U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

NHTSA

DOT HS 812 317

November 2016

Commercial Connected Vehicle Test Procedure Development and Test Results – Blind Spot Warning/Lane Change Warning

Disclaimer

Suggested APA Format Citation:

Howe, G., Xu, G., Hoover, R., Elsasser, D., & Barickman, F. (2016, November). *Commercial connected vehicle test procedure development and test results – Blind spot warning/Lane change warning* (Report No. DOT HS 812 317). Washington, DC: National Highway Traffic Safety Administration.

Technical Report Documentation Page

1. Report No. DOT HS 812 317	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Commercial Connected Vehicle Test Procedure Development and Test Results – Blind Spot Warning/Lane Change Warning		5. Report Date November 2016 6. Performing Organization Code NHTSA/NVS-312
7. Authors Gavin Howe, Guogang Xu, and Dick Hoover of Transportation Research Center, Inc., and Devin Elsasser and Frank Barickman of National Highway Traffic Safety Administration		8. Performing Organization Report No.
9. Performing Organization Name and Address National Highway Traffic Safety Administration Vehicle Research and Test Center P.O. Box 37 East Liberty, OH 43319		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE. Washington, DC 20590		13. Type of Report and Period Covered: Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

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

16. Abstract

This report is one of four documenting NHTSA's test track research performed to support development of objective test procedures to evaluate the safety applications of commercial vehicles with vehicle-to-vehicle (V2V) equipment. The primary focus of this research was on developing the test procedures, with a secondary goal of evaluating the performance of the prototype V2V safety applications. Objective test procedures were developed to evaluate a range of safety applications including intersection movement assist (IMA), blind spot warning/lane change warning (BSW/LCW), forward collision warning (FCW), and emergency electronic brake light (EEBL) warning. This report documents the BSW/LCW 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 BSW/LCW threats, but occasionally the equipment would not recognize that a vehicle was in the V2V equipment determined blind spot warning zone due to the equipment's error in estimating the lateral range between the vehicles.

The V2V equipment determined blind zone was different for each side of the vehicle evaluated in this study (shorter on right side). When the turn signals were activated, the blind zone was extended by a time based on the closing speed of the approaching vehicle.

The BSW/LCW test procedures are generally well developed, but the blind zone definition for commercial vehicles/tractor-trailers combinations needs to be further refined.

17. Key Words: Commercial Connected Vehicles, vehicle-to-vehicle, V2V, vehicle-to-infrastructure, V2I, V2X, Blind Spot Warning, BSW, Lane Change Warning, LCW		18. Distribution Statement: This document is available to the public from the National Technical Information Service, www.ntis.gov	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 141	22. Price

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

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List of Acronyms

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

Executive Summary

The National Highway Traffic Safety Administration is developing test procedures to evaluate the safety applications of vehicle-to-vehicle equipped commercial vehicles. For this research, a commercial vehicle is defined as a medium or heavy truck (including tractor-trailer combinations) or bus with a gross vehicle weight rating of more than 10,000 pounds. The primary focus of this research was on developing the test procedures, with a secondary goal of evaluating the performance of the prototype V2V safety applications. Objective test procedures were developed to evaluate a range of safety applications including intersection movement assist, blind spot warning/lane change warning, forward collision warning, and emergency electronic brake light warning. This report documents the BSW/LCW test procedures and the results of testing commercial vehicles with prototype V2V equipment with the developed procedures.

The primary test vehicles for the V2V study were two Freightliner Cascadia Class 8 tractors that were used in the model deployment study [1]. One was used as a host vehicle (HV – test subject) and the other was generally used as a remote vehicle (RV – collision threat). A Mack CXU612 Class 8 tractor initially used in a Retrofit Safety Device test program was used as an RV. A 2007 Honda Odyssey equipped with a vehicle awareness device was also used as an RV.

In general the V2V equipment was observed to be capable of tracking potential BSW/LCW threats, but occasionally the equipment would not recognize that a vehicle was in the V2V equipment determined blind spot warning zone due to the systems error in estimating the lateral range between the vehicles.

It is important to run BSW/LCW tests with the turn signals off and with the turn signals on prior to the passing vehicle entering the blind zone of the vehicle being overtaken due to a blind zone extension that occurs when the driver activates the turn signals. The V2V equipment pre-set blind zone used when the turn signals are off is increased based on the closing speed of the approaching vehicle. The blind zone is extended by a time-to-collision value based on the closing speed. The TTC value for the V2V equipment evaluated in this study was approximately 5 seconds. Due to the blind zone extension, several test procedures have been modified to allow for both a BSW test and separate LCW test. Methods and calculations for determining the blind zone extension TTC are also now part of these test procedures.

For tests when the V2V equipment being evaluated is on a vehicle overtaking another vehicle, it is not important to test with the turn signals on and with the turn signals off prior to the vehicle being passed entering the blind zone because the V2V equipment determined blind zone does not need to be extended on a vehicle overtaking another vehicle. For these types of tests the turn signal can be applied briefly after the V2V equipped vehicle has started to pass the other vehicle to make sure the V2V equipment changes from a BSW alert to an LCW alert when the turn signals are activated.

The blind zone was different for each side of the vehicle evaluated in this study. It was shorter on the right side than it was on the left side. The blind zone was extended when a trailer (or trailers) was hitched to the tractor, but the blind zone did not extend based on trailer length. Instead a single length was set regardless of trailer or trailer combination length. The blind zone did not generally extend past the end of the trailers. When the turn signals were on, the blind zone extension did increase the blind zone to where it extended past the trailers.

The BSW/LCW test procedures are generally well developed and could be conducted with the V2V equipment evaluated in this study. The blind zone for commercial vehicles/tractor-trailers combinations needs to be further defined. There are several depictions of blind zones for commercial connected vehicles in the literature, but how far the blind zone extends past (or stays within) the length of the vehicle or vehicle combination needs to be addressed. The length of the blind zone directly affects when the BSW and LCW alerts should be issued during the tests conducted in this study.

1 Introduction

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

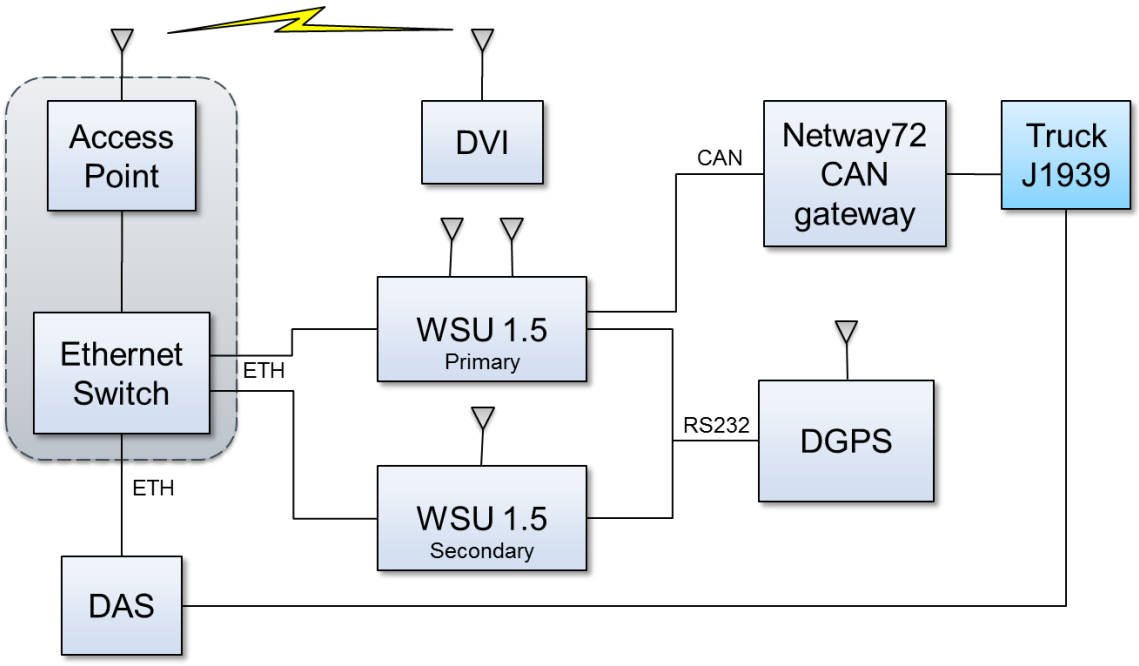


Figure 2: OBE System Architecture

Example BSW/ LCW application Level 2 Inform (no turn signal) and Level 3 Warning (turn signal on) icons that were displayed on the tablet are shown in Figure 3. These icons show the rear view of a trailer next to and slightly ahead of a remote vehicle. The remote vehicle is on the

left of the trailer in these icons. Similar icons for right and both side remote vehicles were also presented on the tablet.

Figure 3: BSW Inform Level 2 Alert and LCW 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 was collected during the course of this study and were labeled RT, GPS, and WSU. The following sections briefly described how this data was collected.

3.1 RT Data Collected on UEI

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

3.2 GPS Data

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

3.3 WSU Data

On the Cascadia tractors, the Denso WSU output DAS packets that were collected on a laptop computer through a hardwired Ethernet. The DAS packets included V2V basic safety messages and some intermediate data. A laptop computer was used to collect the data saved as packet capture (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 Blind Zone Definition Literature Review Summary

On April 3, 2014, the National Transportation Safety Board issued a letter to NHTSA to take action on mitigation of blind spots (H-14-001 through -007). In this document the NTSB refers to *Prioritizing Improvements to Truck Driver Vision* [3], a report by Reed, Blower, and Flannagan that found crashes in which the drivers of large trucks needed to use their mirrors to complete their maneuvers (mirror-relevant crashes) comprised 20 percent of all large-truck crash involvements (fatal and non-fatal combined). Mirror-relevant crashes involving the right side of the truck (lane change/merge and right turns) were more than four times as common as those involving the left side of the truck (lane change/merge and left turns). Reed, Blower, and Flannagan also identified four locations where the vision of drivers of large trucks needed to be improved and ranked them in the following order (Figure 4):

1. Area to the right of the large truck cab that covers an area equivalent to a right-side adjacent lane and 5 meters behind the front bumper of the large truck cab;
2. Area to the right of the truck that covers an area equivalent to a right-side adjacent lane and extends from the back of the large truck cab to 5 meters behind the trailer/cargo area;
3. Area immediately in back of the large truck (about 5 meters); and
4. Area that extends 5 meters in front of the large truck cab and one lane over to the right to cover the adjacent lane.

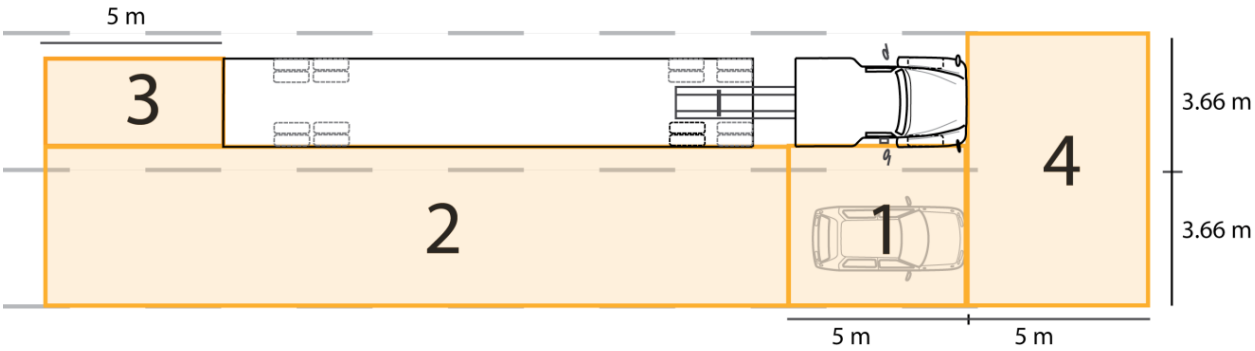


Figure 4: Prioritized Zones for Driver Vision Improvement (highest priority zone is indicated with numeral 1) [3]

A brief BSW/LCW literature review was conducted to examine documents that covered topics that included crash statistics for lane change scenarios, proposed Commercial Connected Vehicle test procedures and performance measures, safety applications and development documents for CCV devices (RSD, WSU, etc.). There were three major findings from the literature review that were of direct interest to the current study: what are the key capabilities of a BSW/LCW alert system, specific BSW/LCW blind zone definitions for automotive connected vehicle

applications, and depictions of CCV blind zones. While they may be documented elsewhere, this literature review did not find specific CCV blind zone definitions.

