicles in the open lane. Initially, the commercial vehicle is separated from the leading vehicles by a distance greater than the FCW application's alert range. The commercial vehicle is driven in the open lane of travel toward, between, and past the stopped leading vehicles.

A.11.2 Test Subject and Purpose

The subject of this test is the V2V-based FCW system of the commercial vehicle. The test determines the ability of the commercial vehicle's system to recognize that the stopped leading vehicles are not in the commercial vehicle's travel lane and, thus, avoid presenting an alert.

A.11.3 Initial Condition

A.11.3.1 Test Velocities

For tests of V2V-based FCW systems where the RVs are driven along the test course to establish a path history for each RV, each RV is driven at a velocity above the minimum velocity at which the RV's OBE will establish and broadcast the RV's path history.

The velocity of the HV as it enters the test course is specified for each trial or set of trials. A minimum velocity may be specified above which an ISS or RSD would issue an alert in scenarios where an alert is expected. A single, standard velocity—not necessarily a minimum velocity—may be specified at which an ISS or RSD would issue an alert in scenarios where an alert is expected. A range of test velocities may be specified to determine the ability of the subject ISS or RSD to suppress alerts in the CCV FCW-4 test procedure scenario, where no alert is expected.

A.11.4 Metric

A.11.4.1 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.11.5 Execution of Procedure

Because application of the HV's service brakes will typically suppress FCW 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 FCW-4 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 between the RVs. 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.

The test procedure is depicted in Figure A-12.

1. To establish a path history for each RV, the RVs are driven in the outside lanes of the test course, one RV in each outside lane, from the beginning of the test course toward the end of the course. As each RV is driven, its driver must maintain its position in the center of its lane, laterally.
2. As each RV approaches the end of the course, its driver slows the RV and, at a specified distance from the beginning of the course, stops the RV in the center of its lane. Traffic cones or other suitable markers may be used to mark the parking location for each RV. The RVs are parked such that their trailing edges are aligned laterally across the test course lanes.
3. When each RV is stopped, the driver places the RV's transmission in park or neutral, releases the service brake, and sets the parking brake. The RV's OBE remains on. The RV drivers may exit the vehicles and move to a location away from the test course.
4. Each driver informs the experimenter that his or her RV is parked.
5. The experimenter arms the data acquisition system and directs the HV driver to begin the trial.
6. The HV driver begins driving toward the beginning of the test course while establishing and maintaining the HV at a specified speed.
7. At the beginning of the test course, the driver drives the HV into the middle lane of the test course. The trial begins when the HV is on the test course. A traffic cone or other suitable marker may be used to indicate the beginning of the test course.
8. The driver drives the HV toward the end of the course while maintaining the HV at the specified speed and while maintaining the HV's lateral position in the center of the middle lane, and proceeds to drive the HV between the RVs.
9. Each trial ends after the HV passes between the RVs.

A.11.6 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 throughout the length of the test course.
2. The HV's service brakes were not applied while the HV was within the test course.
3. The lateral distance between the centerline of the HV and the centerline of the middle lane did not exceed 2.0 feet; and lateral distance between the centerline of each RV and the centerline of it assigned lane did not exceed 2.0 feet.
4. The yaw rates of the RVs and the HV did not exceed ±1 degree/second during the course of the trial.

Developmental 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.11.7 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 valid trials. A FCW system passes if, within each series, a specified percentage of the specified quantity of valid trials is successful.

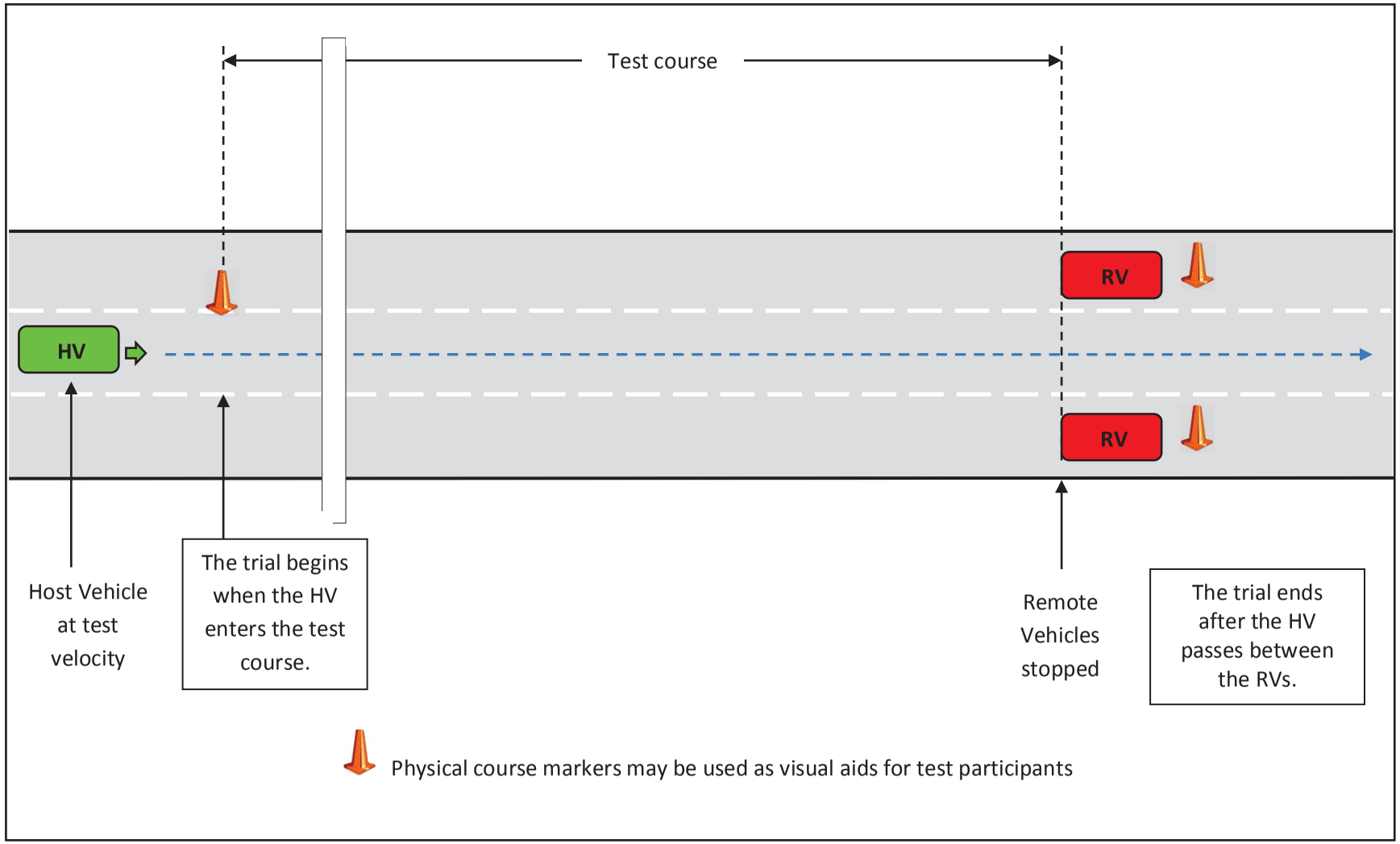


Figure A-12: FCW-4 Test Course Graphic [not to scale]

A.12 FCW-5 - Stopped 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 FCW 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

Two vehicles travel along a curved roadway in the same lane of travel and in the same direction. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The trailing vehicle is a commercial truck equipped with a V2V system that features a FCW application. The two vehicles are separated by a distance greater than the FCW application's alert range. The leading vehicle brakes to a stop in the lane of travel. The trailing vehicle drives in the same lane of travel toward the stopped leading vehicle and enters the FCW application's alert range.

A.12.2 Test Subject and Purpose

The subject of this test is the V2V-based FCW system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to identify the stopped leading vehicle as a collision threat and alert the trailing vehicle's driver of the threat in a timely manner.

A.12.3 Initial Condition

A.12.3.1 Test Velocities

For tests of V2V-based FCW systems where the RV is driven along the test course to establish a path history, the RV is driven at a velocity above the minimum velocity at which the RV's OBE will establish and broadcast the RV's path history.

The velocity of the HV as it enters the test course is specified for each trial or set of trials. A minimum velocity may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity—not necessarily a minimum velocity—may be specified at which an ISS or RSD would issue an alert to produce a successful trial. A range of test velocities may be specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress FCW alerts, and to determine the performance of the subject ISS or RSD from a minimum velocity to a maximum velocity.

A.12.4 Metric

A.12.4.1 Collision Alert

Time-to-collision (TTC) is a measure of the time interval between a pre-crash state and a potential collision of the HV with the RV. A minimum time-to-collision (TTCmin) for alert activation is specified for each trial or set of trials. A collision alert must be presented to the driver before the TTC falls below TTCmin.

A.12.5 Execution of Procedure

Because application of the HV's service brakes will typically suppress FCW alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the lane change has been completed at the end of the trial. 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.

The test procedure is depicted in Figure A-13.

1. To establish a path history, the RV is driven down the center of the primary test lane from the beginning of the test course toward the end of the course.
2. As the RV approaches the end of the course the driver slows the RV and, at a specified distance from the beginning of the course, stops the RV in the center of the primary lane. A traffic cone or other suitable marker may be used to mark the parking location.
3. When the RV is stopped, the driver places the RV's transmission in park or neutral, releases the service brake, and sets the parking brake. The RV's OBE remains on. The RV driver may exit the vehicle and move to a location away from the test course.
4. The RV driver informs the experimenter that the RV is parked.
5. The experimenter arms the data acquisition system and directs the HV driver to begin the trial.
6. The HV driver begins driving toward the beginning of the test course while establishing and maintaining the HV at a specified speed.
7. The HV is driven onto the course in the primary test lane. The trial begins when the HV is on the test course. A traffic cone or other suitable marker may be used to indicate the beginning of the test course.
8. The driver drives the HV toward the RV while maintaining the HV at the specified speed and while maintaining the HV's lateral position in the center of the lane.
9. Each trial ends when the required FCW alert occurs or, if the required FCW alert does not occur, when the TTC falls to less than 90 percent of TTCmin.
10. After the end of the trial, the HV driver steers the HV into the secondary lane, passes the RV, and exits the course. A traffic cone or other suitable marker may be used to indicate to the HV driver where the trial ends and the lane change is to be initiated.

A.12.6 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 FCW alert or before the TTC falls to less than 90 percent of TTCmin.
2. The HV's service brakes were not applied prior to the required FCW alert or before the TTC falls to less than 90 percent of TTCmin.
3. The lateral distance between the centerline of the HV and the centerline of the curved lane did not exceed 2.0 feet.

4. The yaw rate of the HV did not vary more than ±1 degree/second from the rate of rotation based on the specified velocity and radius of the curve.

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

A trial is successful if the HV OBE initiates a high-level FCW alert before the TTC falls below TTCmin. A trial is unsuccessful if the HV OBE initiates a high-level FCW alert after the TTC falls below TTCmin, or if no high-level FCW alert is initiated during the trial. Low-level FCW alerts are not considered.

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

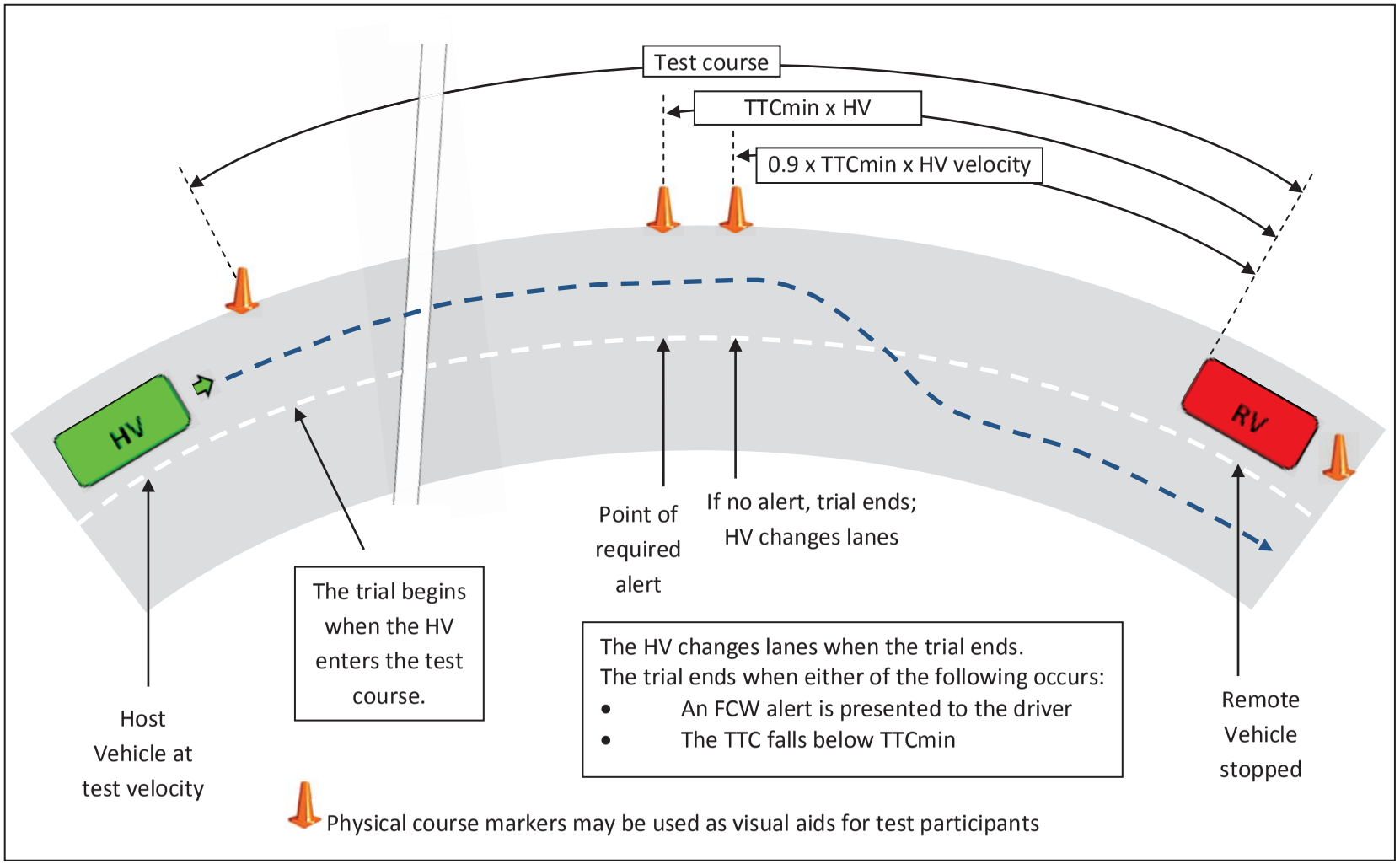


Figure A-13: FCW-5 Test Course Graphic [not to scale]

A.13 FCW-6 - Stopped Vehicle Ahead in 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 FCW 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.13.1 Pre-Crash Scenario

A leading vehicle is driven along a curved roadway and is decelerated by brake application to a stop. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. A commercial vehicle equipped with a V2V system that features a FCW application is driven behind and in the same direction as the leading vehicle but in an adjacent lane. Initially, the commercial vehicle is separated from the leading vehicle by a distance greater than the FCW application's alert range. The commercial vehicle is driven in the adjacent lane toward and past the stopped leading vehicle.