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 a BSW/LCW application.

4.1 Key Capabilities of a BSW/LCW Warning System

The BSW/LCW alert timing is briefly described and communication requirements are listed in *Development of Performance Requirements for Commercial Vehicle Safety Applications* [4]. No definitive blind zones are described, but several references are listed.

> "During a lane change attempt (intended or unintended), the BSW/LCW will alert the subject vehicle's driver if the space adjacent to the subject vehicle is occupied by another vehicle [5, 6]. Compared to light vehicles, CVs are known for their large blind spots around the vehicle that pose a hazard to adjacent traffic. As mentioned, CVs have variable lengths, widths, and heights that create shifting blind spots that must be accounted for in safety countermeasures. Because of the adjacency of the vehicles involved, line-of-sight DSRC communications will be sufficient."

In *Vehicle Safety Communications – Applications (VSC-A) Project: Crash Scenarios and Safety Applications* [5] is a PowerPoint presentation that includes a depiction of left and right side blind zones that start at the front of a light vehicle and that extend beyond the rear bumper of the vehicle (Figure 5).

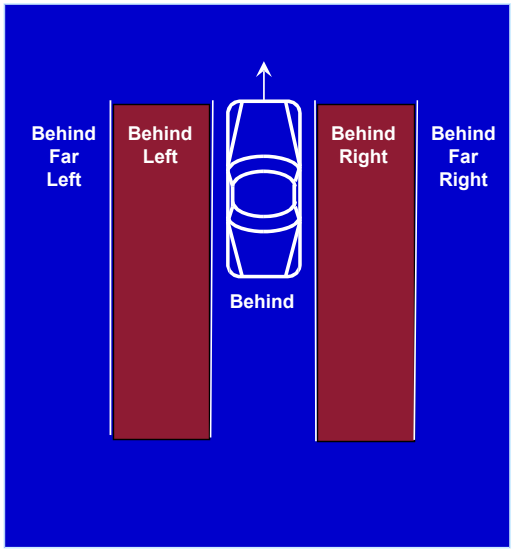


Figure 5 - Blind Zone [5]

In the presentation it states:

> "During a lane change attempt, the Blind Spot Warning/Lane Change Warning (BSW+LCW) application will warn the driver of the host vehicle if the blind spot zone into which the host vehicle intends to switch is, or will soon be, occupied by another vehicle traveling in the same direction.
>
> Secondly, the application will provide advisory information to the driver whenever a vehicle in an adjacent lane is positioned in a blind spot zone of the host vehicle."

This suggests that the LCW will have a different blind zone range than that for a BSW. *Vehicle Safety Communications – Applications (VSC-A) First Annual Report – December 7, 2006 through December 31, 2007* [6] is a joint NHTSA and Office of the Assistant Secretary for Research and Technology (OST-R) publication. This document states the following about BSW/LCW:

> "The BSW+LCW application is intended to warn the driver of the host vehicle during a lane change attempt if the blind spot zone into which the host vehicle intends to switch is, or will soon be, occupied by another vehicle traveling in the same direction. Moreover, the application provides advisory information that is intended to inform the driver of the host vehicle that a vehicle in an adjacent lane is positioned in a blind spot zone of the host vehicle when a lane change is not being attempted."

4.2 BSW/LCW Blind Zone Definitions for Light Vehicles

A brief literature review was conducted to find out how various organizations have defined blind zones. In *Vehicle Safety Communications – Applications (VSC-A), Final Report - Appendix C-1: Minimum Performance Requirements* [7],Crash Avoidance Metrics Partnership (CAMP) defines the blind spot zone as an area which is, or will soon be, occupied by another vehicle traveling in the same direction in the immediate adjacent left or right lane up to 20 meters behind the center of the HV.

In *System Performance Guidelines for a Prototype Integrated Vehicle-Based Safety System (IVBSS) –Light Vehicle Platform* [8], the Integrated Vehicle-Based Safety Systems (IVBSS) require that the LCM (Lane Change-Merge) system should detect vehicles moving in the same direction in adjacent lanes on straight roadways and any roadway with a radius of curvature of more than 250 m. The detection zones should mimic the horizontal and vertical curvature of the HV travel lane. Three detection zones, blind-spot, adjacent-forward, and adjacent-rear are defined for each side of the HV as shown in Figure 6. Each of these three zones is further divided into a small required alert zone and a larger optional advisory zone. The optional advisory zones extend up to 4 m from either side of the HV. The required alert zone extends from 0.5 to 3.2 m from either side of the HV. The optional advisory adjacent rear zone extends from 1 to 35 m from the rear of the HV. The required alert adjacent rear zone extends from 3 to 18 m behind the rear of the HV. The optional advisory blind spot zones extend from 3 m forward of the rear of the HV to 4 m behind the rear of the HV. The required alert blind spot zones run from the B-pillar center to 3 m behind the rear of the HV. The optional advisory adjacent forward zones extend from 1 m back from the B-pillar of the HV to 4.2 m ahead of the HV. The required alert adjacent forward zones run from the B-pillar to 3.2 m ahead of the front of the HV.

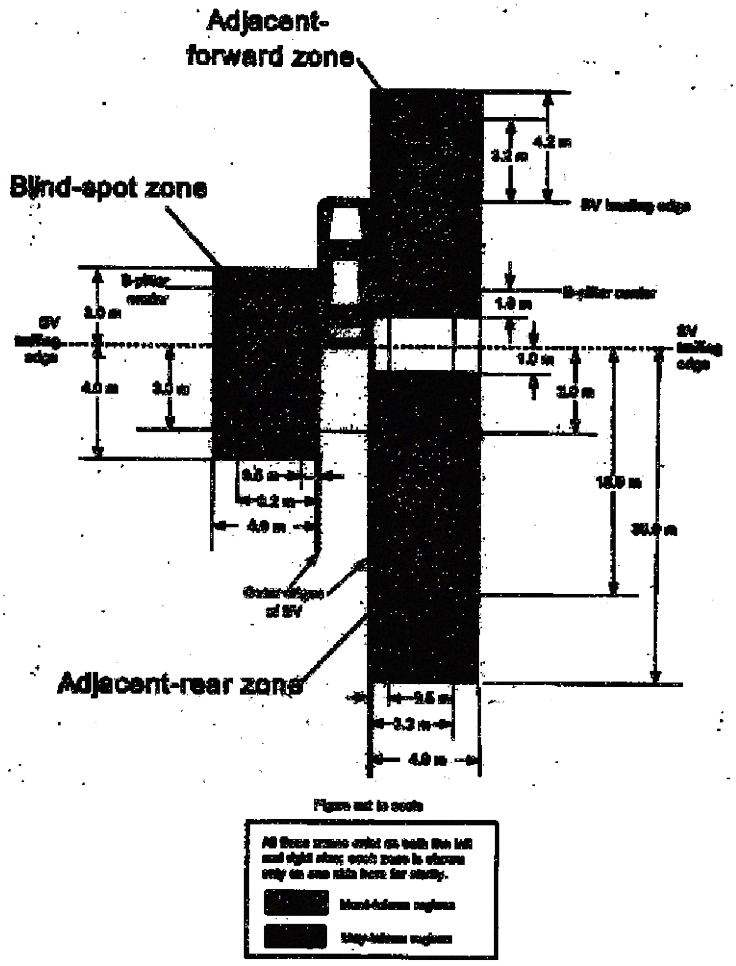


Figure 6 – IVBSS Detection Zones [8]

In *Road Vehicles - Forward Vehicle Collision Warning System - Performance Requirements and Tests Procedures* [9], the ISO LCDAS (Lane Change Decision Aid Systems) defines three types of detection zones based on the warning algorithm and system capabilities. Type-I systems address only blind spot warnings and require a blind spot warning zone adjacent to either side of the vehicle. Type-II systems address only closing vehicle warning and require a closing vehicle warning zone to the rear of either side of the vehicle. Type-III systems are more comprehensive lane-change warning systems that address both blind spot warning and closing vehicle warning functions. They require a lane-change warning zone that extends to either side of the vehicle and to the rear.

All of the ISO LCDAS zones extend laterally from 0.5 to 3.0 m from the side of the HV. The longitudinal range of the 'adjacent zone' used in Type I is from 3 m behind the rear of the HV to a point at which 95 percent of drivers are expected to be able to see the RV in their peripheral vision (as defined by the 95th percentile 'eyelipse' defined in Society of Automotive Engineers -

SAE J941). The 'rear zone' used for Type II extends rearward from 3 m behind the HV. The rear edge of the rear zone is defined as 30 m from the rear edge of the HV.

4.3 Commercial Connected Vehicle Blind Zone Depictions

The *Connected Commercial Vehicle Integrated Truck Project: Applications Performance and Functional Test Report* [10] included seven different BSW test procedures. The sixth BSW test described in the document is BSW-6: RV Tailgates HV (False Positive Test) and is depicted in Figure 7. For this test procedure right and left blind zones (spots) are depicted. Both the left and right blind zones extend rearward of the HV. The left blind zone ends at the front of the HV while the right blind zone extends forward of the HV. No specific numbers for the blind zone lengths are given in the report.

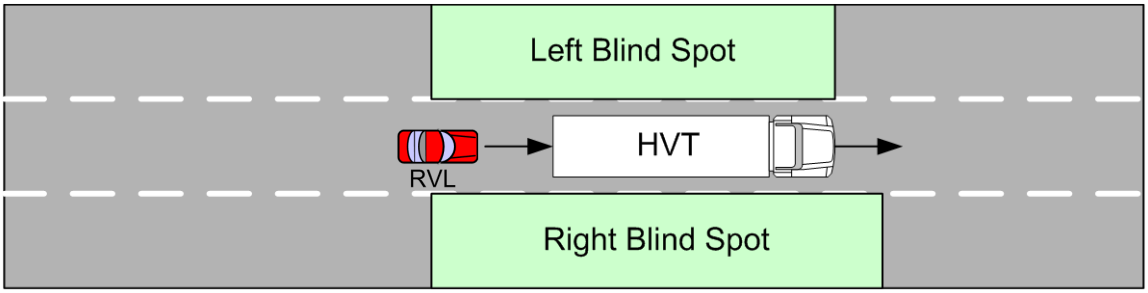


Figure 7 - RV Tailgates HV (False Positive Test) [10]

In *Connected Commercial Vehicle Retrofit Safety Device (CCV-RSD): Safety Applications and Development Plan Draft Technical Report* [11], the blind zones are depicted differently. In this document the blind zones are as shown in Figure 8. No definitive numbers for the length of the zone are given, but it appears that the zones begin at the rear of the trailer and extend forward of the tractor front bumper on the right side and just to the front bumper on the left side. The only description for the length of the zone given in the document is:

> "Blind spot zone may differ between driver-side and passenger-side blind spots."