A.13.2 Test Subject and Purpose

The subject of this test is the V2V-based FCW system of the commercial vehicle. The test determines the ability of the commercial vehicle's system to recognize that the stopped leading vehicle is not in the commercial vehicle's travel lane and, thus, avoid presenting an alert.

A.13.3 Initial Condition

A.13.3.1 Test Velocities

For tests of V2V-based FCW systems where the RV is driven along the test course to establish a path history, the RV is driven at a velocity above the minimum velocity at which the RV's OBE will establish and broadcast the RV's path history.

The velocity of the HV as it enters the test course is specified for each trial or set of trials. A minimum velocity may be specified above which an ISS or RSD would issue an alert in scenarios where an alert is expected. A single, standard velocity—not necessarily a minimum velocity—may be specified at which an ISS or RSD would issue an alert in scenarios where an alert is expected. A range of test velocities may be specified to determine the ability of the subject ISS or RSD to suppress alerts in the CCV FCW-6 test procedure scenario, where no alert is expected.

A.13.4 Metric

A.13.4.1 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.13.5 Execution of Procedure

Because application of the HV's service brakes will typically suppress FCW 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 FCW-6 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.

The test procedure is depicted in Figure A-14.

1. To establish a path history, the RV is driven down the center of the lane assigned to the RV from the beginning of the test course toward the end of the course.
2. As the RV approaches the end of the course the driver slows the RV and, at a specified distance from the beginning of the course, stops the RV in the center of its assigned lane. A traffic cone or other suitable marker may be used to mark the parking location.
3. When the RV is stopped, the driver places the RV's transmission in park or neutral, releases the service brake, and sets the parking brake. The RV's OBE remains on. The RV driver may exit the vehicle and move to a location away from the test course.
4. The RV driver informs the experimenter that the RV is parked.
5. The experimenter arms the data acquisition system and directs the HV driver to begin the trial.
6. The HV driver begins driving toward the beginning of the test course while establishing and maintaining the HV at a specified speed.
7. The HV is driven onto the course in the lane assigned to the HV. The trial begins when the HV is on the test course. A traffic cone or other suitable marker may be used to indicate the beginning of the test course.
8. The driver drives the HV toward the end of the course while maintaining the HV at the specified speed and while maintaining the HV's lateral position in the center of the lane assigned to the HV, and proceeds to drive past the RV.
9. Each trial ends after the HV drives past the RV.

A.13.6 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 throughout the length of the test course.
2. The HV's service brakes were not applied while the HV was within the test course.
3. The lateral distance between the centerline of the HV and the centerline of the lane assigned to the HV did not exceed 2.0 feet; and lateral distance between the centerline of the RV and the centerline of it assigned lane did not exceed 2.0 feet.
4. The yaw rates of the RV and the HV did not exceed ±1 degree/second during the course of the trial.

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.13.7 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. A FCW system passes if, within each series, a specified percentage of the specified quantity of consecutive trials is successful.

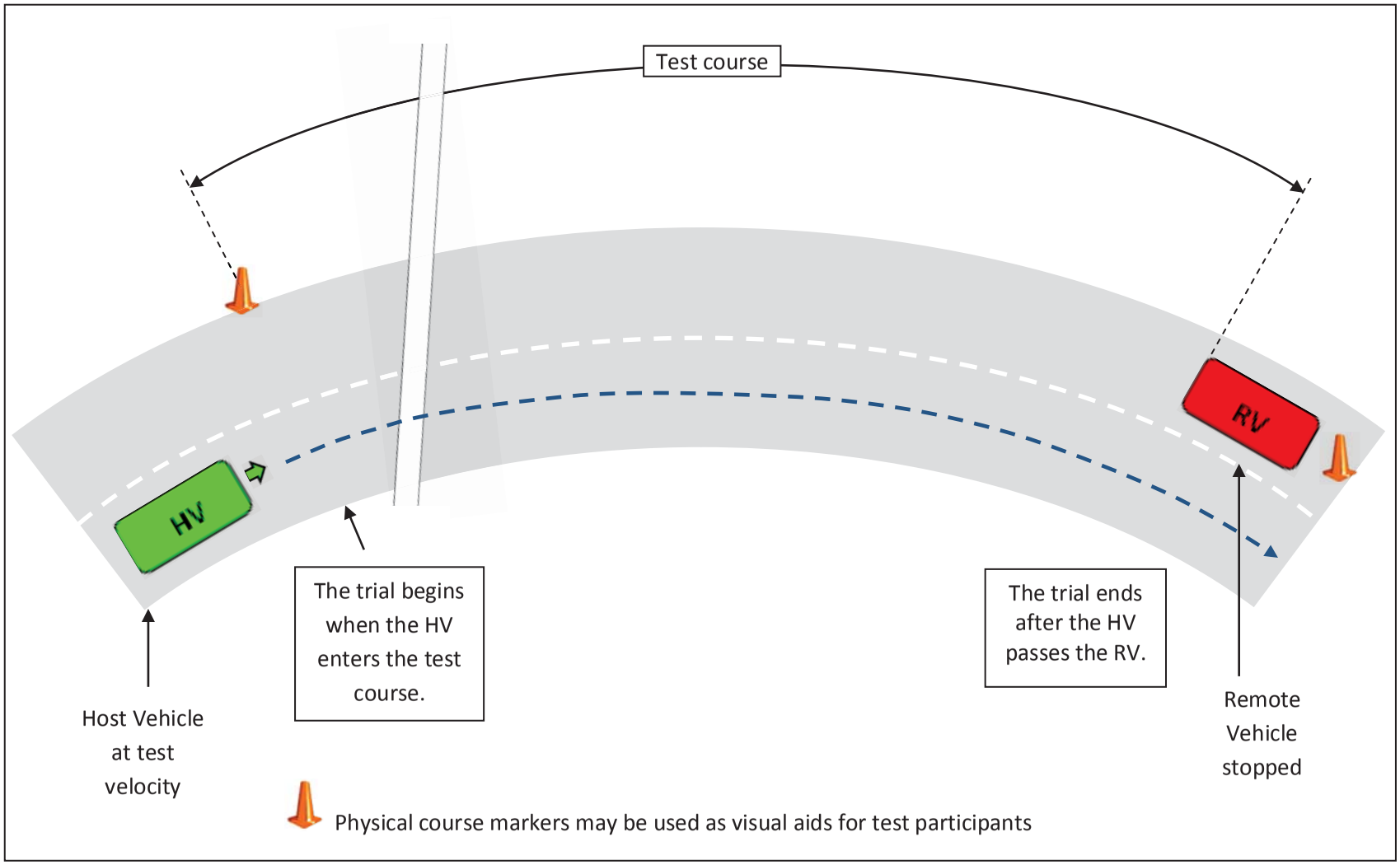


Figure A-14: FCW-6 Test Course Graphic [not to scale]

A.14 FCW-7 - Lane Change Reveal

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific FCW 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

Three vehicles travel along a straight roadway in the same lane of travel and in the same direction. The leading and intermediate vehicles are each equipped with V2V systems that broadcast each vehicle's position, speed, direction of travel, and path history. The trailing vehicle is a commercial truck equipped with a V2V system that features a FCW application. The driver of the leading vehicle applies the vehicle's service brakes and stops the vehicle in the lane of travel. The driver of the intermediate vehicle steers the vehicle into an adjacent lane to avoid the stopped leading vehicle. Thus, the stopped leading vehicle is revealed to the moving trailing vehicle.

A.14.2 Test Subject and Purpose

The subject of this test is the V2V-based FCW system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to identify the stopped leading vehicle as a collision threat and alert the trailing vehicle's driver of the threat in a timely manner.

A.14.3 Initial Condition

A.14.3.1 Test Velocities

For tests of V2V-based FCW systems where a leading RV is driven along the test course to establish a path history, the RV is driven at a velocity above the minimum velocity at which the RV's OBE will establish and broadcast the RV's path history.

The HV and intermediate RV enter the course at the same velocity. The velocity is specified for each trial or set of trials. A minimum velocity may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity—not necessarily a minimum velocity—may be specified at which an ISS or RSD would issue an alert to produce a successful trial. A range of test velocities may be specified to characterize the threshold velocity below which the subject ISS or RSD is designed to suppress FCW alerts, and to determine the performance of the subject ISS or RSD from a minimum velocity to a maximum velocity.

A.14.3.2 Headway

The headway between the intermediate RV and the HV is specified for each trial or set of trials. The headway may be specified as a distance between the rear of the intermediate RV and the front of the HV, or as an interval of time from when the rear of the intermediate RV clears a reference point to when the front of the HV attains the same point.

A.14.4 Metric

A.14.4.1 Collision Alert

Time-to-collision (TTC) is a measure of the time interval between a pre-crash state and a potential collision of the HV with the leading, stopped RV. A minimum time-to-collision (TTCmin) for alert activation is specified for each trial or set of trials. A collision alert must be presented to the driver before the TTC falls below TTCmin.

A.14.5 Execution of Procedure

Because application of the HV's service brakes will typically suppress FCW alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the lane change has been completed at the end of the trial. 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.

The test procedure is depicted in Figure A-15.

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 the intermediate RV which is staged behind the leading RV and all vehicles are oriented to travel toward the opposite end of the test facility.
2. To establish a path history, the leading RV is driven down the center of the primary test lane from the beginning of the test course toward the end of the course.
3. As the leading RV approaches the end of the course the driver slows the RV and, at a specified distance from the beginning of the course, stops the RV in the center of the primary lane. A traffic cone or other suitable marker may be used to mark the parking location.
4. When the leading RV is stopped, the driver places the RV's transmission in park or neutral, releases the service brake, and sets the parking brake. The RV's OBE remains on. The RV driver may exit the vehicle and move to a location away from the test course.
5. The driver of the leading RV informs the experimenter that the RV is parked.
6. The experimenter arms the data acquisition system and directs the drivers of the intermediate RV and the HV to begin the trial.
7. The drivers of the intermediate RV and the HV begin driving toward the beginning of the test course while establishing and maintaining the specified speed and headway.
8. The intermediate RV and the HV are driven onto the course in the primary test lane. The trial begins when both the intermediate RV and the HV are on the test course. A traffic cone or other suitable marker may be used to indicate the beginning of the test course.
9. The drivers of the intermediate RV and the HV drive their vehicles toward the stopped leading RV while maintaining the specified velocity and headway, and while maintaining each vehicle's lateral position in the center of the lane.
10. When the TTC of the intermediate RV in relation to the stopped leading RV falls to less than 90 percent of TTCmin, the driver of the intermediate RV steers the vehicle into the secondary lane to avoid the stopped leading RV. A traffic cone or other suitable marker

may be used to indicate to the driver of the intermediate RV where the lane change is to be initiated.

11. Each trial ends when the host vehicle OBE issues the required FCW alert or, if the required FCW alert does not occur, when the TTC of the HV in relation to the stopped leading RV falls to less than 90 percent of TTCmin.
12. After the end of the trial, the HV driver steers the HV into the secondary lane, passes the stopped leading RV, and exits the course. The same traffic cone or other suitable marker suggested in Step 10 may be used to indicate to the HV driver where the trial ends and the lane change is to be initiated.

A.14.6 Trial Validity

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

1. The velocity of the intermediate RV and the HV did not deviate from the specified velocity by more than 1.0 mph throughout the length of the test course.
2. The headway between the intermediate RV and the HV did not deviate from the specified headway by more than 10 percent throughout the length of the test course.
3. The HV's service brakes were not applied while the HV was within the test course.
4. The lateral distance between the centerlines of the vehicles and the centerline of the primary lane did not exceed 2.0 feet.
5. The yaw rates of the vehicles did not exceed ±1 degree/second during the course of the trial.

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 if the HV OBE initiates a high-level FCW alert before the TTC falls below TTCmin. A trial is unsuccessful if the HV OBE initiates a high-level FCW alert after the TTC falls below TTCmin, or if no high-level FCW alert is initiated during the trial. Low-level FCW alerts are not considered.

Each test series is comprised of a specified quantity of valid trials. A FCW system passes if, within each series, a specified percentage of the specified quantity of valid trials is successful.