Under requirements it states that:

> "BSW/LCW shall inform the HV driver whenever a remote vehicle is located within a blind spot zone of the HV."

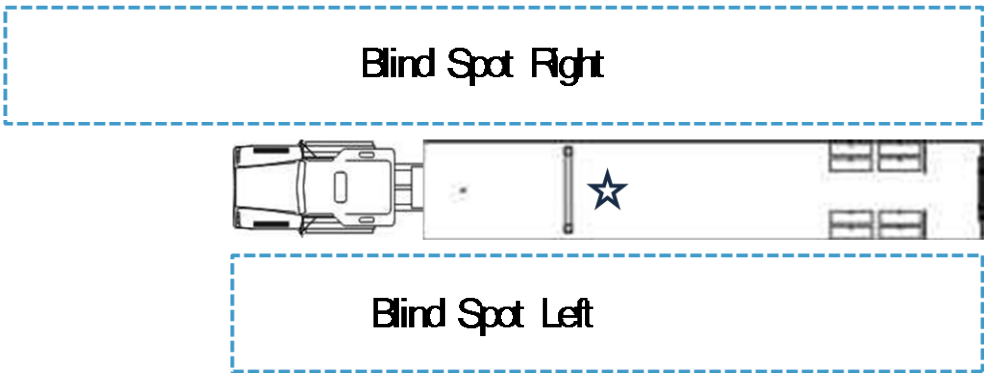


Figure 8 - BSW/LCW Scenario [11]

4.4 Summary of Key Findings, How They Relate to Initial Results, and Proposed Changes to Test Procedures

One key finding of the literature review is that a properly designed BSW/LCW V2V system will have a longer blind zone range for an LCW than that for a BSW and that the previous versions of the BSW/LCW test procedures did not allow for a proper evaluation of an LCW system. The previous versions of the BSW/LCW test procedures had the test driver cycle the turn signals after a BSW alert was issued:

> "Once an 'Inform Left' alert occurs, the driver of the HV cycles the turn signals. First activating the left turn signal, followed by activating the right turn signal."

This version of the procedure did not allow a proper evaluation of the blind zone extension capabilities of the V2V system being evaluated. Since the turn signals are not turned on until after an "Inform Left" (BSW alert), the ability to evaluate whether there is a blind zone extension is lost. Cycling the turn signals after the BSW alert only shows whether the LCW alert will come on for a proper turn signal (and not for an opposite direction turn signal) and what the latency or delay in the LCW alert is after the application of the turn signals. To determine whether the V2V system has LCW blind zone extension capabilities the current version of the test procedures (documented in Appendix A) now have separate BSW and LCW tests with the HV turn signals off and on respectively before the RV makes the pass of the HV. The results of the BSW and LCW tests with the turn signal off (BSW) and turn signal on (LCW) before the pass can then be compared to determine if the V2V system has blind zone extension capabilities. The length and/or time extension of the blind zone can then be determined.

Another key finding is that even though definitive base left and right blind zones for BSW alerts for CCVs were not found, the few depictions of blind zones for heavy trucks that were found suggest that the base BSW blind zones should at least run the length of the tractor-trailers combination. The crash data analysis in Reed, Blower, and Flannagan's report [3] suggests that the blind zone should extend 5 meters forward and rearward of the tractor-trailer combination.

5 Blind Spot Warning/Lane Change Warning Results

There were nine Blind Spot Warning/Lane Change Warning (BSW/LCW) test procedures evaluated in this study. The test procedures:

- BSW/LCW-1: RV Passes HV on Left, Straight Road

- BSW/LCW-2: RV Passes HV on Right, Straight Road
- BSW/LCW-3: HV Passes RV, Straight Road
- BSW/LCW-4: RVs Pass HV on Left And Right, Straight Road
- BSW/LCW-5: RV Tailgates HV, Straight Road
- BSW/LCW-6: HV And RV Separated by One Lane, Straight Road
- BSW/LCW-7: RV Passes HV on Right, Curved Road
- BSW/LCW-8: RV Passes Slow Moving HV on Left, Straight Road
- BSW/LCW-9: HV Passes Slow Moving RV on Left, Straight Road

The test procedures for these tests are documented in Appendix A– BSW/LCW Test Procedures.

The tractor/trailer combination lengths are listed in Table 2. Physical measurement and WSU broadcasted values are presented.

Table 2: Tractor-Trailer Combination Lengths – Measured Versus WSU Broadcast

Tractor	Data Source	Combination Length (m)			
		Bobtail	2x28 foot	40 ft	53 ft
Red Cascadia	WSU	8.54	23.32	18.44	22.76
	Measured	8.05	23.84	17.97	21.83
Blue Cascadia	WSU	7.62	22.40	17.52	21.84
	Measured	7.23	22.77	16.89	20.75

5.1 BSW/LCW-1: RV Passes HV on Left, Straight Road

For the BSW/LCW-1 test procedure, two vehicles travel along a straight roadway in adjacent lanes and in the same direction. While the leading HV maintains a constant velocity, the trailing RV is moving at a higher rate of speed and enters into the BSW/LCW-application's left-side alert zone of the HV. This test assesses the ability of the HV's system to identify the vehicle in its blind zone, then alert the HV's driver of the threat, and finally to extinguish the alert when the threat had passed. In the initial drafts of the test procedure the BSW/LCW features were evaluated by allowing the RV to drive into HV blind zone (activating a BSW Level 2 alert) and then the LCW feature was evaluated by activating the turn signal to the left indicating that the HV driver intends to make a lane change into the lane occupied by the RV (activating an LCW Level 3 alert). In an initial analysis of the data it was observed that this did not evaluate the BSW/LCW application's ability to extend the blind zone when the turn signal was activated. It was decided to instead run the procedure twice: one set of tests with the turn signals off and one set with the turn signals on. Details for this test procedure can be found in Appendix A, Section A.8. The HV and RV initial speeds were 35 and 40 mph respectively for the tests conducted in this study.

The HV was the Red Cascadia and the RV was either the Honda Odyssey or Blue Cascadia. The vehicle-trailer combinations evaluated are presented in Table 3.

Table 3: BSW/LCW-1 Vehicle Combinations Evaluated

HV Trailer	RV	RV Trailer
Bobtail	Honda Odyssey	-
40’ Shipping Container		-
Bobtail	Blue Cascadia	Bobtail
53’ Box Trailer		40’ Shipping Container
Double 28’		40’ Shipping Container
Double 28’		53’ Box Trailer

5.1.1 BSW-1 Results

The BSW-1 test alert summary is shown in Table 4. All but one combination had a BSW alert for every test. The HV Bobtail with RV = Honda Odyssey had 5 of 6 tests with BSW alerts.

Table 4: BSW-1 Test Alert Summary

HV Trailer	RV	RV Trailer	No. of Tests w/ BSW Alerts
Bobtail	Honda Odyssey	-	5 of 6
40’ Ship. Cont.		-	8 of 8
Bobtail	Blue Cascadia	Bobtail	5 of 5
53’ Box Trailer		40’ Ship. Cont.	7 of 7
Double 28’		40’ Ship, Cont.	5 of 5
Double 28’		53’ Box Trailer	6 of 6

HV to RV longitudinal and lateral range traces for a test with a BSW alert are shown in Figure 9. Both WSU and RT data are shown in this figure. The WSU lateral range has a couple of deviations in value as the RV approaches the HV. It initially ramps below the RT data and then jumps back to the RT data near 24 seconds and then jumps above the RT data near 28.5 seconds and then ramps back toward the RT data. These jumps occurred in all of the tests. There is an almost 1 meter difference in the RT and WSU lateral range (lower subplot) during portions of the BSW alert with the WSU data showing the HV and RV being further apart than the RT data. The longitudinal and lateral range traces for the test with no BSW alert are shown in Figure 10. For this test the WSU lateral range was greater than 5.5 meters in the time frame when an alert would have been expected (15 to 25 seconds). The RT data shows that the HV and RV were closer laterally than what the WSU data shows and is consistent with the RT data shown in Figure 9 for a test with a BSW alert. This test should have produced a BSW alert.

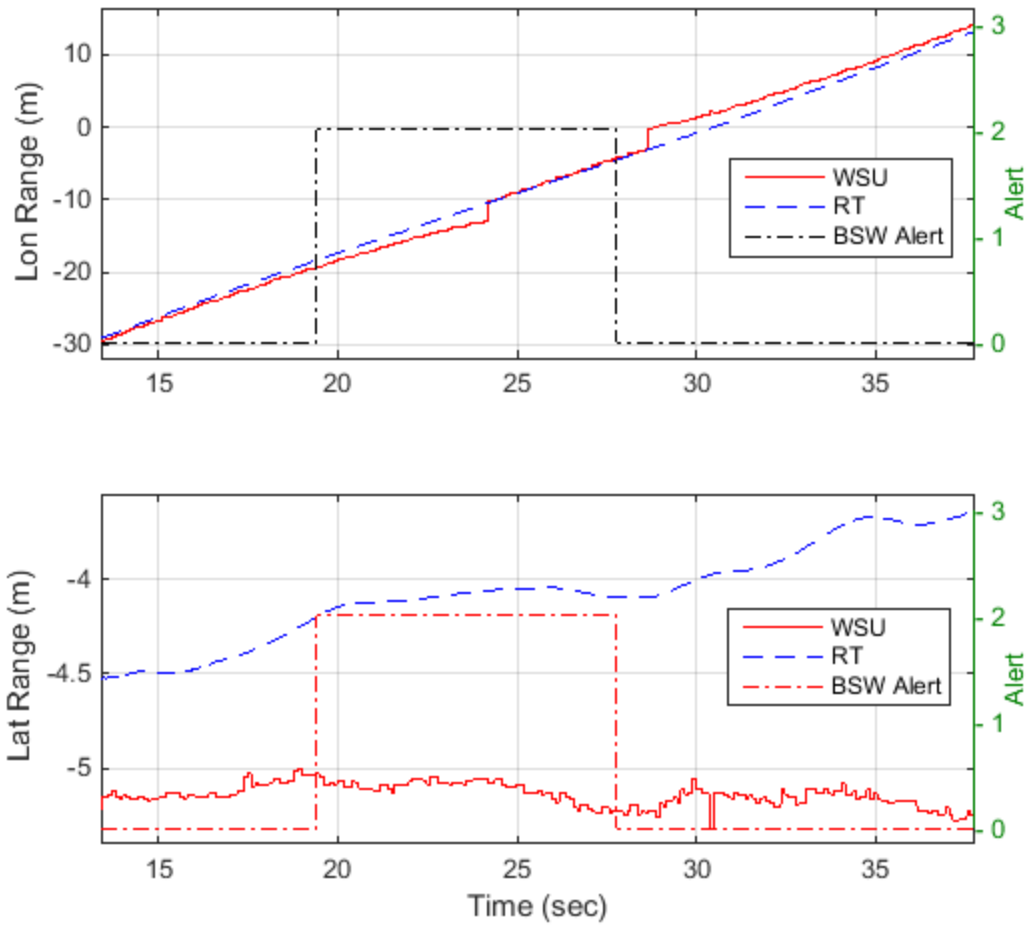


Figure 9: Example Longitudinal and Lateral Range for BSW-1 Test With BSW Alert (Test 773 - HV Bobtail With RV = Honda Odyssey)

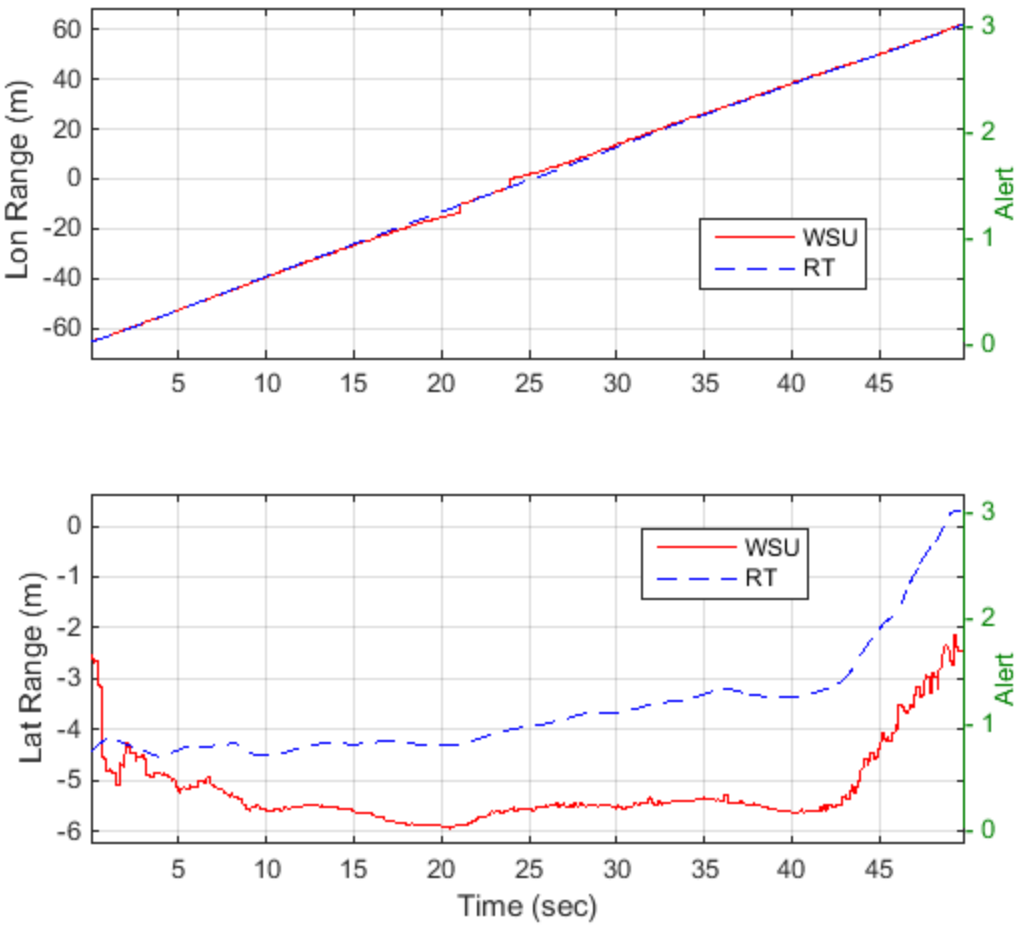


Figure 10: Longitudinal and Lateral Range for Test 775 – No BSW Alert (HV Bobtail With RV = Honda Odyssey)

Average and standard deviation of WSU data for HV to RV ranges at alert onset and offset are shown in Table 5. The HV front bumper to RV front bumper at alert onset, HV rear bumper (or trailer bumper) to RV front bumper at alert onset, and HV front bumper to RV front bumper at alert offset are listed. Negative values indicate that the RV was behind the HV and positive values indicate the RV was ahead of the HV (for the vehicle parts indicated in the column heading). More complete data for each individual test is presented in Appendix B, Section B.1. WSU, RT, and GPS data is presented in the appendix. The HV front to RV front at onset average values ranged from -12.6 to -21.4 meters with the HV bobtail conditions having lower magnitude values (-12.6 to -14.0 meters) and the HV with trailer conditions having larger values (-20.7 to -21.4 meters). This indicates the V2V system was adjusting the blind spot zone of the HV depending on whether the driver selected a trailer or bobtail condition in the V2V system setup. The HV rear to RV front at onset ranged from -6 meters to 2.7 meters. The HV front to RV front at offset average values ranged from 0.6 to 3.2.

Table 5: BSW-1 Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset – WSU Data

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Rear to RV Front at Onset (m)		HV Front to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Bobtail	Honda Odyssey	-	-14.0	0.1	-6.0	0.1	0.6	0.2
40’ Ship		-	-20.8	0.1	-2.8	0.1	0.8	0.4
Bobtail	Blue Cascadia	Bobtail	-12.6	1.7	-4.6	1.7	0.6	1.2
53’ Box		40’ Ship	-20.7	0.3	1.1	0.3	3.2	1.0
Doubles		40’ Ship	-21.2	0.1	2.7	0.1	2.4	0.5
Doubles		53’ Box	-21.4	0.1	2.4	0.1	0.8	0.1

The standard deviation for the HV bobtail and RV = Blue Cascadia Bobtail combination has a higher standard deviation (1.7 meters) than the other combinations (0.1 to 0.3 meters) for the alert onset values listed in Table 5. This is due to one test having a slight delay in alert onset (Test 996). The longitudinal and lateral range for this test is shown in Figure 11. The WSU lateral range is near 5.6 meters prior to the alert and ramps up to 5.4 meters at the alert onset. The GPS data show that the tractors were actually closer together than this. The WSU 5.4 meter distance appears to be the distance when the HV starts to recognize that the RV is within one lane of separation. This lateral distance was seen in other late warning onset or early warning offset tests. Two of these will be discussed in the LCW-1 results presented in the next section.

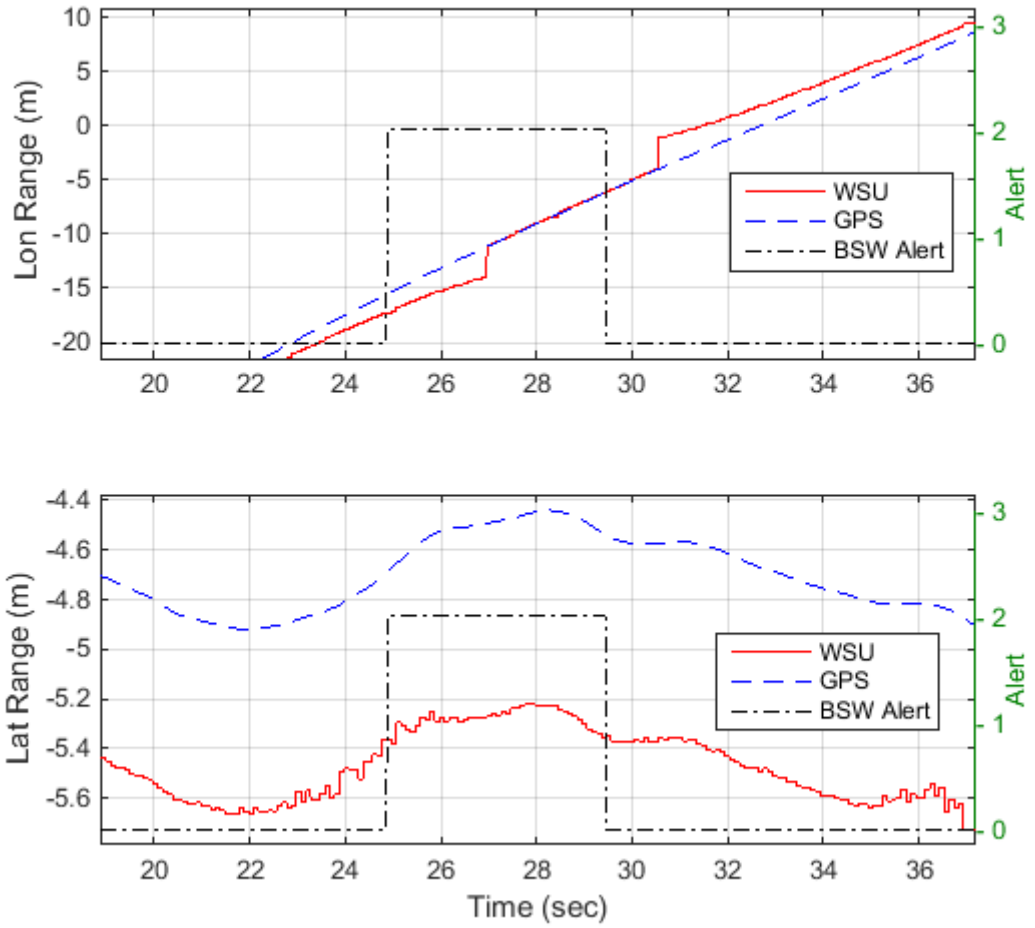


Figure 11: Lateral and Longitudinal Range for Test 996 – HV = Red Cascadia Bobtail, RV = Blue Cascadia Bobtail

Boxplots for the HV front to RV front range at BSW alert onset and offset are shown in Figure 12. 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 B15 represents the Blue Cascadia, the third line represents the HV/RV speeds in mph, and the fourth line is the alert level (Lv2 = BSW alert) and number of tests. Red plus signs represent data points that are considered outliers. For alert onset (left subplot), the HV with trailer conditions had greater negative values versus those for the HV bobtail conditions. There was not a large difference in HV to RV range at alert offset for the various HV and RV trailer conditions (right subplot).

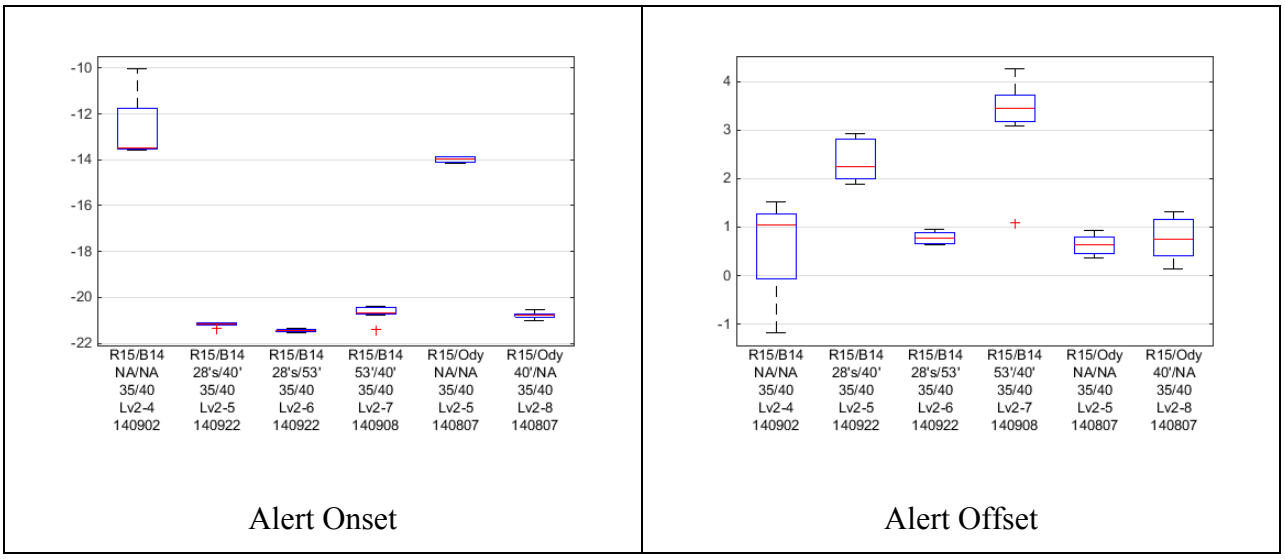


Figure 12: BSW-1 Boxplots of HV Front to RV Front Range at Alert Onset and Offset

Depictions of the HV and RV average relative positions at alert onset and alert offset are shown in Figure 13 and Figure 14 respectively. The HV bobtail conditions are shown in the top two subplots and the HV with trailer conditions are shown in the bottom four subplots. On the top of each subplot the scale starts from 0 at the RV front bumper and at the bottom of each subplot the scale starts from 0 at the HV front bumper. The yellow box underneath the blue RV vehicle represents $\pm$ one standard deviation for the HV to RV range. The relative position of the HV and RV in the figures suggests that the WSU in the Cascadia trucks sets the blind zone onset for BSW at one length for the bobtail condition and another for an attached trailer that does not change with trailer length. Unless the blind zone is defined to only extend to a certain distance back regardless of trailer length, the fact that the blind zone does not change with trailer length is not consistent with the blind zone depictions found in the literature review presented previously. The results from the literature review suggest that the blind zone should at least extend to the length of the trailer if not beyond. From the results presented in Figure 14, the WSU determined blind zone offset does not appear to change with trailer condition and occurs when the RV is slightly ahead of the HV.