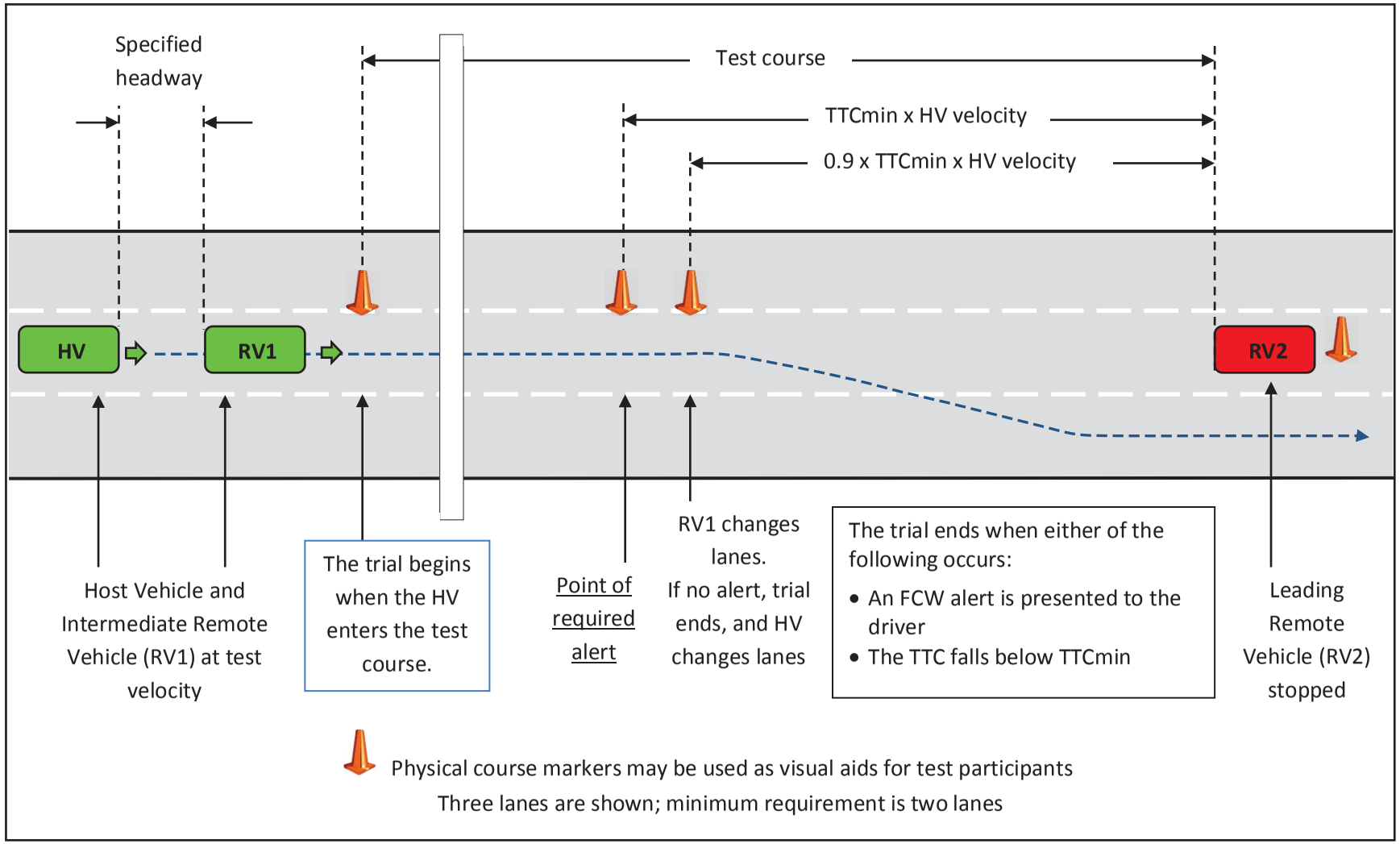


Figure A-15: FCW-7 Test Course Graphic [not to scale]

A.15 FCW-8 - Tailgate

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific FCW 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.15.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in the same lane of travel and in the same direction. The leading vehicle is equipped with a V2V system that broadcasts the leading vehicle's position, speed, direction of travel, and path history. The trailing vehicle is a commercial truck equipped with a V2V system that features a FCW application. The two vehicles travel at the same velocity and are separated by a minimal distance such that the trailing vehicle tailgates the leading vehicle.

A.15.2 Test Subject and Purpose

The subject of this test is the V2V-based FCW system of the commercial vehicle. The test determines the ability of the commercial vehicle's system to avoid presenting an alert when closely following another vehicle while both vehicles are maintaining the same velocity.

A.15.3 Initial Condition

A.15.3.1 Test Velocities

The velocity of the HV and the RV as they enter and travel through the test course is specified for each trial or set of trials. A minimum velocity may be specified above which an ISS or RSD would issue an alert in scenarios where an alert is expected. A single, standard velocity—not necessarily a minimum velocity—may be specified at which an ISS or RSD would issue an alert in scenarios where an alert is expected. A range of test velocities may be specified to characterize the ability of the subject ISS or RSD to suppress alerts throughout a spectrum of conditions.

A.15.3.2 Headway

The headway between the RV and the HV is specified for each trial or set of trials. The specified headway is minimal such that the HV tailgates 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 range of headways may be specified to characterize the ability of the subject ISS or RSD to suppress alerts throughout a spectrum of conditions.

A.15.4 Metric

A.15.4.1 Driver-Vehicle Interface Response

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

A.15.5 Execution of Procedure

Because application of the HV's service brakes will typically suppress FCW 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 FCW-8 test procedure, it is important to avoid invalidating test trials by inadvertently suppressing any false alerts via brake application or other means. 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 conditions. Steps 1 through 4 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 5 through 8 comprise the specified procedure.

The test procedure is depicted in Figure A-16.

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.
2. The experimenter arms the HV's data acquisition system and directs the driver of both vehicles to begin driving.
3. The RV driver begins driving and establishes and maintains the specified velocity.
4. The HV driver begins driving soon after the RV begins moving and establishes the specified headway.
5. The experimenter announces to the drivers that the trial has begun.
6. For the specified trial duration, the drivers maintain the specified velocity and headway and maintain the lateral position of the vehicles in the center of the primary test lane.
7. Each trial ends when the specified velocity and headway have been maintained for the specified duration.
8. The experimenter announces to the drivers that the trial has ended.
9. The HV driver slows the HV to extend the headway and both vehicles exit the test course.

A.15.6 Trial Validity

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

1. The velocity of both vehicles did not deviate from the specified velocity by more than 1.0 mph throughout the length of the test course.

2. The headway between the vehicles did not deviate from the specified headway by more than 10 percent throughout the length of the test course.
3. The HV's service brakes were not applied while the HV was within the test course.
4. The lateral distance between the centerlines of the vehicles and the centerline of the primary lane did not exceed 2.0 feet.
5. The yaw rates of the vehicles did not exceed ±1 degree/second during the course of the trial.

Developmental 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.15.7 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 FCW application alert.

Each test series is comprised of a specified quantity of valid trials. A FCW system passes if, within each series, a specified percentage of the specified quantity of valid trials is successful.

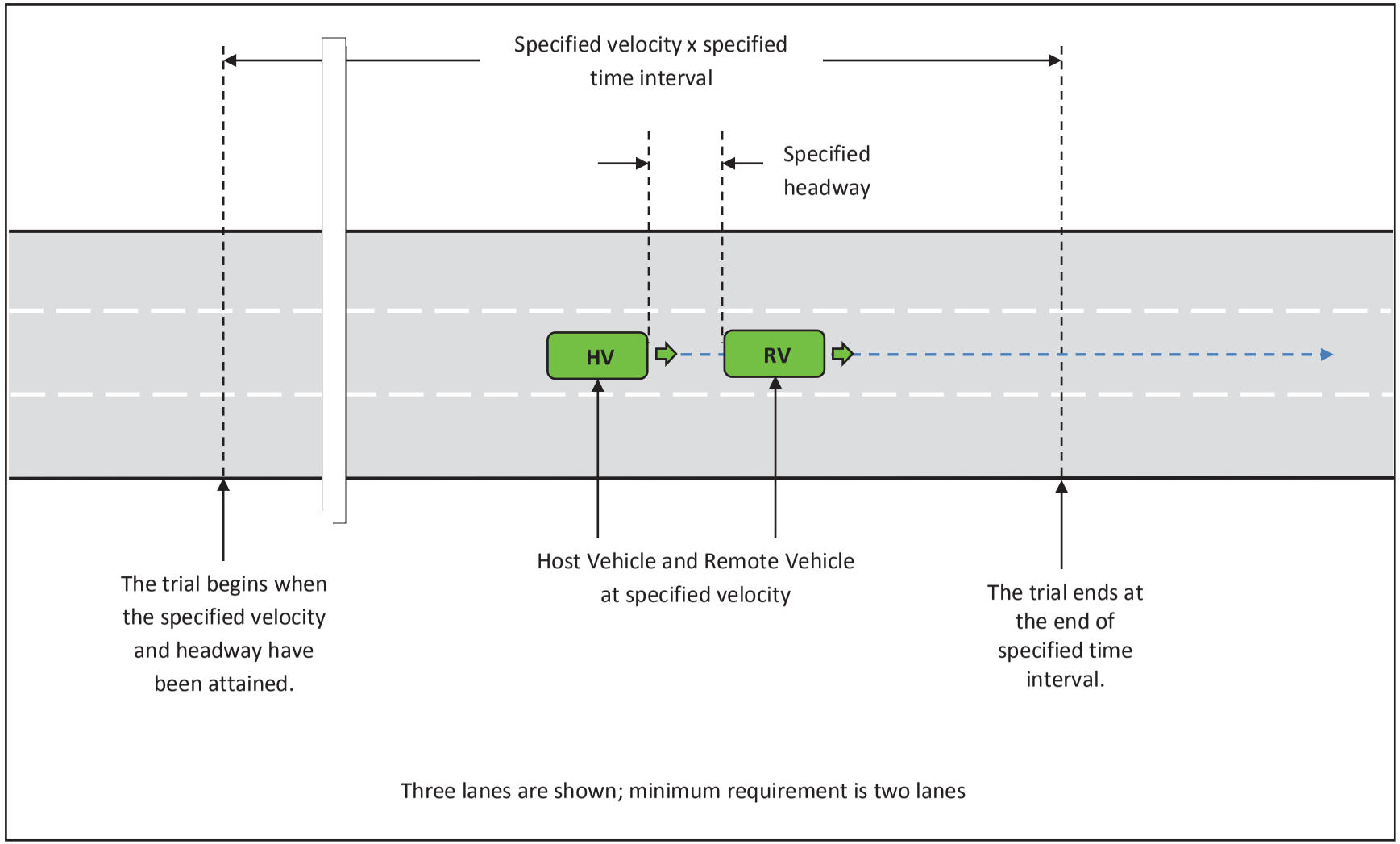


Figure A-16: FCW-8 Test Course Graphic [not to scale]

A.16 FCW-9 - Target Switch

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a specific FCW 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.16.1 Pre-Crash Scenario

Three vehicles travel along a straight, multi-lane roadway in the same direction. The leading and intermediate vehicles are each equipped with V2V systems that broadcast each vehicle's position, speed, direction of travel, and path history. The trailing vehicle is a commercial truck equipped with a V2V system that features a FCW application. The trailing vehicle approaches the intermediate vehicle which is traveling in the same lane ahead of but slower than the trailing vehicle. The leading vehicle is traveling a short distance ahead of the intermediate vehicle in one of the adjacent lanes at a velocity slower than the intermediate vehicle. As the three vehicles converge, the leading vehicle moves to the lane occupied by the other two vehicles. The intermediate vehicle moves to one of the adjacent lanes to avoid the leading vehicle and the trailing vehicle approaches the slower leading vehicle.

A.16.2 Test Subject and Purpose

The subject of this test is the V2V-based FCW system of the trailing vehicle. The test determines the ability of the trailing vehicle's system to recognize that the primary collision threat changes from the intermediate vehicle to the leading vehicle, and to alert the trailing vehicle's driver of each collision threat in a timely manner.

A.16.3 Initial Condition

A.16.3.1 Test Velocities

The velocities are specified for each trial or set of trials. The velocity of the lead vehicle, RV2, is lowest and that of the trailing vehicle, the HV, is highest. The velocity of the intermediate vehicle, RV1, is between the velocities of the HV and RV2.

When specifying velocities, the following might be considered:

- Minimum velocities for each vehicle may be specified above which the HV's ISS or RSD would issue an alert to produce a successful trial.
- A set of standard velocities—not necessarily minimum velocities—may be specified at which an ISS or RSD would issue an alert to produce a successful trial.
- Multiple velocity combinations may be specified to characterize the range of performance of the subject ISS or RSD.

A.16.4 Metric

A.16.4.1 Collision Alert

Time-to-collision (TTC) is a measure of the time interval between a pre-crash state and a potential collision of the HV with either of the RVs. Minimum times-to-collision for alert activation are specified for each trial or set of trials. A minimum TTC is specified for each RV (TTCminRV1, TTCminRV2). TTCminRV1 and TTCminRV2 may be equal or distinct.

Preliminary Metric: Alert of Imminent Collision with Intermediate Vehicle

A minimum time-to-collision of the HV with RV1 (TTCminRV1) is specified. An alert of an imminent collision of the HV with RV1 must be presented to the HV's driver before the HV-to-RV1 TTC falls below TTCminRV1.

Primary Metric: Alert of Imminent Collision with Leading Vehicle

A minimum time-to-collision of the HV with RV2 (TTCminRV2) is specified. An alert of an imminent collision of the HV with RV2 must be presented to the HV's driver after an alert of an imminent collision with RV1 is presented and before the HV-to-RV2 TTC falls below TTCminRV2.

Sequence of Metrics

For clarity, the sequence of events in regard to the metrics is:

1. The HV closes on RV1 and an alert of imminent collision with RV1 is presented to the HV's driver (preliminary metric).
2. RV2 changes from an adjacent lane to the lane occupied by RV1 and the HV, and RV1 changes to the opposite adjacent lane to avoid RV2.
3. The HV closes on RV2 and an alert of imminent collision with RV2 is presented to the HV's driver (primary metric).

A.16.5 Execution of Procedure

Because application of the HV's service brakes will typically suppress FCW alerts, the HV driver should refrain from applying the HV's brakes during the trial. The driver may apply the brakes after the lane change has been completed at the end of the trial. 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 RV1 attains its specified velocity. There may be a variety of methods for establishing the initial conditions. Steps 1 through 4 of the following procedure comprise one recommendation for establishing the initial conditions. Steps 5 through 9 comprise the specified procedure.

The test procedure is depicted in Figure A-17, Figure A-18, and Figure A-19.

1. At one end of the straight road test facility, the HV and RV1 are staged in the primary test lane and RV2 is staged in a lane adjacent to the primary test lane. 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. The staging positions for each vehicle are determined by analyses of the specified velocities, specified TTCs, FCW alert range limit, and acceleration capabilities of the test vehicles.