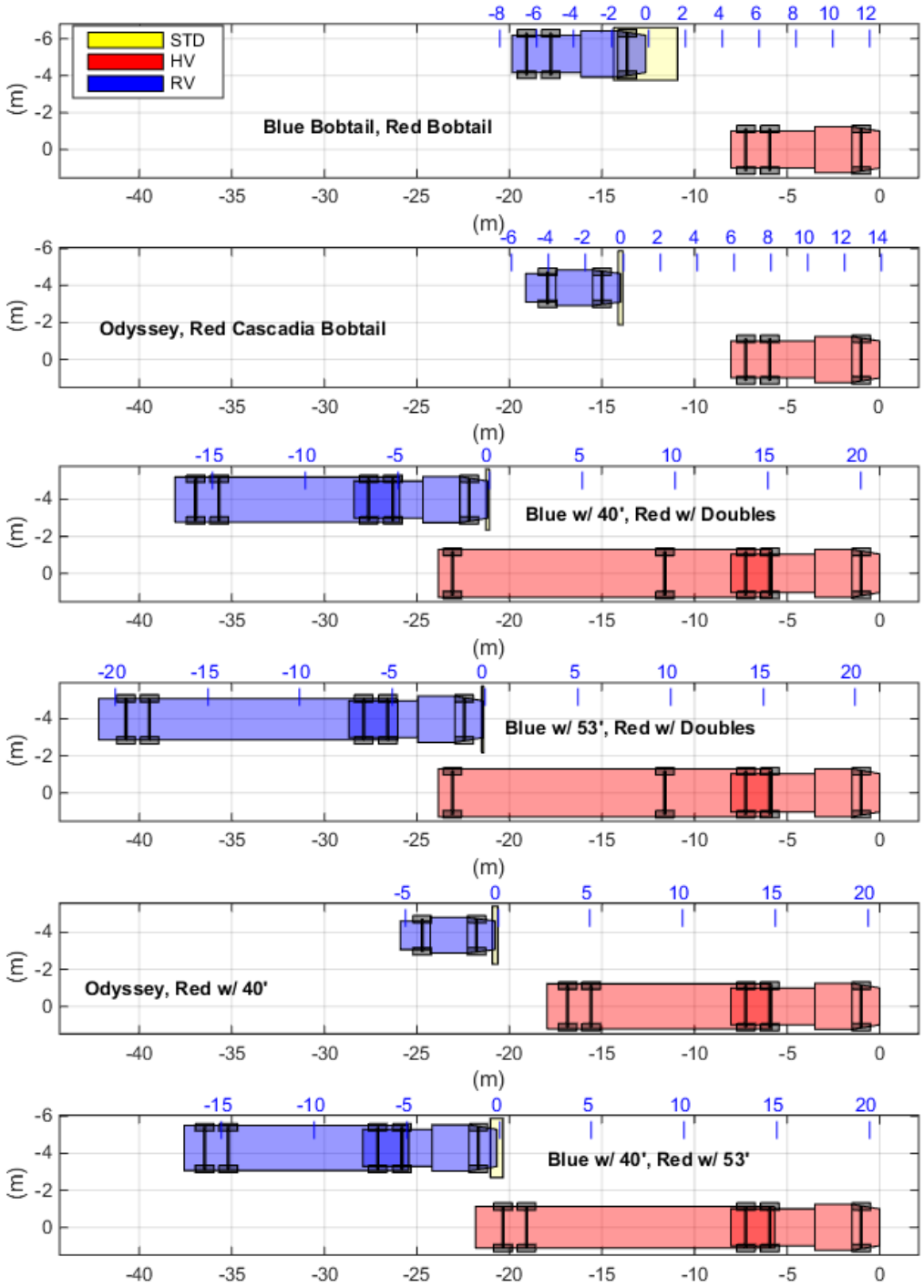


Figure 13: BSW-1 HV and RV Average Relative Position at Alert Onset

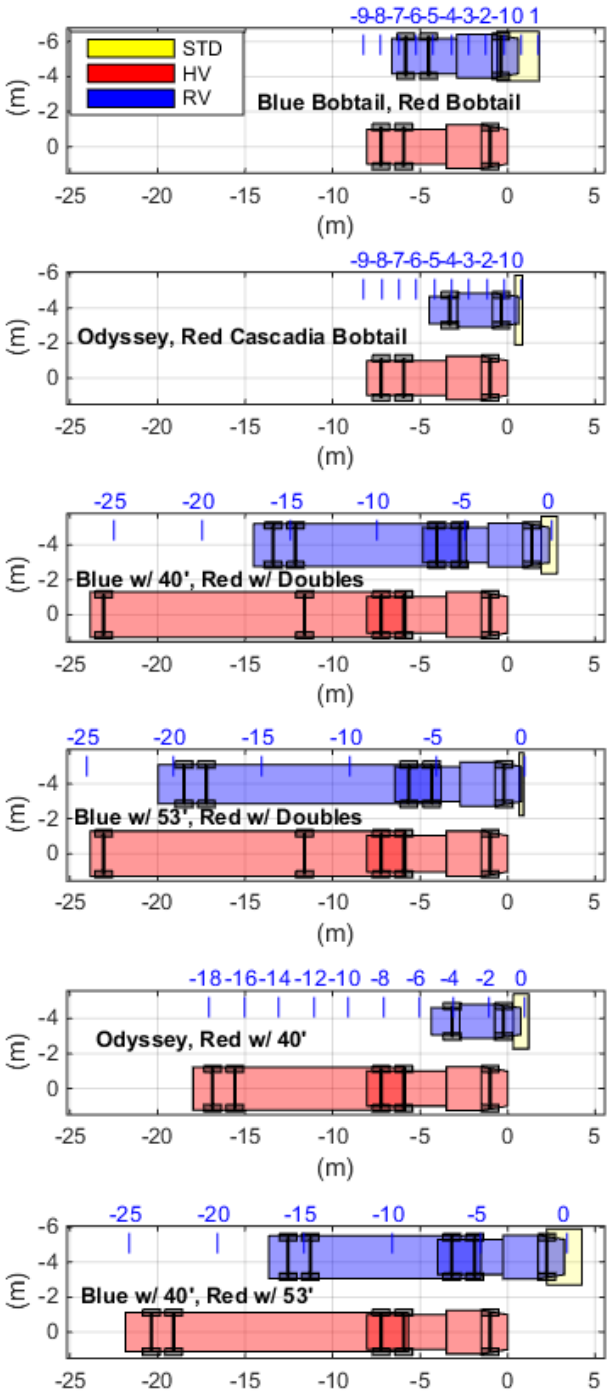


Figure 14: BSW-1 HV and RV Average Relative Position at Alert Offset

5.1.2 LCW-1 Results

The LCW-1 test procedure is essentially the same as the BSW-1 test procedure except for the LCW-1 test procedure the HV driver used the left turn signal to indicate intent to change lanes. The left turn signal was activated prior to the RV entering the WSU determined blind zone. As will be shown below, the WSU blind zone is extended when the turn signal is activated. The LCW-1 test alert summary is shown in Table 6. All combinations had an LCW alert for every test.

Table 6: LCW-1 Test Alert Summary

HV Trailer	RV	RV Trailer	No. of Tests w/ BSW Alerts
Bobtail	Honda Odyssey	-	6 of 6
40' Ship. Cont.		-	8 of 8
Bobtail	Blue Cascadia	Bobtail	5 of 5
53' Box Trailer		40' Ship. Cont.	5 of 5
Double 28'		40' Ship, Cont.	5 of 5
Double 28'		53' Box Trailer	5 of 5

Average and standard deviation of WSU data for HV to RV ranges at alert onset and offset are shown in Table 7. More complete data for each individual test are presented in Appendix B, Section B.1. WSU, RT, and GPS data are presented in the appendix. The HV front to RV front at onset average values ranged from -21.1 to -34.1 meters with the HV bobtail conditions having lower magnitude values (-21.1 to -24.7 meters) and the HV with trailer conditions having larger values (-30.5 to -34.1 meters). The HV rear to RV front at onset ranged from -9.7 meters to -16.7 meters (no overlap). The HV front to RV front at offset average values ranged from -1.2 to 2.9 meters.

Table 7: LCW-1 Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Rear to RV Front at Onset (m)		HV Front to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Bobtail	Honda Odyssey	-	-21.1	9.3	-13.1	9.3	0.9	0.3
40' Ship		-	-30.5	1.2	-12.5	1.2	-1.2	5.1
Bobtail	Blue Cascadia	Bobtail	-24.7	2.0	-16.7	2.0	1.3	0.2
53' Box		40' Ship	-32.0	0.9	-10.2	0.9	2.8	1.6
Doubles		40' Ship	-33.5	0.9	-9.7	0.9	2.9	0.1
Doubles		53' Box	-34.1	0.4	-10.2	0.4	0.7	0.1

The standard deviation for the HV bobtail and RV = Honda Odyssey combination has a higher value (9.3 meters) than the other combinations (0.4 to 2.0 meters) for the alert onset values listed in Table 7. This is due to one test having a long delay in alert onset (Test 792). The longitudinal and lateral ranges for this test are shown in Figure 15. The WSU lateral range is near 5.5 meters prior to the alert and ramps up to 5.4 meters at the alert onset. The RT data show that the HV and

RV were actually closer together than this. As noted in the previous section, the WSU 5.4 meter distance appears to be the distance when the HV starts to recognize that the RV is within one lane of separation. The standard deviation for the HV w/ 40' shipping container and RV = Honda Odyssey at offset has a higher standard deviation value (5.1 meters) than the other combinations (0.1 to 1.6 meters). This higher value was also due to one test that had the WSU lateral range dip below -5.4 meters (greater in magnitude) at the alert offset (Test 825). Again, the RT data for this test showed that the HV and RV were closer together than what the WSU reported. This one test caused the average value for this combination to go from a positive value to a negative value (-1.2 meters).

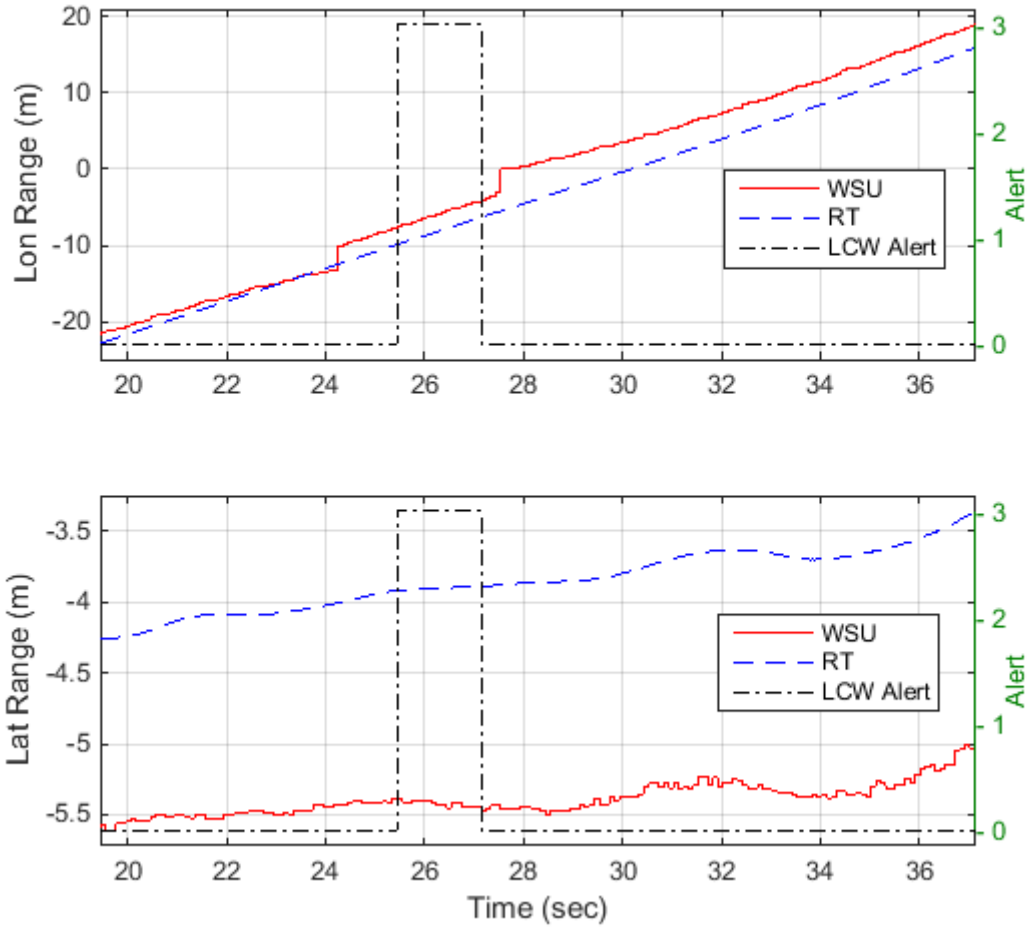


Figure 15: Lateral and Longitudinal Range for Test 792 – HV = Red Cascadia Bobtail, RV = Honda Odyssey

Boxplots for the HV front to RV front range at LCW alert onset and offset are shown in Figure 16. For alert onset (left subplot), the HV with trailer conditions had a greater negative value versus the HV bobtail conditions. There was not a large difference in HV to RV range at alert offset for the various HV and RV trailer conditions (right subplot).

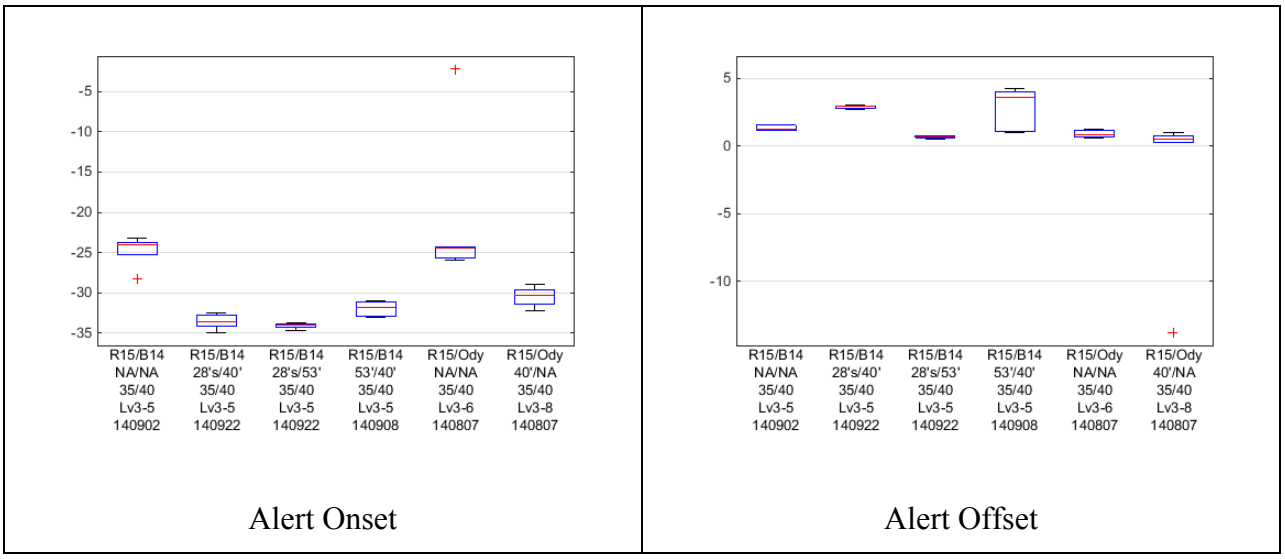


Figure 16: LCW-1 Boxplots of HV Front to RV Front Range at Alert Onset and Offset

Depictions of the HV and RV average relative positions at alert onset and alert offset are shown in Figure 17 and Figure 18 respectively. The relative position of the HV and RV in the figures suggests that the WSU in the Cascadia trucks sets the blind zone onset for LCW further back than it was for the BSW results shown in the previous section (Figure 13). This is explored further in the following section.

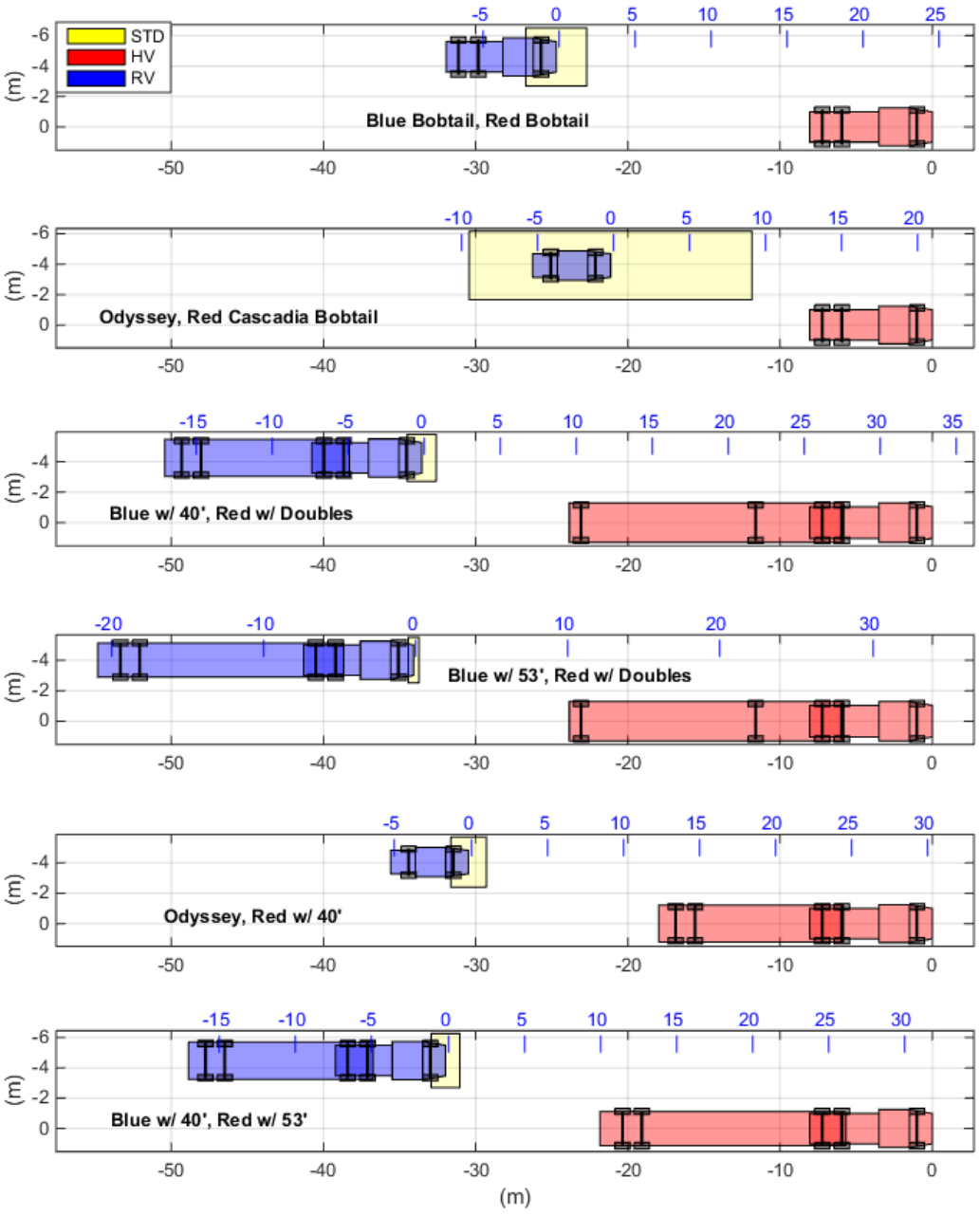


Figure 17: LCW-1 HV and RV Average Relative Position at Alert Onset

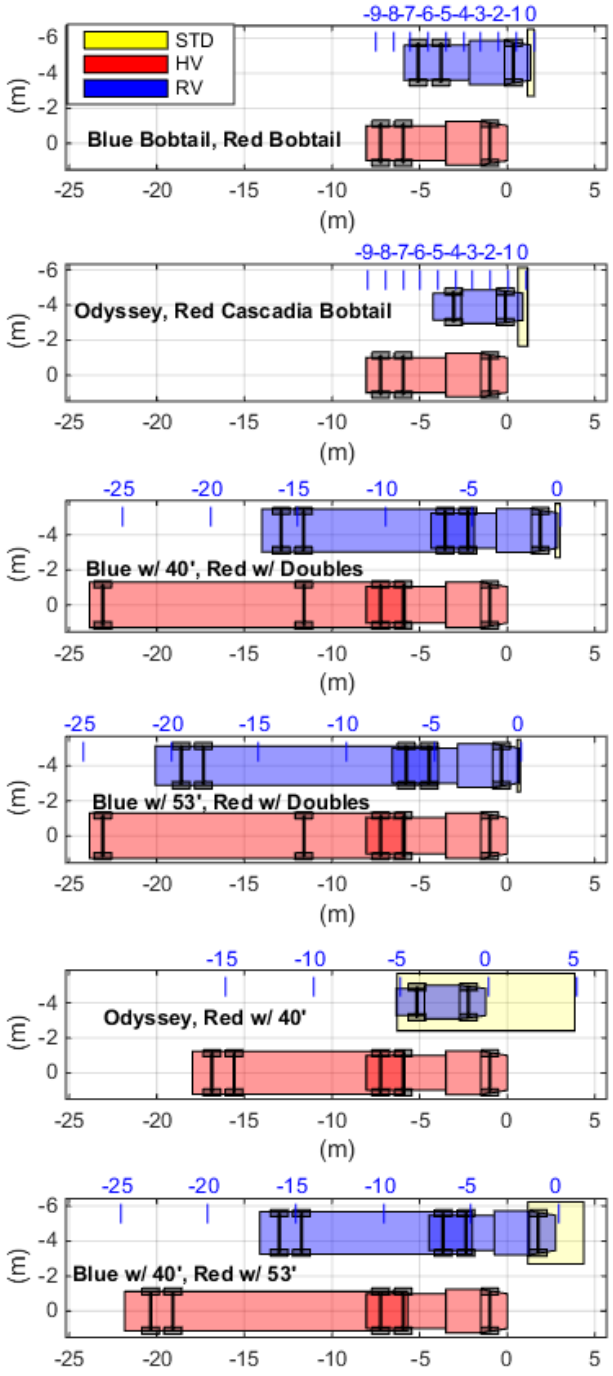


Figure 18: LCW-1 HV and RV Average Relative Position at Alert Offset

5.1.3 BSW to LCW Blind Zone Extension

As noted in the previous section, the relative position of the RV to the HV at alert onset was different for the LCW-1 tests versus the BSW-1 tests. The RV was further back from the HV for the LCW-1 alerts. This indicates the V2V system adjusted the alert thresholds based on the driver activating the turn signal with the intent to change lanes. The relative average positions at alert onset for the HV bobtail and the RV = Honda Odyssey are shown in Figure 19. The change in distance is known as the blind zone extension.