2. The experimenter arms the HV's data acquisition system and directs the drivers of all three vehicles to begin driving.
3. The three vehicles are accelerated at the same rate.
4. RV2 attains and then maintains its specified velocity; RV1 and the HV continue to accelerate at the specified rate.
5. The trial begins when RV1 attains and then maintains its specified velocity. RV2 continues to maintain its specified velocity and the HV continues to accelerate at the specified rate.

   Preliminary metric: Because the HV is now closing on RV1, an alert of imminent forward collision with RV1 will likely be presented to the HV driver. Despite the alert, the HV driver continues to accelerate the HV at the specified rate to the HV's specified velocity.

6. When the HV attains its specified velocity, the experiment directs the drivers of RV2 and RV1 to change lanes—RV2 moves from the adjacent lane to the primary lane and RV1 moves from the primary lane to the opposite adjacent lane to avoid RV2; all vehicles maintain their specified velocities.
7. Each trial ends when an alert of imminent forward collision with RV2 is presented to the HV driver or, if an alert of imminent forward collision with RV2 is not presented, when the TTC falls to less than 90 percent of TTCminRV2.
8. After the end of the trial, the HV driver steers the HV into the adjacent lane opposite the adjacent lane now occupied by RV1 and passes RV2.
9. All vehicles exit the test course.

A.16.6 Trial Validity

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

1. The velocities of the RVs and the HV did not deviate from the specified velocities by more than 1.0 mph, once the vehicle attained the specified velocities.
2. The HV's service brakes were not applied during the trial.
3. The lateral distance between the centerlines of the vehicles and the centerline of the primary lane did not exceed 2.0 feet, other than during lanes changes.
4. The yaw rates of the vehicles did not exceed ±1 degree/second during the course of the trial, other than during lane changes.

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

A trial is successful if all of the following events occur during the trial:

- The HV OBE initiates an alert of imminent collision with RV1 before the HV-to-RV1 TTC falls below TTCminRV1.
- The HV OBE initiates an alert of imminent collision with RV2 after an alert of imminent collision with RV1 is displayed and before the HV-to-RV2 TTC falls below TTCminRV2.

A trial is unsuccessful if any of the following occurs:

- The HV OBE does not initiate an alert of imminent collision with RV1 and/or an alert of imminent collision with RV2 before the TTC falls below TTCminRV1 and/or TTCmin RV2, respectively.
- The sequence of alerts is reversed such that an alert of imminent collision with RV2 is initiated before and alert of imminent collision with RV1 is displayed.

Low-level FCW alerts are not considered.

Each test series is comprised of a specified quantity of valid trials. A FCW system passes if, within each series, a specified percentage of the specified quantity of valid trials is successful.

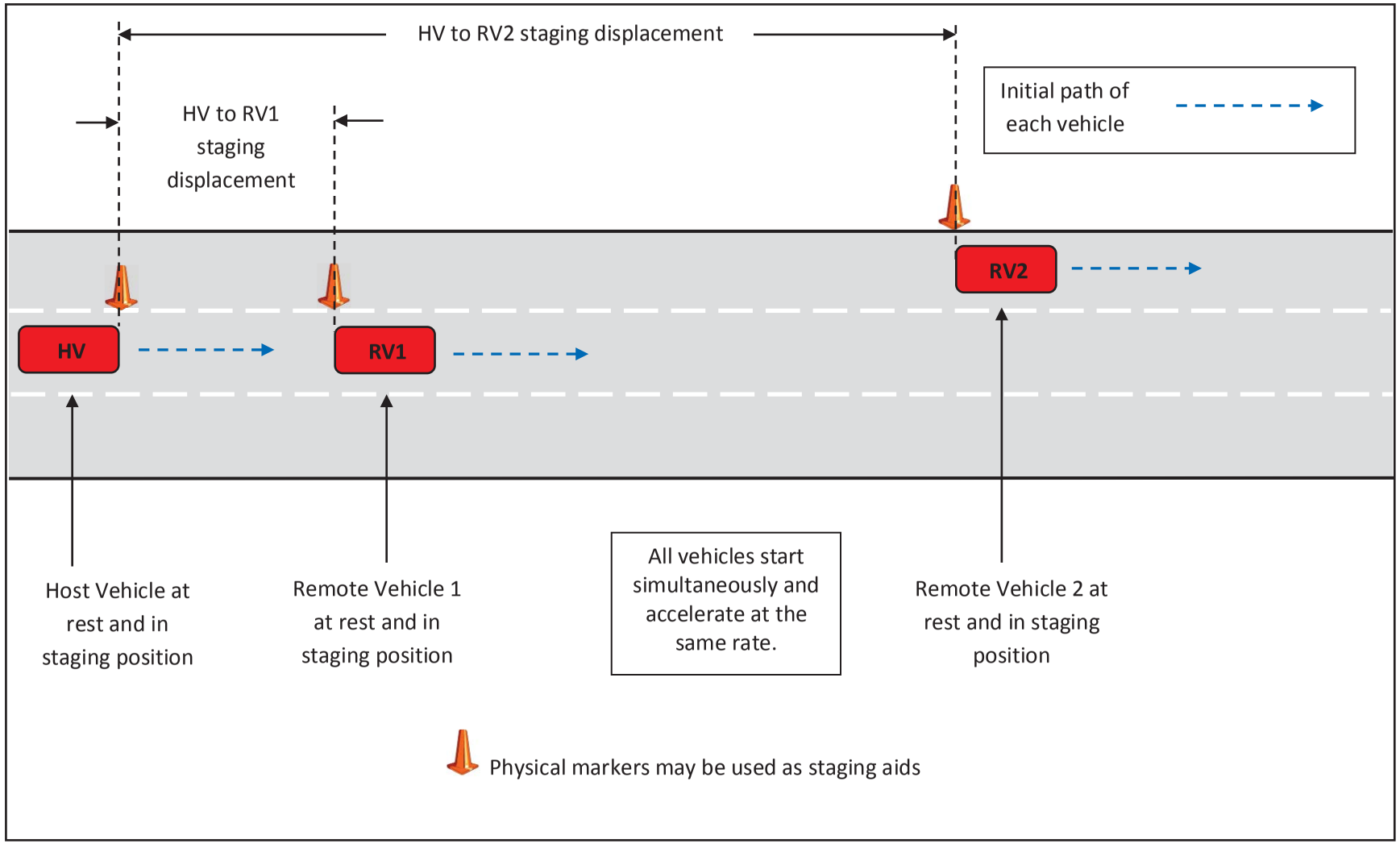


Figure A-17: FCW-9 Test Course Graphic, Initial Conditions [not to scale]

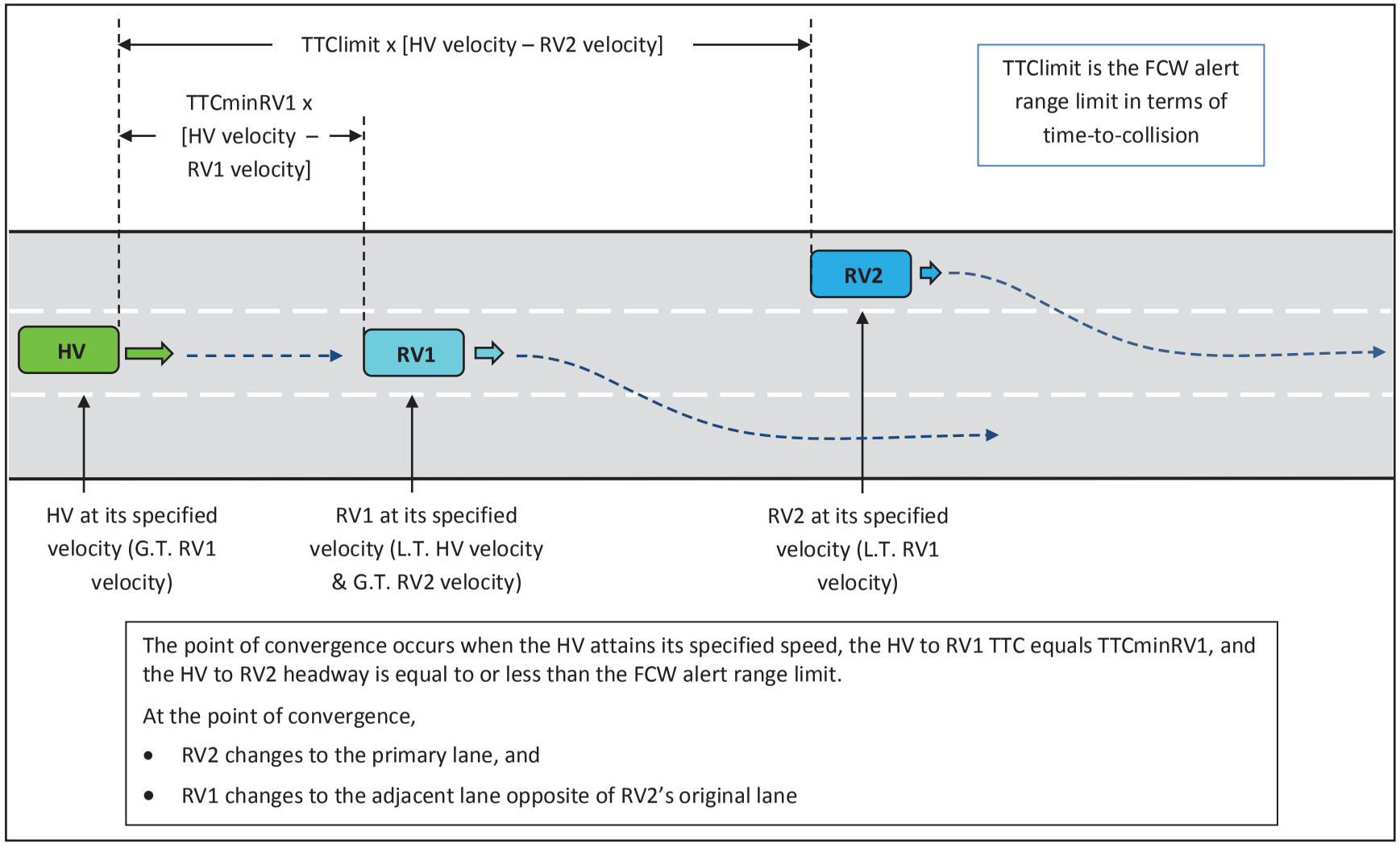


Figure A-18: FCW-9 Test Course Graphic, Point of Convergence [not to scale]

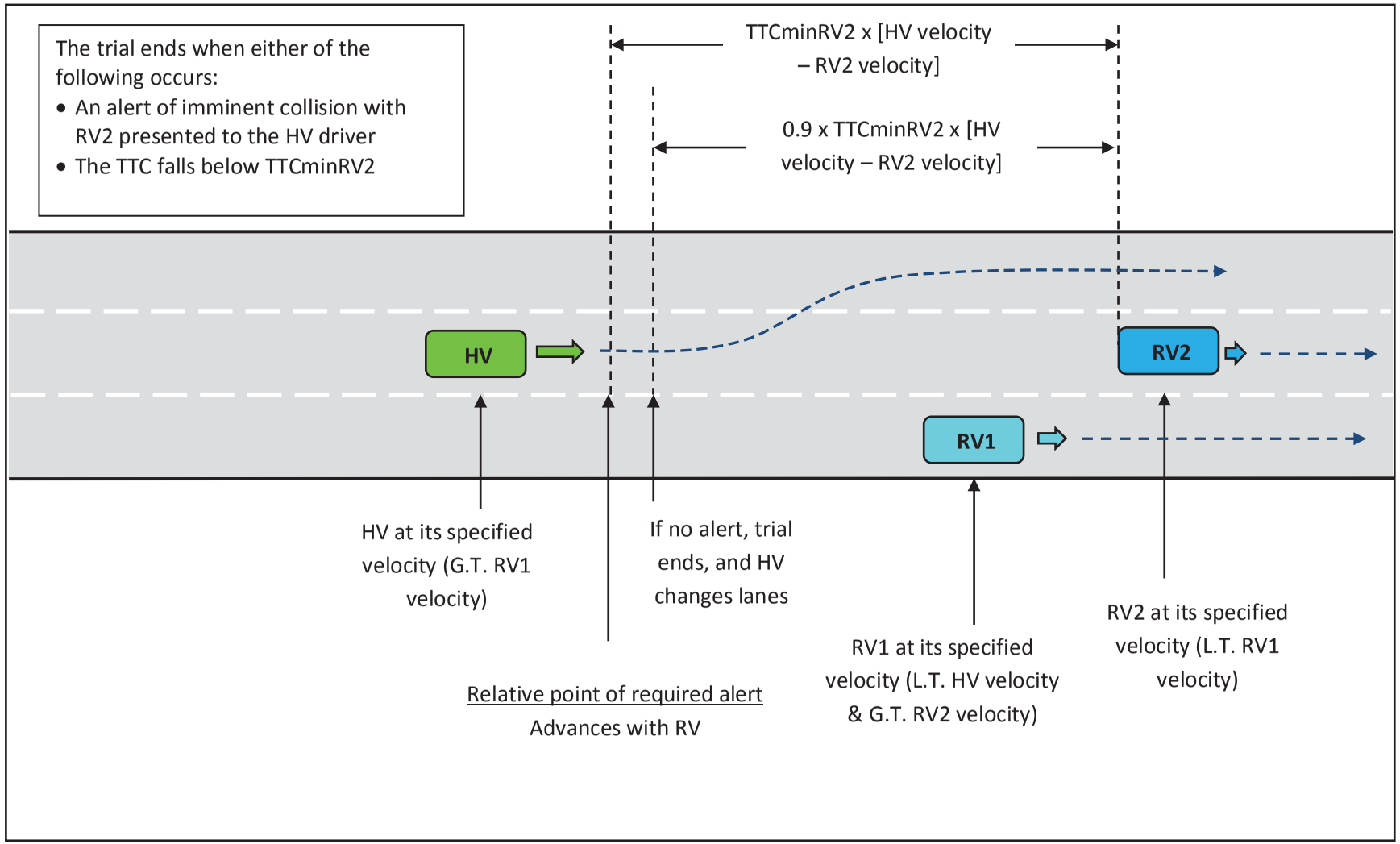


Figure A-19: FCW-9 Test Course Graphic, End of Trial [not to scale]

Appendix B - Tabulated Test Results

B.1 FCW-1 Tabulated Test Results

Table B-1: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia Bobtail

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1093	7.1		7.1	141.0		143.6	45.1	0
1094	7.1		7.2	142.0		145.2	45.3	0
1095	7.1		7.2	141.5		144.7	45.1	0
1096	7.1		7.1	141.0		143.6	45.2	0
1097	7.1		7.2	142.3		145.4	45.2	0
Ave.	7.1		7.2	141.6		144.5	45.2	0
Std.	0.0		0.0	0.6		0.9	0.1	
C. of V. (%)	0.3		0.5	0.4		0.6	0.2	

Table B-2: TTC, Longitudinal Range, and Speed at FCW Level 3 Alert for HV = Red Cascadia Bobtail, RV = Blue Cascadia Bobtail

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1093	6.3		6.4	126.9		129.5	45.1	0
1094	6.3		6.5	127.8		131.0	45.4	0
1095	6.3		6.4	125.4		128.6	45.2	0
1096	6.2		6.3	124.9		127.5	45.1	0
1097	6.3		6.4	126.1		129.3	45.3	0
Ave.	6.3		6.4	126.2		129.2	45.2	0
Std.	0.0		0.1	1.2		1.3	0.1	
C. of V. (%)	0.7		0.8	0.9		1.0	0.3	

Table B-3: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Single 28' Trailer - Faux

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1089	7.0		7.1	140.5		143.2	45.2	0
1090	7.1		7.2	142.8		145.9	45.3	0
1091	7.1		7.2	141.7		144.4	45.0	0
1092	7.1		7.2	141.2		144.3	45.0	0
Ave.	7.1		7.2	141.5		144.5	45.1	0
Std.	0.1		0.1	1.0		1.1	0.2	
C. of V. (%)	0.7		0.8	0.7		0.8	0.4	

Table B-4: TTC, Longitudinal Range, and Speed at FCW Level 3 Alert for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Single 28' Trailer - Faux

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1089	6.3		6.4	126.3		129.2	45.2	0
1090	6.2		6.3	124.6		127.8	45.2	0
1091	6.3		6.4	125.6		128.4	44.9	0
1092	6.4		6.5	127.1		130.2	45.0	0
Ave.	6.3		6.4	125.9		128.9	45.1	0
Std.	0.1		0.1	1.1		1.1	0.1	
C. of V. (%)	1.0		1.0	0.8		0.8	0.3	

Table B-5: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Double 28' Trailers - Faux

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1073	6.8		6.8	135.2		137.6	45.1	0
1074	7.1		7.1	141.5		143.7	45.1	0
1075	7.0		7.1	141.0		143.0	45.3	0
1076	7.0		7.1	140.0		142.2	45.1	0
1077	7.0		7.1	140.3		143.1	45.0	0
Ave.	7.0		7.0	139.6		141.9	45.1	0
Std.	0.1		0.1	2.6		2.5	0.1	
C. of V. (%)	1.8		1.8	1.8		1.7	0.3	

Table B-6: TTC, Longitudinal Range, and Speed at FCW Level 3 Alert for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Double 28' Trailers - Faux

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1073	6.4		6.4	127.1		129.5	45.1	0
1074	6.2		6.2	123.4		125.6	45.0	0
1075	6.2		6.3	124.8		126.9	45.3	0
1076	6.2		6.3	123.9		126.1	45.0	0
1077	6.3		6.4	126.2		129.0	45.1	0
Ave.	6.3		6.3	125.1		127.4	45.1	0
Std.	0.1		0.1	1.5		1.8	0.1	
C. of V. (%)	1.1		1.3	1.2		1.4	0.2	

Table B-7: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 40' Shipping Container - Faux

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1083	7.1		7.2	141.8		144.9	45.3	0
1084	7.0		7.1	139.9		142.8	45.1	0
1085	7.1		7.2	141.1		144.3	45.2	0
1087	7.1		7.1	140.6		142.9	45.0	0
Ave.	7.1		7.1	140.8		143.7	45.1	0
Std.	0.0		0.0	0.8		1.0	0.2	
C. of V. (%)	0.4		0.4	0.6		0.7	0.3	

Table B-8: TTC, Longitudinal Range, and Speed at FCW Level 2 Alert for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 40' Shipping Container - Faux

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1083	6.3		6.4	127.6		130.6	45.5	0
1084	6.3		6.4	125.8		128.7	45.1	0
1085	6.3		6.4	124.9		128.1	45.1	0
1087	6.2		6.3	124.5		126.8	45.1	0
Ave.	6.3		6.4	125.7		128.6	45.2	0
Std.	0.0		0.1	1.3		1.6	0.2	
C. of V. (%)	0.7		0.8	1.1		1.2	0.5	

Table B-9: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 53' Box Trailer - Faux

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1078	7.1		7.2	141.5		144.0	45.0	0
1079	7.1		7.2	142.2		145.6	45.1	0
1080	7.0		7.1	139.4		143.0	44.9	0
1081	7.1		7.2	140.1		143.2	44.9	0
1082	7.1		7.2	141.1		144.5	45.1	0
Ave.	7.1		7.2	140.8		144.1	45.0	0
Std.	0.0		0.0	1.1		1.1	0.1	
C. of V. (%)	0.4		0.5	0.8		0.7	0.2	

Table B-10: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 53' Box Trailer - Faux

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1078	6.3		6.4	125.4		128.0	44.9	0
1079	6.3		6.4	126.1		129.6	45.1	0
1080	6.2		6.3	123.3		126.9	44.9	0
1081	6.2		6.4	124.0		127.3	44.9	0
1082	6.3		6.4	124.9		128.3	45.0	0
Ave.	6.3		6.4	124.7		128.0	45.0	0
Std.	0.1		0.0	1.1		1.0	0.1	
C. of V. (%)	0.9		0.6	0.9		0.8	0.2	

Table B-11: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia w/ 28' Double Trailers - Faux, RV = Blue Cascadia w/ 53' Box Trailer

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1456	7.2	7.3	7.3	145.5	147.9	148.1	45.6	0
1457	7.2	7.3	7.3	146.3	148.5	148.9	45.6	0
1458	7.2	7.2	7.2	143.0	144.8	145.2	45.1	0
1459	7.2	7.2	7.2	148.2	149.1	149.6	46.3	0
1460	7.1	7.2	7.2	144.3	145.9	146.4	45.5	0
Ave.	7.2	7.2	7.3	145.5	147.2	147.7	45.6	0
Std.	0.0	0.0	0.0	2.0	1.8	1.8	0.4	
C. of V. (%)	0.5	0.7	0.5	1.4	1.2	1.2	0.9	

Table B-12: TTC, Longitudinal Range, and Speed at FCW Level 3 Alert for HV = Red Cascadia w/ 28' Double Trailers - Faux, RV = Blue Cascadia w/ 53' Box Trailer

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1456	6.4	6.5	6.5	129.2	131.6	131.8	45.6	0
1457	6.4	6.4	6.5	129.9	131.9	132.5	45.8	0
1458	6.3	6.4	6.4	126.9	128.7	129.1	45.2	0
1459	6.4	6.4	6.4	131.9	132.5	133.0	46.4	0
1460	6.4	6.4	6.4	128.1	129.8	130.3	45.5	0
Ave.	6.4	6.4	6.4	129.2	130.9	131.4	45.7	0
Std.	0.0	0.0	0.0	1.9	1.6	1.6	0.5	
C. of V. (%)	0.4	0.6	0.5	1.5	1.2	1.2	1.0	

Table B-13: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia w/ 28' Double Trailers - Faux, RV = Blue Cascadia w/ 28' Double Trailers

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1474	7.2	7.3	7.3	145.1	147.9	148.1	45.5	0.0
1475	7.1	7.1	7.2	141.8	143.5	144.3	45.3	0.0
1476	7.2	7.1	7.2	144.5	145.7	146.4	45.6	0.0
1477	7.1	7.1	7.2	142.5	143.8	144.3	45.1	0.0
1478	7.1	7.1	7.2	141.7	143.0	143.8	45.0	0.0
Ave.	7.1	7.1	7.2	143.1	144.8	145.4	45.3	0.0
Std.	0.1	0.1	0.1	1.6	2.0	1.8	0.3	0.0
Cos.(%)	0.7	1.0	0.7	1.1	1.4	1.3	0.6	

Table B-14: TTC, Longitudinal Range, and Speed at FCW Level 3 Alert for HV = Red Cascadia w/ 28' Double Trailers - Faux, RV = Blue Cascadia w/ 28' Double Trailers

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1474	6.4	6.5	6.5	128.8	131.2	131.8	45.5	0.0
1475	6.3	6.3	6.4	126.1	127.4	128.1	45.3	0.0
1476	6.3	6.4	6.4	128.2	129.4	130.2	45.6	0.0
1477	6.3	6.3	6.4	126.4	127.7	128.1	45.2	0.0
1478	6.3	6.3	6.4	125.6	127.1	127.8	45.0	0.0
Ave.	6.3	6.3	6.4	127.0	128.6	129.2	45.3	0.0
Std.	0.0	0.1	0.1	1.4	1.7	1.7	0.2	0.0
Cos.(%)	0.6	1.0	0.9	1.1	1.3	1.4	0.5	

Table B-15: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia w/ 53' Box Trailer, RV = Blue Cascadia w/ 40' Shipping Container

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1186	6.9	7.1	7.1	137.4	140.6	141.5	44.5	0
1187	7.1	7.2	7.2	142.1	145.9	145.9	45.3	0
1188	7.0	7.1	6.8	140.1	143.9	135.8	45.0	0
1189	7.1	7.2	7.0	140.9	143.4	139.8	44.8	0
1190	6.9	7.1	7.2	138.5	143.2	143.3	44.9	0
Ave.	7.0	7.1	7.1	139.8	143.4	141.3	44.9	0
Std.	0.1	0.0	0.2	1.9	1.9	3.8	0.3	
C. of V. (%)	0.9	0.7	2.6	1.3	1.3	2.7	0.7	

Table B-16: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia w/ 53' Box Trailer, RV = Blue Cascadia w/ 40' Shipping Container

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1186	6.2	6.3	6.3	121.5	124.7	125.5	44.4	0.0
1187	6.2	6.4	6.4	125.9	129.7	129.7	45.4	0.0
1188	6.2	6.3	6.7	124.0	127.8	134.0	45.1	0.0
1189	6.3	6.4	6.7	124.9	127.6	133.8	44.8	0.0
1190	6.2	6.3	6.4	124.5	127.4	127.6	44.9	0.0
Ave.	6.2	6.3	6.5	124.2	127.4	130.1	44.9	0.0
Std.	0.0	0.0	0.2	1.6	1.8	3.8	0.4	
C. of V. (%)	0.7	0.7	2.8	1.3	1.4	2.9	0.8	

B.2 FCW-2 Tabulated Test Results

Table B-17: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia Bobtail

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1040	5.7		6.0	47.0		49.5	45.0	
1041	5.6		5.6	47.0		47.5	44.9	
1042	5.6		5.9	48.8		51.8	45.6	
1043	5.6		5.6	48.8		49.8	45.5	
1044	5.6		5.8	47.0		49.3	45.1	
Ave.	5.6		5.8	47.7		49.6	45.2	
Std.	0.1		0.2	1.0		1.5	0.3	
C. of V. (%)	1.0		2.8	2.1		3.1	0.7	

Table B-18: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia Bobtail

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1041	4.8		4.8	41.0		41.5	45.1	
1042	4.9		5.2	42.6		45.7	45.6	
1043	4.8		4.9	42.6		43.6	45.6	
1044	4.8		5.0	40.2		42.5	45.0	
Ave.	4.8		5.0	41.5		43.2	45.3	
Std.	0.1		0.1	1.1		1.6	0.3	
C. of V. (%)	1.2		2.9	2.6		3.6	0.7	

Table B-19: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Single 28' Trailer - Faux

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1045	5.8		5.6	49.0		47.8	45.1	
1046	5.7		6.0	48.5		50.9	45.2	
1047	5.7		5.6	47.8		47.9	45.2	
1048	5.8		5.9	48.8		49.8	44.9	
1049	5.7		5.7	50.7		51.5	45.8	
Ave.	5.7		5.8	49.0		49.6	45.2	
Std.	0.1		0.2	1.1		1.7	0.3	
C. of V. (%)	1.2		2.7	2.2		3.4	0.7	

Table B-20: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Single 28' Trailer - Faux

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1045	5.1		4.9	43.0		41.8	45.2	
1046	5.0		5.2	42.4		44.9	45.2	
1047	5.0		4.8	41.9		41.1	45.2	
1048	4.9		5.0	41.2		42.2	44.7	
1049	4.9		5.0	43.6		44.3	45.7	
Ave.	5.0		5.0	42.4		42.9	45.2	
Std.	0.1		0.2	0.9		1.6	0.4	
C. of V. (%)	1.1		3.0	2.2		3.8	0.8	

Table B-21: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Double 28' Trailers - Faux

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1069	5.7		5.8	51.0		51.6	45.7	
1070	5.7		5.8	49.8		50.6	45.1	
1071	5.8		5.7	50.7		50.3	45.3	
1072	5.7		5.7	48.7		49.7	44.9	
Ave.	5.7		5.7	50.1		50.5	45.3	
Std.	0.0		0.0	1.0		0.8	0.3	
C. of V. (%)	0.6		0.9	2.1		1.6	0.7	

Table B-22: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Double 28' Trailers - Faux

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1069	4.9		4.9	43.9		43.6	45.8	
1070	4.8		5.1	42.7		45.2	45.2	
1071	4.9		4.8	42.8		42.4	45.3	
1072	5.0		5.0	42.7		43.3	44.9	
Ave.	4.9		4.9	43.0		43.6	45.3	
Std.	0.1		0.1	0.6		1.2	0.4	
C. of V. (%)	1.4		2.9	1.3		2.7	0.8	

Table B-23: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Double 40' Shipping Container - Faux