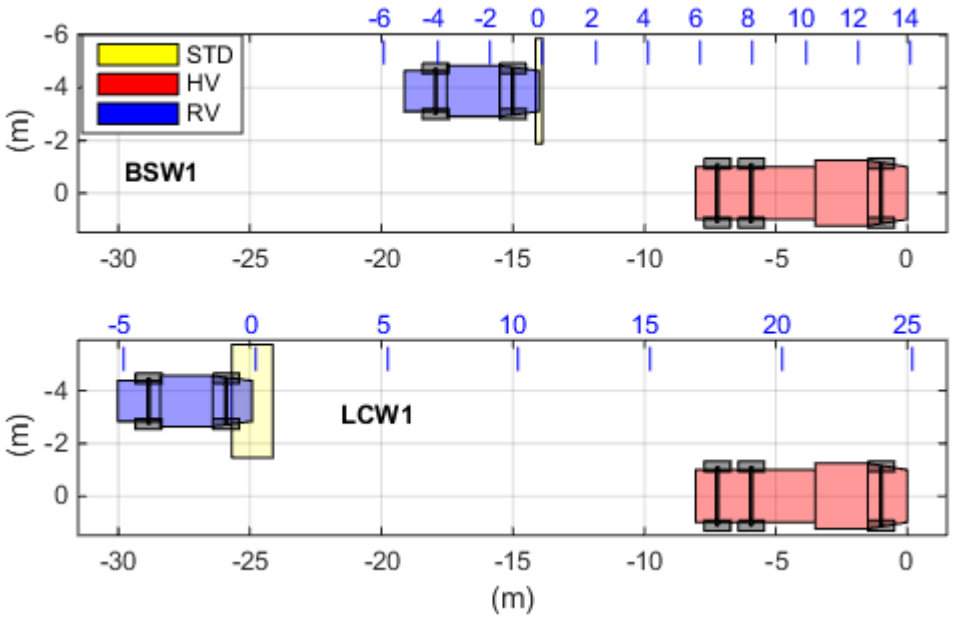


Figure 19: HV and RV Average Relative Position for BSW-1 and LCW-1 Alert Onset - HV Bobtail, RV = Honda Odyssey

The TTC for the BSW/LCW blind zone extension is calculated as follows:

$$TTC_{ex} = \frac{(S_{TsOn} - S_{TsOff})}{V_{Hv} - V_{Rv}}$$

Where:

TTC_{ex} ≡ TTC for blind zone extension when turn signal is on

S_{TsOn} ≡ Distance HV Rear to RV Front (range) at warning onset when turn signal is on

S_{TsOff} ≡ Distance HV Rear to RV Front at warning onset when turn signal is off

V_{Hv} ≡ HV Speed

V_{Rv} ≡ RV Speed

The TTC for the BSW/LCW blind zone extension determination for each HV/RV combination evaluated for the BSW/LCW-1 test procedures are given in Table 8. The calculated TTC ranged from 4.9 to 5.1 seconds. The WSU data was used to calculate these values. The average longitudinal range values did not include the data from the tests that were considered outliers due to the lateral range being too large at either the onset or offset of the BSW/LCW alert (namely Tests 792, 835, 996 and 1000 – Test 996 has not been discussed in previous sections, but also appears to have a slight delay in alert onset).

Table 8: BSW/LCW-1 Blind Zone Extension TTC Determination

HV Trailer	RV	RV Trailer	Avg. Long. Range		Avg. Delta Range (m)	Avg. Delta Speed (mph)	TTC_{ex} (sec)
			TS On	TS Off			
Bobtail	Honda Odyssey	-	-16.9	-6.0	10.9	4.9	5.0
40’ Ship. Cont.		-	-12.7	-2.8	9.9	4.4	5.0
Bobtail	Blue Cascadia	Bobtail	-16.7	-5.5	11.2	5.0	5.0
53’ Box Trailer		40’ Ship. Cont.	-10.2	1.1	11.3	5.1	4.9
Double 28’		40’ Ship, Cont.	-9.7	2.7	12.4	5.4	5.1
Double 28’		53’ Box Trailer	-10.2	2.4	12.6	5.6	5.0

Due to the blind zone extension that occurs when the turn signals are activated. The BSW/LCW-1 test procedure presented in Appendix A, Section A.8 has been modified to allow for both a BSW test and separate LCW test. Methods and calculations for determining the blind zone extension TTC are also now part of the test procedure.

5.2 BSW/LCW-2: RV Passes HV on Right, Straight Road

The BSW/LCW-2 test procedures are the same as the BSW/LCW-1 except for the BSW/LCW-2 procedures the RV travelled in the right lane adjacent to the HV (left in BSW/LCW-1). Details for this test procedure can be found in Appendix A, Section A.9. The HV and RV initial speeds were 35 and 40 mph respectively for the tests conducted in this study.

The HV was the Red Cascadia and the RV was either the Honda Odyssey or Blue Cascadia. The vehicle-trailer combinations evaluated are presented in Table 9.

Table 9: BSW/LCW-2 Vehicle Combinations Evaluated

HV Trailer	RV	RV Trailer
Bobtail	Honda Odyssey	-
40’ Shipping Container		-
Bobtail	Blue Cascadia	Bobtail
53’ Box Trailer		40’ Shipping Container
Double 28’		40’ Shipping Container
Double 28’		53’ Box Trailer

5.2.1 BSW-2 Results

The BSW-2 test alert summary is shown in Table 10. Every test had a BSW alert. There were no issues with delayed alert onset or early alert offset for the BSW-2 tests.

Table 10: BSW-2 Test Alert Summary

HV Trailer	RV	RV Trailer	No. of Tests w/ BSW Alerts
Bobtail	Honda Odyssey	-	7 of 7
40’ Ship. Cont.		-	5 of 5
Bobtail	Blue Cascadia	Bobtail	5 of 5
53’ Box Trailer		40’ Ship. Cont.	10 of 10
Double 28’		40’ Ship, Cont.	5 of 5
Double 28’		53’ Box Trailer	5 of 5

Average and standard deviation of WSU data for the HV to RV ranges at alert onset and offset are shown in Table 11. HV front bumper to RV front bumper at alert onset, HV rear bumper (or trailer bumper) to RV front bumper at alert onset, and HV front bumper to RV front bumper at alert offset are listed. More complete data for each individual test are presented in Appendix B, Section B.2. WSU, RT, and GPS data are presented in the appendix. The HV front to RV front at onset average values ranged from -13.5 to -17.9 meters with the HV bobtail conditions having lower magnitude values (-13.5 to -14.0 meters) and the HV with trailer conditions having larger values (-17.2 to -17.9 meters). The HV rear to RV front at onset ranged from -5.9 meters to 6.1 meters. The HV front to RV front at offset average values ranged from -4.2 to 2.0 meters. The HV with 40’ Shipping Container and RV = Honda Odyssey combination average value had the RV much further behind the HV than the other vehicle combinations at alert offset.

Table 11: BSW-2 Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Rear to RV Front at Onset (m)		HV Front to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Bobtail	Honda Odyssey	-	-14.0	0.1	-5.9	0.1	0.8	0.2
40’ Ship		-	-17.4	0.1	0.6	0.1	-4.2	0.1
Bobtail	Blue Cascadia	Bobtail	-13.5	0.1	-5.5	0.1	2.0	0.3
53’ Box		40’ Ship	-17.2	0.2	4.7	0.2	-0.1	0.3
Doubles		40’ Ship	-17.7	0.1	6.1	0.1	-1.0	0.4
Doubles		53’ Box	-17.9	0.1	5.9	0.1	1.3	0.3

Boxplots for the HV front to RV front range at BSW alert onset and offset are shown in Figure 20. For alert onset (left subplot), the HV with trailer conditions had greater negative values versus those for the HV bobtail conditions, but not as a great a difference as was seen in the BSW-1 results. As noted earlier, the HV with 40’ Shipping Container and RV = Honda Odyssey combination had the RV much further behind the HV than the other vehicle combinations at alert offset (right subplot).

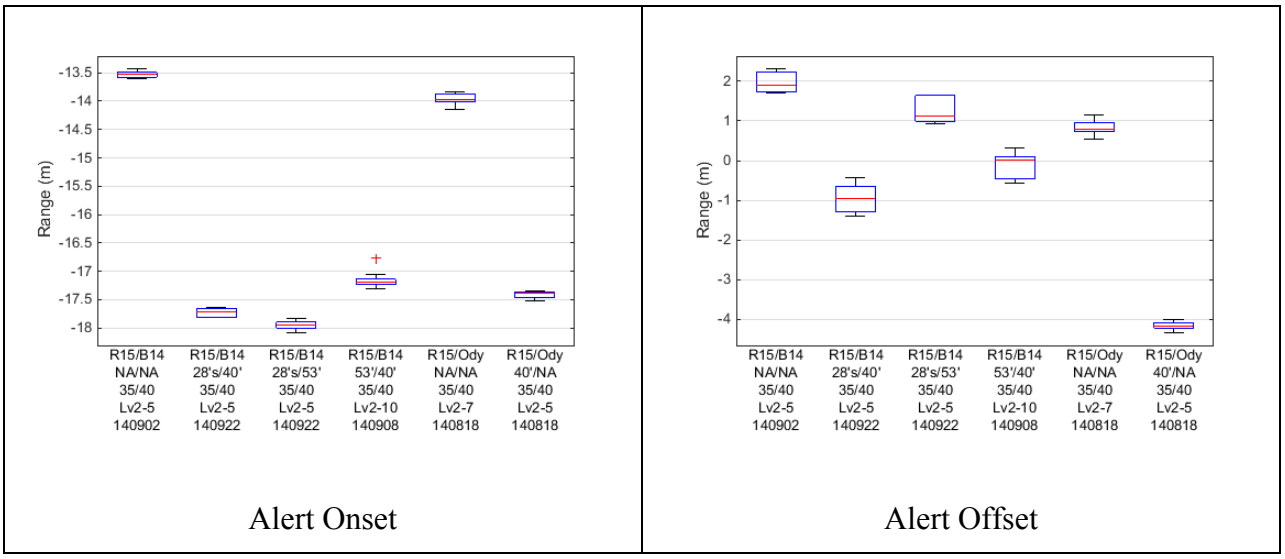


Figure 20: BSW-2 Boxplots of HV Front to RV Front Range at Alert Onset and Offset

Depictions of the HV and RV average relative positions at alert onset and alert offset are shown in Figure 21 and Figure 22 respectively. The HV bobtail conditions are shown in the top two subplots and the HV with trailer conditions are shown in the bottom four subplots. The relative position of the HV and RV in the figures suggests that the WSU in the Cascadia trucks sets the blind zone onset for BSW at one length for the bobtail condition and another for an attached trailer that does not change with trailer length. This difference is not as large as was seen in the BSW-1 results when the HV was on the left side of the RV. From the results presented in Figure 22, the HV with 40' Shipping Container and RV = Honda Odyssey combination had the RV front bumper much further behind the HV front bumper than the other vehicle combinations at alert offset (sixth subplot). Most of the other combinations had the RV front bumper ahead or just slightly behind the HV front bumper.