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1050	5.6		5.7	46.7		48.4	45.0	
1051	5.6		5.7	47.4		48.2	45.1	
1052	5.6		5.8	47.7		49.9	45.3	
1053	5.6		5.7	49.2		50.7	45.9	
1054	5.7		5.9	47.6		49.8	45.2	
Ave.	5.6		5.8	47.7		49.4	45.3	
Std.	0.0		0.1	0.9		1.1	0.4	
C. of V. (%)	0.7		1.3	1.9		2.2	0.8	

Table B-24: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Double 40' Shipping Container - Faux

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1050	4.7		4.9	40.0		41.6	45.0	
1051	4.8		4.9	40.6		41.4	45.0	
1052	4.7		5.0	40.1		42.3	45.0	
1053	4.8		5.0	42.1		43.7	45.7	
1054	4.8		5.1	40.9		43.0	45.1	
Ave.	4.8		5.0	40.7		42.4	45.2	
Std.	0.0		0.1	0.9		1.0	0.3	
C. of V. (%)	0.9		1.5	2.2		2.3	0.7	

Table B-25: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Double 53' Box Trailer - Faux

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1064	5.8		6.2	52.8		56.4	46.0	
1065	5.7		6.0	49.7		52.6	45.0	
1066	5.8		5.8	49.8		50.3	45.1	
1067	5.7		6.0	49.1		51.8	45.0	
1068	5.8		6.0	50.6		52.8	45.4	
Ave.	5.8		6.0	50.4		52.8	45.3	
Std.	0.0		0.2	1.4		2.3	0.4	
C. of V. (%)	0.9		2.7	2.8		4.3	1.0	

Table B-26: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ Double 53' Box Trailer - Faux

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1064	5.0		5.3	45.5		48.5	46.1	
1065	4.9		5.3	42.7		46.1	44.9	
1066	4.9		5.1	42.8		44.4	45.0	
1067	4.9		5.1	42.2		44.0	44.9	
1068	5.0		5.1	44.4		45.0	45.5	
Ave.	5.0		5.2	43.5		45.6	45.3	
Std.	0.0		0.1	1.4		1.8	0.5	
C. of V. (%)	0.9		2.2	3.2		3.9	1.2	

Table B-27: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Honda Odyssey

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
921	5.8	5.8	5.8	54.1	55.3	55.5	46.1	24.9
922	5.8	5.7	5.7	50.1	50.8	51.0	45.0	24.9
923	5.7	5.8	5.8	52.1	54.0	54.3	45.7	24.8
924	5.7	5.6	5.7	49.0	49.8	50.1	44.6	24.7
925	5.7	5.7	5.7	51.9	53.2	53.4	45.6	24.8
Ave.	5.7	5.7	5.7	51.4	52.6	52.9	45.4	24.8
Std.	0.0	0.1	0.1	2.0	2.3	2.2	0.6	0.1
C. of V. (%)	0.9	1.4	1.2	3.8	4.3	4.3	1.4	0.3

Table B-28: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Honda Odyssey

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
921	5.0	5.0	5.0	46.4	47.7	47.8	46.2	24.8
922	4.8	4.8	4.8	42.1	42.8	43.0	44.8	24.9
923	4.9	5.0	5.1	45.5	47.5	47.7	45.8	24.8
924	4.9	4.8	4.9	41.9	42.7	43.1	44.4	24.7
925	5.0	5.0	5.0	45.3	46.6	46.8	45.7	24.7
Ave.	4.9	4.9	5.0	44.3	45.4	45.7	45.4	24.8
Std.	0.1	0.1	0.1	2.1	2.5	2.5	0.8	0.1
C. of V. (%)	1.2	2.0	1.8	4.7	5.5	5.4	1.7	0.3

Table B-29: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia w/ 28' Double Trailers - Faux, RV = Blue Cascadia w/ 53' Box Trailer

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1461	6.0	6.1	6.1	57.3	57.5	57.6	46.3	25.1
1462	5.9	6.1	6.1	55.5	57.7	57.9	46.8	25.7
1463	5.9	5.9	5.9	54.7	55.3	55.5	46.5	25.5
1464	5.8	5.9	5.9	51.0	52.4	52.5	45.3	25.5
1465	5.8	5.9	5.9	52.6	53.8	54.0	45.8	25.5
Ave.	5.9	6.0	6.0	54.2	55.3	55.5	46.1	25.4
Std.	0.1	0.1	0.1	2.4	2.3	2.3	0.6	0.2
C. of V. (%)	1.7	1.7	1.7	4.5	4.1	4.1	1.3	0.9

Table B-30: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia w/ 28' Double Trailers - Faux, RV = Blue Cascadia w/ 53' Box Trailer

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1461	5.2	5.2	5.2	50.5	50.6	50.9	46.6	24.8
1462	5.1	5.4	5.4	48.8	51.0	51.3	47.0	25.7
1463	5.1	5.1	5.2	48.2	48.7	49.0	46.8	25.6
1464	5.1	5.2	5.2	44.8	46.1	46.3	45.4	25.5
1465	5.0	5.1	5.1	45.3	46.5	46.7	45.8	25.5
Ave.	5.1	5.2	5.2	47.5	48.6	48.8	46.3	25.4
Std.	0.1	0.1	0.1	2.4	2.3	2.3	0.7	0.4
C. of V. (%)	1.0	1.9	1.9	5.1	4.7	4.7	1.4	1.5

Table B-31: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia w/ 28' Double Trailers - Faux, RV = Blue Cascadia w/ 28' Double Trailers

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1479	5.7	5.7	5.8	48.4	50.0	50.1	45.3	25.8
1480	5.6	5.8	5.7	47.5	48.6	48.7	44.9	26.0
1481	5.8	5.7	5.7	49.3	49.4	49.6	45.2	25.8
1482	5.6	5.6	5.7	48.8	49.3	49.5	45.3	25.7
1483	5.8	5.7	5.8	49.9	50.4	50.6	45.4	25.6
Ave.	5.7	5.7	5.7	48.8	49.5	49.7	45.2	25.8
Std.	0.1	0.0	0.0	0.9	0.7	0.7	0.2	0.1
C. of V. (%)	1.4	0.8	0.8	1.8	1.3	1.5	0.4	0.6

Table B-32: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia w/ 28' Double Trailers - Faux, RV = Blue Cascadia w/ 28' Double Trailers

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1479	5.0	5.1	5.1	42.3	43.9	44.1	45.2	25.8
1480	4.8	4.9	4.9	40.7	41.9	41.9	44.9	25.9
1481	4.9	4.8	4.8	41.6	41.7	41.8	45.3	25.8
1482	4.9	4.9	4.9	42.7	43.3	43.4	45.4	25.7
1483	5.0	5.0	5.0	42.9	43.4	43.6	45.4	25.8
Ave.	4.9	4.9	5.0	42.0	42.8	43.0	45.2	25.8
Std.	0.1	0.1	0.1	0.9	1.0	1.0	0.2	0.1
C. of V. (%)	1.3	1.9	2.1	2.1	2.3	2.4	0.4	0.2

Table B-33: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia w/ 53' Box Trailer, RV = Blue Cascadia w/ 40' Shipping Container

At Level 2 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1219	5.7	5.8	5.9	48.9	50.0	50.3	45.2	25.9
1221	6.0	6.1	6.1	56.4	57.8	58.0	45.4	24.2
1223	5.7	5.9	5.9	49.0	50.9	50.1	45.1	25.9
1225	5.9	5.9	6.0	50.0	50.3	50.8	45.0	25.9
1227	5.9	6.0	6.1	52.8	53.9	54.3	44.9	25.0
Ave.	5.8	6.0	6.0	51.4	52.6	52.7	45.1	25.4
Std.	0.1	0.1	0.1	3.2	3.3	3.4	0.2	0.8
C. of V. (%)	2.0	2.0	2.2	6.2	6.3	6.5	0.4	3.0

Table B-34: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia w/ 53' Box Trailer, RV = Blue Cascadia w/ 40' Shipping Container

At Level 3 FCW Alert Onset								
Test No.	TTC (sec)			Lon. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1219	5.0	5.1	5.1	42.1	43.1	43.5	45.0	26.0
1221	5.2	5.4	5.4	49.8	51.2	51.3	45.4	24.1
1223	4.9	5.1	5.0	42.2	44.1	43.2	45.1	25.9
1225	4.9	5.0	5.1	41.4	42.6	43.1	45.0	25.9
1227	5.1	5.2	5.3	45.7	46.8	47.2	44.9	24.9
Ave.	5.0	5.2	5.2	44.2	45.6	45.7	45.1	25.4
Std.	0.1	0.1	0.1	3.5	3.5	3.6	0.2	0.8
C. of V. (%)	2.8	2.8	2.8	7.9	7.7	7.8	0.5	3.2

B.3 FCW-3 Tabulated Test Results

Table B-35: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Honda Odyssey

At Level 3 FCW Alert Onset											
Test No.	Speeds (mph)		TTC (sec)			TTL (sec)			Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
926	43.8	37.9	4.2	4.0	4.0	11.5	11.3	10.8	30.4	29.8	29.7
927	45.3	37.8	3.4	3.1	3.1	8.1	7.7	7.6	26.5	25.8	25.8
928	45.3	36.9	3.2	3.1	3.1	7.8	7.1	7.4	26.8	26.4	26.4
929	44.7	37.9	3.0	2.9	2.9	7.5	7.4	7.6	23.0	22.4	22.4
930	44.7	36.1	3.3	3.2	3.3	7.7	6.9	7.3	27.2	26.5	26.6
931	44.4	37.0	3.4	3.4	3.4	8.7	8.0	8.3	26.9	26.5	26.6
Ave.	44.7	37.3	3.4	3.3	3.3	8.5	8.1	8.2	26.8	26.3	26.3
Std.	0.5	0.7	0.4	0.4	0.4	1.5	1.6	1.3	2.4	2.4	2.3
C. of V. (%)	1.2	2.0	12.7	12.1	11.3	17.6	20.1	16.4	8.8	9.0	8.9

Table B-36: Longitudinal Range at RV Brake Onset and RV Average Deceleration for HV = Red Cascadia Bobtail, RV = Honda Odyssey

Test No.	Lon. Range at RV Brake (m)			RV Ave. Decel. (m/s/s)		
	WSU	RT	GPS	WSU	RT	GPS
926	32.4	31.5	31.3	-2.2	-2.1	-2.2
927	28.9	27.9	27.9	-2.9	-2.8	-2.8
928	29.6	28.7	28.7	-2.7	-2.7	-2.6
929	25.0	24.2	24.2	-2.8	-2.6	-2.5
930	30.8	29.4	29.3	-2.3	-2.2	-2.2
931	29.6	28.7	28.6	-2.5	-2.3	-2.2
Ave.	29.4	28.4	28.3	-2.6	-2.5	-2.4
Std.	2.5	2.4	2.3	0.3	0.3	0.3
C. of V. (%)	8.3	8.4	8.3	11.5	11.4	10.7

Table B-37: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia w/ 28' Doubles - Faux, RV = Blue Cascadia w/ 53' Box Trailer

At Level 3 FCW Alert Onset											
Test No.	Speeds (mph)		TTC (sec)			TTL (sec)			Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1466	44.6	41.3	4.1	3.8	3.9	18.4	21.6	19.8	31.9	31.7	31.7
1467	46.4	40.3	3.2	3.6	3.6	10.0	12.7	13.1	32.9	34.6	34.5
1468	45.2	41.5	4.0	4.0	4.0	16.7	20.3	19.4	33.0	33.0	33.0
1469	45.4	42.3	3.8	4.4	4.2	16.5	25.2	26.3	32.5	34.7	34.6
1470	45.3	42.2	3.8	4.0	4.0	15.2	22.9	24.0	31.0	31.1	31.0
Ave.	45.4	41.5	3.8	4.0	4.0	15.3	20.5	20.5	32.3	33.0	33.0
Std.	0.7	0.8	0.3	0.3	0.2	3.2	4.7	5.0	0.8	1.6	1.6
C. of V. (%)	1.5	1.9	9.1	7.4	5.1	20.9	23.1	24.5	2.5	5.0	5.0

Table B-38: Longitudinal Range at RV Brake Onset and RV Average Deceleration for HV = Red Cascadia w/ 28' Doubles - Faux, RV = Blue Cascadia w/ 53' Box Trailer

Test No.	Lon. Range at RV Brake (m)			RV Ave. Decel. (m/s/s)		
	WSU	RT	GPS	WSU	RT	GPS
1466	32.4	32.1	32.1	-2.2	-2.3	-2.3
1467	33.9	35.5	35.5	-2.9	-3.2	-3.0
1468	33.6	33.6	33.5	-2.7	-3.0	-2.8
1469	33.1	35.1	35.1	-2.8	-3.0	-2.9
1470	31.5	31.4	31.3	-2.9	-3.1	-2.9
Ave.	32.9	33.5	33.5	-2.7	-2.9	-2.8
Std.	1.0	1.8	1.8	0.3	0.3	0.3
C. of V. (%)	2.9	5.3	5.4	10.6	11.6	10.2

Table B-39: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia w/ 28' Doubles - Faux, RV = Blue Cascadia w/ 28' Doubles

At Level 2 FCW Alert Onset											
Test No.	Speeds (mph)		TTC (sec)			TTL (sec)			Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1488	46.0	43.0	6.1	5.7	5.7	22.1	36.6	36.1	48.4	48.4	48.3

Table B-40: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia w/ 28' Doubles - Faux, RV = Blue Cascadia w/ 28' Doubles

At Level 3 FCW Alert Onset											
Test No.	Speeds (mph)		TTC (sec)			TTL (sec)			Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1484	44.9	42.8	4.9	4.5	4.9	27.6	40.0	40.0	38.0	37.6	37.5
1485	45.1	43.3	5.0	5.4	5.2	27.6	40.0	37.5	42.0	41.6	41.5
1486	46.4	43.9	5.2	5.0	5.4	24.0	36.6	38.1	42.6	42.1	42.0
1487	45.7	42.9	4.4	4.9	4.7	20.3	33.5	34.1	44.0	42.2	42.1
1488	46.1	41.0	5.1	5.2	5.1	14.9	20.6	19.1	47.6	47.6	47.5
Ave.	45.7	42.8	4.9	5.0	5.1	22.9	34.1	33.8	42.8	42.2	42.1
Std.	0.6	1.1	0.3	0.3	0.3	5.4	8.0	8.5	3.5	3.6	3.6
C. of V. (%)	1.4	2.5	6.4	6.8	5.9	23.6	23.5	25.1	8.1	8.5	8.5

Table B-41: Longitudinal Range at RV Brake Onset and RV Average Deceleration for HV = Red Cascadia w/ 28' Doubles - Faux, RV = Blue Cascadia w/ 28' Doubles

Test No.	Lon. Range at RV Brake (m)			RV Ave. Decel. (m/s/s)		
	WSU	RT	GPS	WSU	RT	GPS
1484	38.2	37.5	37.5	-2.7	-2.8	-2.8
1485	42.3	41.8	41.7	-2.6	-2.7	-2.7
1486	43.0	42.4	42.4	-2.7	-2.9	-2.8
1487	44.5	42.4	42.3	-3.0	-3.2	-3.0
1488	48.9	48.7	48.5	-2.7	-2.9	-2.8
Ave.	43.4	42.6	42.5	-2.7	-2.9	-2.8
Std.	3.9	4.0	4.0	0.1	0.2	0.1
C. of V. (%)	8.9	9.3	9.3	5.3	5.5	5.0

Table B-42: TTC, Longitudinal Range, and Speed at FCW Level 2 Warning for HV = Red Cascadia w/ 53' Box Trailer, RV = Blue Cascadia w/ 40' Shipping Container

At Level 2 FCW Alert Onset											
Test No.	Speeds (mph)		TTC (sec)			TTL (sec)			Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1230	46.3	27.7	5.9	6.2	6.1	12.8	14.6	14.6	118.8	121.0	121.0
1232	45.6	24.1	6.4	6.2	6.5	11.3	11.7	11.7	110.5	112.0	111.9
1234	45.7	24.1	6.2	6.2	6.3	11.5	12.3	12.3	117.7	118.4	118.3
1236	45.2	23.7	6.3	6.3	6.4	11.4	11.9	11.8	113.6	114.2	114.1
1238	45.1	23.6	5.8	6.0	6.1	11.2	12.0	12.1	114.6	115.2	115.3
Ave.	45.6	24.6	6.1	6.2	6.3	11.6	12.5	12.5	115.0	116.1	116.1
Std.	0.5	1.7	0.3	0.1	0.2	0.6	1.2	1.2	3.3	3.5	3.5
C. of V. (%)	1.0	7.0	4.5	1.8	2.7	5.5	9.5	9.6	2.9	3.1	3.1

Table B-43: TTC, Longitudinal Range, and Speed at FCW Level 3 Warning for HV = Red Cascadia w/ 53' Box Trailer, RV = Blue Cascadia w/ 40' Shipping Container

At Level 3 FCW Alert Onset											
Test No.	Speeds (mph)		TTC (sec)			TTL (sec)			Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1230	46.3	25.2	5.8	5.8	5.9	11.3	12.5	12.6	115.9	118.3	118.3
1232	45.6	23.2	6.3	6.3	6.4	10.6	11.0	11.0	108.6	110.0	110.0
1234	45.8	22.5	6.0	6.1	6.1	10.4	11.1	11.0	114.6	115.3	115.3
1236	45.3	21.8	6.0	5.9	5.9	10.2	10.6	10.6	110.5	111.1	111.1
1238	45.1	22.9	5.5	5.9	6.0	10.8	11.5	11.6	113.6	114.2	114.4
Ave.	45.6	23.1	5.9	6.0	6.1	10.7	11.3	11.3	112.6	113.8	113.8
Std.	0.5	1.3	0.3	0.2	0.2	0.4	0.8	0.8	3.0	3.3	3.4
C. of V. (%)	1.0	5.5	4.7	3.4	3.1	3.8	6.6	7.0	2.7	2.9	2.9

Table B-44: Longitudinal Range at RV Brake Onset and RV Average Deceleration for HV = Red Cascadia w/ 53' Box Trailer, RV = Blue Cascadia w/ 40' Shipping Container

Test No.	Lon. Range at RV Brake (m)			RV Ave. Decel. (m/s/s)		
	WSU	RT	GPS	WSU	RT	GPS
1230	127.9	129.2	129.1	-3.3	-3.6	-3.5
1232	130.6	131.3	131.3	-2.4	-2.6	-2.5
1234	131.8	131.8	131.8	-2.9	-3.2	-3.0
1236	130.3	129.9	129.8	-2.8	-3.0	-2.9
1238	130.2	130.0	129.8	-3.0	-3.2	-3.0
Ave.	130.1	130.5	130.4	-2.9	-3.1	-3.0
Std.	1.4	1.1	1.1	0.3	0.4	0.4
C. of V. (%)	1.1	0.8	0.9	11.2	12.1	12.4

B.4 FCW-5 Tabulated Test Results

Table B-45: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 28' Doubles

At Level 2 FCW Alert Onset											
Test No.	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1490	7.2		7.2	143		144	-0.9		-1.3	45.0	0.0
1491	7.1		7.1	139		140	-0.9		-1.4	44.4	0.0
1492	7.2		7.2	143		144	-0.9		-1.3	45.0	0.0
1493	7.2		7.1	143		144	-1.1		-1.4	45.2	0.0
1494	7.2		7.2	145		146	-0.9		-1.4	45.2	0.0
Ave.	7.2		7.2	143		144	-0.9		-1.4	45.0	0.0
Std.	0.1		0.0	2		2	0.1		0.1	0.3	0.0
C. of V. (%)	0.8		0.7	1		1	9.8		5.4	0.7	

Table B-46: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 28' Doubles

At Level 3 FCW Alert Onset											
Test No.	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1490	6.4		6.4	127		128	0.1		-1.3	44.9	0.0
1491	6.3		6.3	123		125	-0.1		-1.4	44.3	0.0
1492	6.3		6.3	125		126	0.1		-1.2	44.9	0.0
1493	6.4		6.4	127		128	-0.2		-1.4	45.1	0.0
1494	6.4		6.4	128		129	0.0		-1.4	45.3	0.0
Ave.	6.3		6.3	126		127	0.0		-1.3	44.9	0.0
Std.	0.0		0.0	2		2	0.1		0.1	0.4	0.0
C. of V. (%)	0.8		0.7	2		1	776.7		8.2	0.8	

Table B-47: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 40' Shipping Container – Set 1

At Level 2 FCW Alert Onset											
Test No.	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1506	7.1		7.1	143		144	-0.3		-0.6	45.1	0.0
1507	7.1		7.1	143		144	-0.7		-0.6	45.1	0.0
1508	7.2		7.2	145		146	-0.7		-0.7	45.5	0.0
1509	7.2		7.2	144		145	-0.3		-0.5	45.3	0.0
1510	7.2		7.2	144		144	-0.9		-1.3	45.0	0.0
Ave.	7.2		7.2	144		145	-0.6		-0.7	45.2	0.0
Std.	0.0		0.0	1		1	0.3		0.3	0.2	0.0
C. of V. (%)	0.5		0.4	1		1	45.9		41.4	0.5	

Table B-48: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 40' Shipping Container – Set 1

At Level 3 FCW Alert Onset											
Test No.	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1506	6.4		6.4	129		130	-0.8		-0.6	45.4	0.0
1507	6.4		6.4	129		130	-1.1		-0.5	45.2	0.0
1508	6.4		6.4	129		130	-1.1		-0.6	45.5	0.0
1509	6.4		6.4	128		129	-0.8		-0.5	45.4	0.0
1510	6.4		6.4	128		128	-1.5		-1.2	45.2	0.0
Ave.	6.4		6.4	128		129	-1.0		-0.7	45.3	0.0
Std.	0.0		0.0	0		1	0.3		0.3	0.1	0.0
C. of V. (%)	0.3		0.5	0		1	25.9		45.0	0.3	

Table B-49: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 40' Shipping Container – Set 2

At Level 2 FCW Alert Onset											
Test No.	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1522	7.0		7.2	138		144	0.0		0.2	44.6	-0.5
1523	7.0		7.3	140		145	0.4		0.3	44.8	-2.0
1524	7.1		7.4	142		148	0.8		0.5	45.0	-1.7
1525	7.0		7.3	140		145	0.5		0.2	44.7	-1.0
1526	7.1		7.3	142		148	0.6		0.4	45.3	-0.6
Ave.	7.0		7.3	140		146	0.4		0.3	44.9	-1.1
Std.	0.1		0.1	2		2	0.3		0.1	0.3	0.7
C. of V. (%)	0.8		0.8	1		1	63.7		26.5	0.6	59.3

Table B-50: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 40' Shipping Container – Set 2

At Level 3 FCW Alert Onset											
Test No.	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1522	6.2		6.5	124		130	-0.7		0.3	44.8	-0.5
1523	6.3		6.6	126		132	-0.5		0.4	44.9	-2.0
1524	6.3		6.6	126		132	-0.2		0.5	45.1	-1.7
1525	6.2		6.5	124		130	-0.3		0.3	44.8	-1.0
1526	6.3		6.6	128		134	-0.3		0.3	45.5	-0.6
Ave.	6.3		6.5	125		131	-0.4		0.4	45.0	-1.1
Std.	0.0		0.1	2		2	0.2		0.1	0.3	0.7
C. of V. (%)	0.8		0.8	1		1	56.2		20.0	0.7	59.1

Table B-51: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 2 Warning for HV = Red Cascadia /w 53' Box Trailer, RV = Blue Cascadia w/ 40' Shipping Container

At Level 2 FCW Alert Onset											
Test No.	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1198	7.2	7.2	7.3	145	145	146	-1.3	-0.4	-1.1	45.0	0.0
1199	7.2	7.2	7.3	144	144	146	-1.4	-0.3	-1.0	45.0	0.0
1200	7.2	7.1	7.2	145	144	146	-1.2	-0.3	-1.0	45.3	0.0
1201	6.9	6.9	7.0	138	140	141	-1.1	-0.4	-1.1	45.0	0.0
1202	7.2	7.2	7.3	143	146	147	-1.3	0.0	-0.8	45.1	0.0
Ave.	7.1	7.1	7.2	143.1	143.7	145.3	-1.3	-0.3	-1.0	45.1	0.0
Std.	0.1	0.1	0.1	2.8	2.3	2.6	0.1	0.1	0.1	0.1	0.0
C. of V. (%)	1.9	1.5	1.6	1.9	1.6	1.8	8.6	49.1	12.3	0.3	

Table B-52: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 3 Warning for HV = Red Cascadia /w 53' Box Trailer, RV = Blue Cascadia w/ 40' Shipping Container

At Level 3 FCW Alert Onset											
Test No.	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1198	6.3	6.4	6.5	126	129	130	0.0	-0.3	-1.0	45.1	0.0
1199	6.4	6.4	6.5	128	128	130	-0.3	-0.2	-0.9	45.0	0.0
1200	6.4	6.3	6.4	129	128	130	0.0	-0.2	-0.9	45.3	0.0
1201	6.3	6.3	6.4	126	128	129	-0.5	-0.3	-1.0	45.1	0.0
1202	6.3	6.4	6.5	127	129	131	-0.3	0.0	-0.7	45.1	0.0
Ave.	6.3	6.4	6.5	127.3	128.4	130.0	-0.2	-0.2	-0.9	45.1	0.0
Std.	0.1	0.0	0.0	1.1	0.7	0.9	0.2	0.1	0.1	0.1	0.0
C. of V. (%)	0.9	0.6	0.7	0.8	0.5	0.7	93.3	56.6	12.1	0.3	

B.5 FCW-6 Tabulated Test Results

Table B-53: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 28' Doubles

At Level 3 FCW Alert Onset												
Test No.	RV Lane	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
		WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1496	L	1.3		1.3	25		26	0.3		-5.1	44.9	0.0
1500	L	1.3		1.3	25		26	0.3		-5.4	45.3	0.0
Ave.		1.3		1.3	25		26	0.3		-5.3	45.1	0.0
Std.		0.0		0.0	0		0	0.0		0.2	0.3	0.0
C. of V. (%)		0.0		1.5	1		1	0.4		3.4	0.6	

Table B-54: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 40' Shipping Container – Set 1

At Level 3 FCW Alert Onset												
Test No.	RV Lane	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
		WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1511	L	1.2		1.2	23		24	-0.1		-5.3	44.8	0.0
1512	L	1.3		1.4	26		27	0.0		-5.8	44.6	0.0
1513	L	1.2		1.3	25		25	-1.6		-5.8	45.4	0.0
1515	L	1.3		1.5	27		29	0.0		-6.0	45.1	0.0
Ave.		1.3		1.3	25		27	-0.4		-5.7	45.0	0.0
Std.		0.1		0.1	1		2	0.8		0.3	0.3	0.0
C. of V. (%)		5.6		8.1	6		8	175.5		5.0	0.7	

Table B-55: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV = Blue Cascadia w/ 40' Shipping Container – Set 2

At Level 3 FCW Alert Onset												
Test No.	RV Lane	TTC (sec)			Lon. Range (m)			Lat. Range (m)			Speeds (mph)	
		WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	HV	RV
1527	L	1.1		1.3	21		27	-0.3		-4.5	45.5	0.0
1528	L	1.0		1.3	21		26	-0.4		-4.2	45.6	0.0
1530	L	0.6		0.9	13		18	-1.6		-4.3	45.5	0.0
1531	L	0.9		1.1	18		24	-0.9		-4.3	46.1	0.0
Ave.		0.9		1.2	18		24	-0.8		-4.3	45.7	0.0
Std.		0.2		0.2	4		4	0.6		0.1	0.3	0.0
C. of V. (%)		22.7		17.2	23		17	73.1		3.3	0.6	

B.6 FCW-7 Tabulated Test Results

Table B-56: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV1 = Mack /w 53' Box Trailer, RV2 = Blue Cascadia /w 53' Box Trailer

At Rv2 Level 2 FCW Alert Onset											
Test	Speeds (mph)		TTC (sec)			Lon. Range (m)			Lat. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1659	45.3	0.0	7.0	7.2	7.2	141	145	145	0.1	-0.2	0.2
1660	44.6	0.0	7.0	7.1	7.1	139	141	142	-0.2	-0.4	0.0
1661	45.5	0.0	7.0	7.1	7.2	142	144	145	-0.5	-0.1	-0.1
1662	45.3	0.0	7.1	7.2	7.2	142	145	145	0.6	-0.2	-0.2
1663	45.8	0.0	7.1	7.2	7.2	143	146	147	-0.1	-0.6	0.0
Ave.	45.3	0.0	7.0	7.1	7.2	141	144	145	0	0	0
Std.	0.4		0.0	0.0	0.0	2	2	2			
C. of V. (%)	0.9		0.4	0.5	0.4	1	1	1			

Table B-57: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV1 = Mack /w 53' Box Trailer, RV2 = Blue Cascadia /w 53' Box Trailer

At Rv2 Level 3 FCW Alert Onset											
Test	Speeds (mph)		TTC (sec)			Lon. Range (m)			Lat. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1659	45.3	0.0	6.2	6.3	6.4	125	128	129	0.6	-0.1	0.1
1660	44.9	0.0	6.3	6.4	6.4	125	127	128	-0.2	-0.4	-0.1
1661	45.5	0.0	6.3	6.4	6.4	127	130	131	-0.2	0.1	-0.1
1662	45.3	0.0	6.3	6.3	6.4	125	128	129	0.6	0.0	-0.2
1663	45.8	0.0	6.3	6.4	6.4	127	130	131	0.2	-0.5	0.0
Ave.	45.4	0.0	6.3	6.3	6.4	126	129	130	0	0	0
Std.	0.4		0.0	0.0	0.0	1	1	1			
C. of V. (%)	0.8		0.6	0.5	0.3	1	1	1			

Table B-58: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV1 = Mack /w 40' Shipping Container, RV2 = Blue Cascadia /w 53' Box Trailer

At Rv2 Level 2 FCW Alert Onset											
Test	Speeds (mph)		TTC (sec)			Lon. Range (m)			Lat. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1702	45.3	0.0	7.1		7.2	143		145	-0.8		-0.1
1703	46.5	0.0	7.2		7.2	149		150	-0.3		-0.4
1704	45.7	0.0	7.1		7.1	143		145	0.0		0.0
1705	44.6	0.0	7.0		7.1	139		141	-0.8		-0.2
1706	45.4	0.0	7.1		7.1	143		144	-0.5		-0.2
1707	45.0	0.0	7.1		7.0	141		141	-0.8		-0.2
Ave.	45.4	0.0	7.1		7.1	143		144	-1		0
Std.	0.7		0.1		0.1	3		3			
C. of V. (%)	1.4		1.0		0.9	2		2			

Table B-59: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV1 = Mack /w 40' Shipping Container, RV2 = Blue Cascadia /w 53' Box Trailer

At Rv2 Level 3 FCW Alert Onset											
Test	Speeds (mph)		TTC (sec)			Lon. Range (m)			Lat. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1702	45.0	0.0	6.3		6.3	125		127	0.2		-0.1
1703	45.9	0.0	6.3		6.3	128		129	0.0		-0.3
1704	45.5	0.0	6.3		6.3	125		127	-0.1		0.0
1705	44.7	0.0	6.2		6.3	123		125	-0.8		-0.2
1706	45.1	0.0	6.2		6.2	124		126	-1.4		-0.2
1707	45.0	0.0	6.3		6.2	125		125	-0.8		-0.1
Ave.	45.2	0.0	6.3		6.3	125		126	-1		0
Std.	0.4		0.0		0.0	2		2			
C. of V. (%)	1.0		0.8		0.6	1		1			

Table B-60: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 2 Warning for HV = Red Cascadia Bobtail, RV1 = Mack /w 28' Doubles, RV2 = Blue Cascadia /w 53' Box Trailer

At Rv2 Level 2 FCW Alert Onset											
Test	Speeds (mph)		TTC (sec)			Lon. Range (m)			Lat. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1724	46.0	0.0	7.1		6.9	144		141	-0.5		-0.1
1725	44.8	0.0	6.9		6.8	139		134	1.2		0.1
1726	45.2	0.0	7.0		6.9	140		140	0.6		0.3
1727	45.2	0.0	7.0		6.8	140		138	-0.1		0.2
1728	45.7	0.0	7.0		6.9	143		141	0.9		0.2
Ave.	45.4	0.0	7.0		6.9	141		139	0		0
Std.	0.5		0.0		0.1	2		3			
C. of V. (%)	1.0		0.6		0.9	1		2			

Table B-61: TTC, Longitudinal Range, Lateral Range and Speed at FCW Level 3 Warning for HV = Red Cascadia Bobtail, RV1 = Mack /w 28' Doubles, RV2 = Blue Cascadia /w 53' Box Trailer

At Rv2 Level 3 FCW Alert Onset											
Test	Speeds (mph)		TTC (sec)			Lon. Range (m)			Lat. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1724	46.3	0.0	6.2		6.1	127		126	-1.0		-0.1
1725	45.3	0.0	6.2		5.2	125		105	-0.4		0.0
1726	45.1	0.0	6.2		6.1	124		123	0.8		0.3
1727	45.0	0.0	6.2		6.1	124		122	-0.1		0.2
1728	46.0	0.0	6.3		6.2	128		127	0.6		0.3
Ave.	45.6	0.0	6.2		6.0	126		121	0		0
Std.	0.6		0.1		0.4	2		9			
C. of V. (%)	1.2		1.0		6.8	1		7			

B.7 FCW-8 Tabulated Test Results

Table B-62: Longitudinal Range at FCW Level 2 Warning HV = Red Cascadia Bobtail, RV = Blue Cascadia Bobtail, HV/RV Speed = 25 mph

Test No.	Longitudinal Range (m)
630.14	9.2
630.15	8.3
630.16	9.3
630.18	8.3
630.19	7.6
Avg.	8.5
Std. Dev.	0.7
C. of V. (%)	8.5

Table B-63: Longitudinal Range at FCW Level 2 Warning HV = Red Cascadia Bobtail, RV = Blue Cascadia /w Faux 53' Box Trailer, HV/RV Speed = 25 mph

Test No.	Longitudinal Range (m)
630.1	10.7
630.2	9.1
630.3	9.5
630.4	8.8
630.5	8.8
Avg.	9.4
Std. Dev.	0.8
C. of V. (%)	8.3

Table B-64: Longitudinal Range at FCW Level 2 Warning HV = Red Cascadia Bobtail, RV = Blue Cascadia /w Faux 53' Box Trailer, HV/RV Speed = 55 mph

Test No.	Longitudinal Range (m)
630.7	16.9
630.9	16.3
630.11	15.4
630.12	15.2
630.13	17.5
Avg.	16.3
Std. Dev.	1.0
C. of V. (%)	6.1

Table B-65: Longitudinal Range at FCW Level 3 Warning HV = Red Cascadia Bobtail, RV = Blue Cascadia /w Faux 53' Box Trailer, HV/RV Speed = 25 mph

Test No.	Longitudinal Range (m)
630.1	7.7
630.2	5.7
630.3	4.9
630.4	6.4
630.5	7.3
Avg.	6.4
Std. Dev.	1.2
C. of V. (%)	18.0

Table B-66: Longitudinal Range at FCW Level 3 Warning HV = Red Cascadia Bobtail, RV = Blue Cascadia /w Faux 53' Box Trailer, HV/RV Speed = 55 mph

Test No.	Longitudinal Range (m)
630.7	8.2
630.9	8.0
630.11	6.6
630.12	7.1
630.13	6.5
Avg.	7.3
Std. Dev.	0.8
C. of V. (%)	10.7

B.8 FCW-9 Tabulated Test Results

Table B-67: TTC, Longitudinal Range and Speed at FCW Level 2 Warning on RV2 for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 40' Shipping Container, RV1 = Mack /w 28' Doubles

Test	Speeds (mph)		Rv2 TTC (sec)			Rv2 Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS
1805	45.6	30.2	5.4	5.9	6.0	36.5	40.3	41.0
1806	45.0	30.3	5.3	5.1	5.2	34.1	33.7	34.3
1807	45.2	30.4	5.3	5.8	5.9	34.8	38.3	38.9
1808	45.3	30.2	5.3	5.3	5.4	35.3	35.9	36.5

1809	45.2	30.2	5.1	5.6	5.7	33.5	37.7	38.3
1811	45.3	30.2	5.3	5.6	5.6	35.4	37.7	38.2
Ave.	45.3	30.2	5.3	5.5	5.7	34.9	37.3	37.9
Std.	0.2	0.1	0.1	0.3	0.3	1.1	2.2	2.3
Cos.(%)	0.5	0.2	1.9	5.0	5.1	3.1	6.0	6.0

Table B-68: TTC, Longitudinal Range and Speed at FCW Level 3 Warning on RV2 for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 40' Shipping Container, RV1 = Mack /w 28' Doubles

Test	Speeds (mph)		Rv2 TTC (sec)			Rv2 Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS
1805	45.8	30.3	4.5	5.0	5.1	30.9	34.7	35.3
1806	44.7	30.2	4.5	4.4	4.4	28.8	28.4	28.9
1807	45.3	30.4	4.5	4.9	5.1	29.5	32.9	33.6
1808	45.3	30.1	4.6	4.6	4.7	30.6	31.2	31.8
1809	45.0	30.2	4.5	4.8	4.9	29.3	31.6	32.2
1811	45.2	30.2	4.5	4.7	4.8	29.4	31.6	32.0
Ave.	45.2	30.3	4.5	4.7	4.8	29.8	31.7	32.3
Std.	0.3	0.1	0.1	0.2	0.2	0.8	2.1	2.1
Cos.(%)	0.8	0.4	1.2	5.1	5.2	2.8	6.6	6.6

Table B-69: TTC, Longitudinal Range and Speed at FCW Level 2 Warning on RV2 for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 28' Doubles, RV1 = Mack /w 40' Shipping Container

Test	Speeds (mph)		RV2 TTC (sec)			RV2 Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS
1813	45.5	30.9	5.3	5.6	5.6	34.8	36.5	37.0
1814	44.8	30.8	5.3	5.1	5.2	32.3	31.6	32.1
1815	45.0	30.8	5.2	5.1	5.1	33.0	32.0	32.3
1817	45.3	30.2	5.4	5.3		35.9	35.6	
1818	45.2	30.2	5.4	5.0		35.1	33.7	

Ave.	45.1	30.6	5.3	5.2	5.3	34.2	33.9	33.8
Std.	0.3	0.3	0.1	0.2	0.3	1.5	2.2	2.7
C. of V. (%)	0.6	1.1	1.6	4.5	5.6	4.4	6.4	8.1

Table B-70: TTC, Longitudinal Range and Speed at FCW Level 3 Warning on RV2 for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 28' Doubles, RV1 = Mack /w 40' Shipping Container

Test	Speeds (mph)		RV2 TTC (sec)			RV2 Lon. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS
1813	45.5	30.9	4.4	4.7	4.7	28.9	30.5	31.0
1814	45.0	30.9	4.5	4.3	4.4	28.0	27.2	27.8
1815	45.0	30.9	4.5	4.3	4.3	27.8	26.9	27.2
1817	45.3	30.3	4.6	4.5		30.4	30.1	
1818	45.1	30.2	4.5	4.2		29.6	28.2	
Ave.	45.2	30.6	4.5	4.4	4.5	28.9	28.6	28.6
Std.	0.2	0.4	0.0	0.2	0.2	1.1	1.6	2.0
C. of V. (%)	0.5	1.1	1.1	4.2	5.2	3.7	5.8	7.1

Table B-71: TTC, Longitudinal Range, Lateral Range and Speed at First FCW Alert Warning on RV1 after RV2 Alert Extinguished for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 40' Shipping Container, RV1 = Mack /w 28' Doubles

Test	Speeds (mph)		TTC (sec)			Lon. Range (m)			Lat. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1805	46.0	21.0	3.8	4.2	4.0	43	47	46	-1.6	-0.4	-1.0
1806*	44.9	20.4	5.5	5.5	5.6	59	60	61	-0.7	0.2	0.0
1807	45.9	20.4	4.1	4.3	4.4	46	49	50	-1.3	0.1	0.1
1808	45.6	21.6	2.6	3.1	2.6	28	33	29	-1.4	-0.1	-0.3
1809	44.8	20.4	1.1	1.4	1.5	12	15	16	-0.6	2.5	-0.3
1811	45.1	20.4	4.5	4.4	4.4	49	48	49	-1.5	-0.3	-0.3
Ave.	45.4	20.7	3.6	3.8	3.7	39.5	42.0	41.7	-1.2	0.3	-0.3
Std.	0.5	0.5	1.5	1.4	1.5	17.0	15.8	16.4	0.4	1.1	0.4
C. of V.(%)	1.2	2.4	43.4	37.4	39.7	42.9	37.8	39.3	-35.1	335.6	-118.9

* FCW Alert Level 2

Table B-72: TTC, Longitudinal Range, Lateral Range and Speed at First FCW Alert Warning on RV1 after RV2 Alert Extinguished for HV = Red Cascadia Bobtail, RV2 = Blue Cascadia /w 28' Doubles, RV1 = Mack /w 40' Shipping Container

Test	Speeds (mph)		TTC (sec)			Lon. Range (m)			Lat. Range (m)		
	HV	RV	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS
1813	45.7	20.5	4.2	4.2	4.3	46	47	48	-0.8	-0.2	-0.5
1814*	45.1	20.0	5.5	6.0	5.7	60	67	62	-1.5	-0.1	-0.3
1815	45.2	20.5	3.2	3.3	3.3	36	36	37	-1.6	-0.3	-0.5
1817	44.9	20.5	3.7	3.8		40	42		-1.3	-0.3	
1818	45.3	20.4	4.7	4.5		52	50		-0.2	0.2	
Ave.	45.2	20.4	4.3	4.4	4.4	46.9	48.5	49.1	-1.1	-0.1	-0.4
Std.	0.3	0.2	0.9	1.0	1.2	9.6	11.6	12.6	0.6	0.2	0.1
C. of V.(%)	0.6	1.1	20.5	23.1	26.5	20.5	24.0	25.7	-51.7	-137.0	-31.0

* FCW Alert Level 2

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