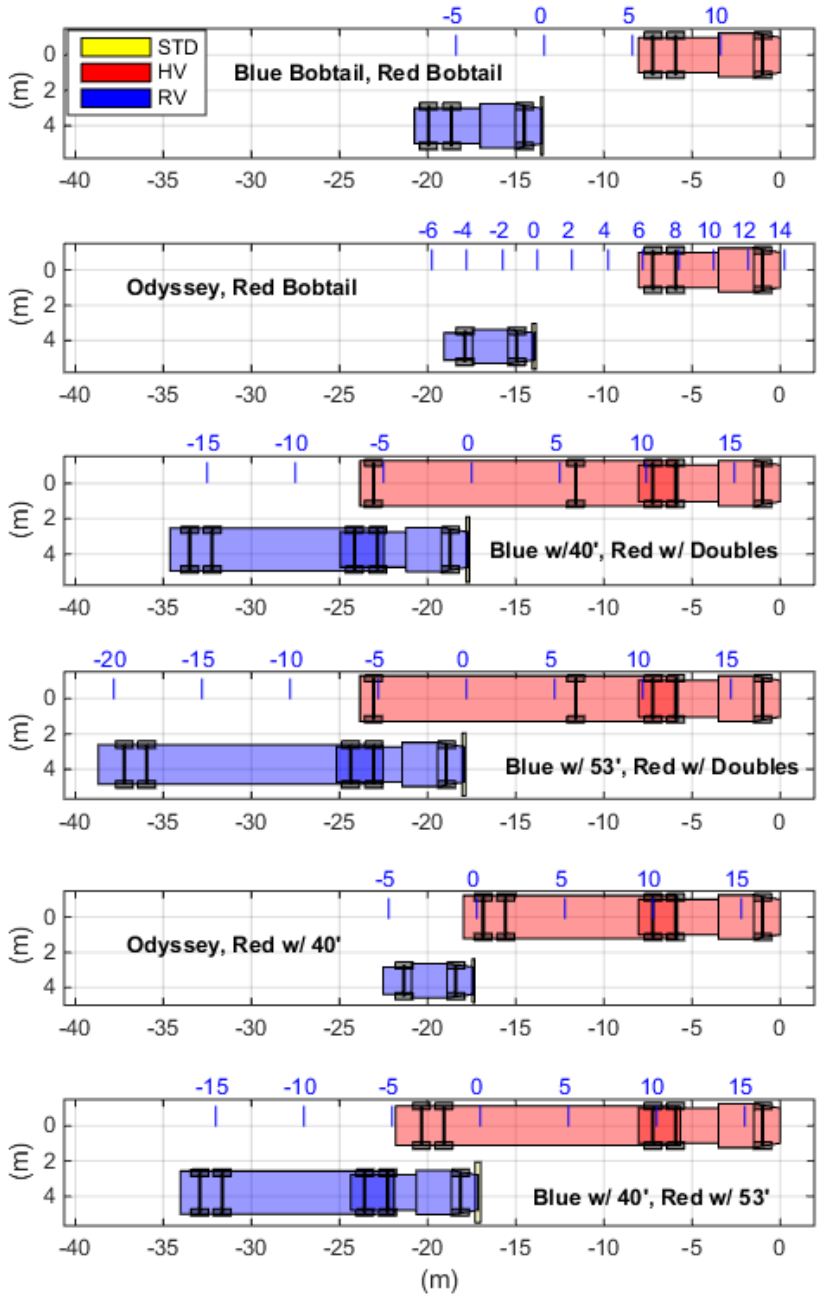


Figure 21: BSW-2 HV and RV Average Relative Position at Alert Onset

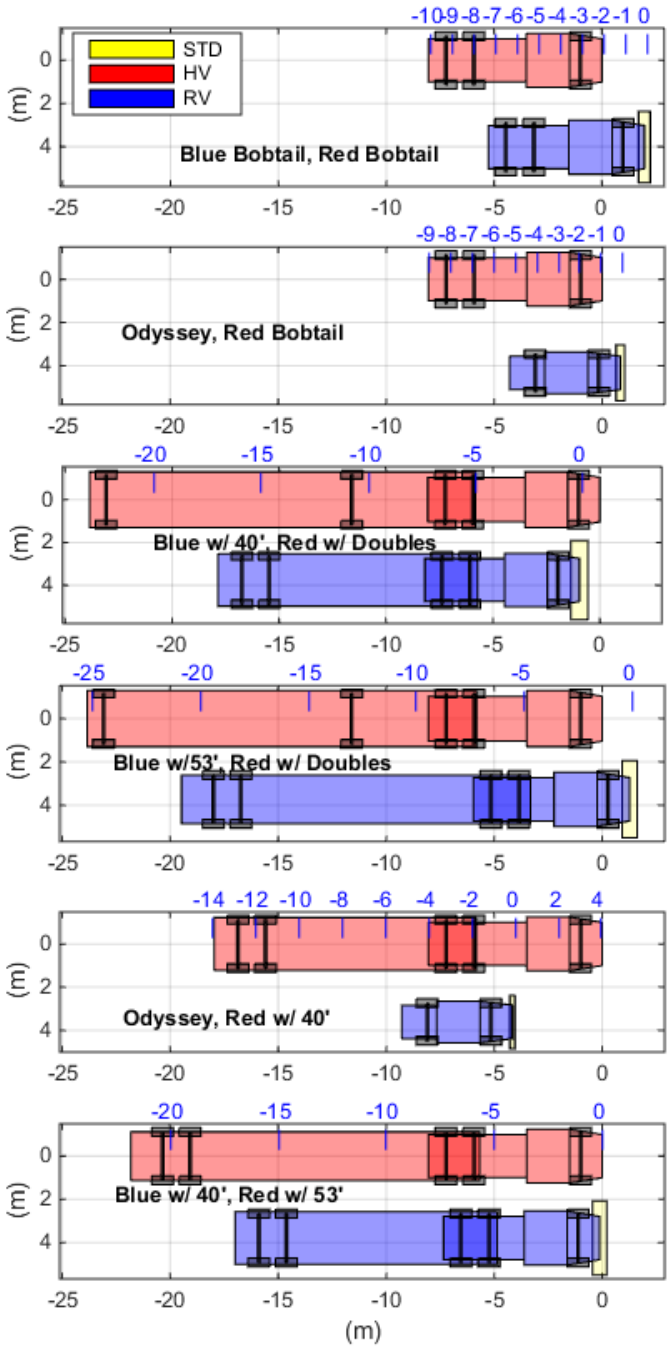


Figure 22: BSW-2 HV and RV Average Relative Position at Alert Offset

5.2.2 LCW-2 Results

The LCW-2 test procedure is essentially the same as the BSW-2 test procedure except tor the LCW-2 test procedure the HV driver used the right turn signal to indicate intent to change lanes. The right turn signal was activated prior to the RV entering the WSU determined blind zone. The LCW-2 test alert summary is shown in Table 12. All combinations had an LCW alert for every test. There were no issues with delayed alert onset or early alert offset for the LCW-2 tests.

Table 12: LCW-2 Test Alert Summary

HV Trailer	RV	RV Trailer	No. of Tests w/ BSW Alerts
Bobtail	Honda Odyssey	-	6 of 6
40' Ship. Cont.		-	7 of 7
Bobtail	Blue Cascadia	Bobtail	5 of 5
53' Box Trailer		40' Ship. Cont.	5 of 5
Double 28'		40' Ship, Cont.	5 of 5
Double 28'		53' Box Trailer	7 of 7

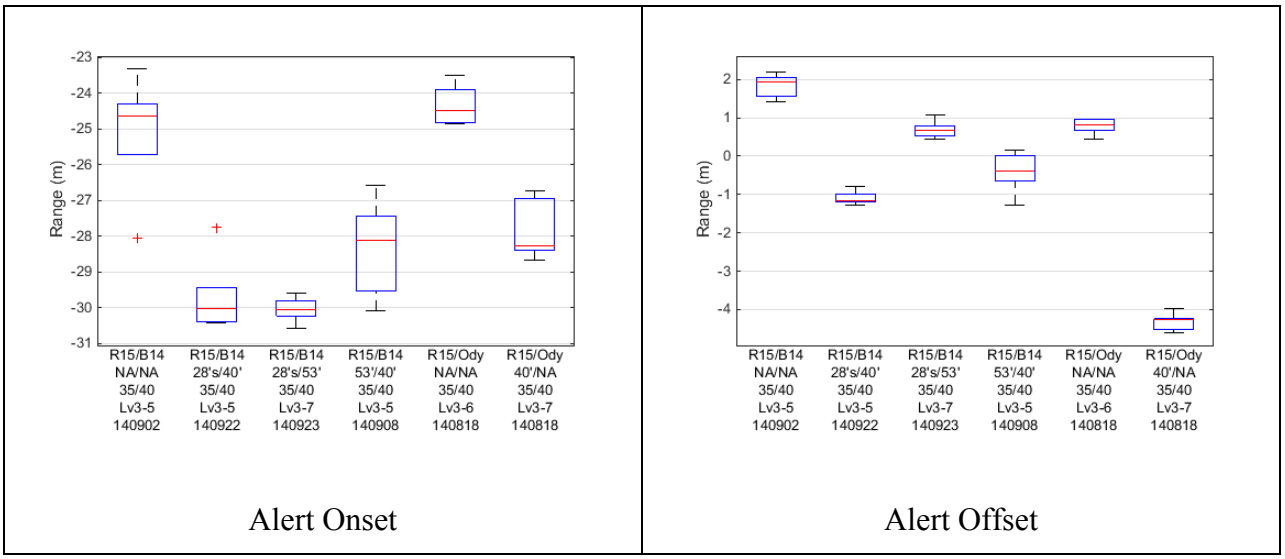
Average and standard deviation of WSU data for the HV to RV ranges at alert onset and offset are shown in Table 13. More complete data for each individual test are presented in Appendix B, Section B.2. WSU, RT, and GPS data are presented in the appendix. The HV front to RV front at onset average values ranged from -24.3 to -30.0 meters with the HV bobtail conditions having lower magnitude values (-24.3 to -25.1 meters) and the HV with trailer conditions having larger values (-27.8 to -30.0 meters). The HV rear to RV front at onset average ranged from -5.9 meters to -17.1 meters (no overlap). The HV front to RV front at offset average values ranged from -4.3 to 1.8 meters. As with the BSW-2 results, the HV with 40' Shipping Container and RV = Honda Odyssey combination average alert offset value shows the alert extinguished when the RV front bumper was much further behind the HV front bumper when compared to the other vehicle combinations.

Table 13: LCW-2 Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Rear to RV Front at Onset (m)		HV Front to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Bobtail	Honda Odyssey	-	-24.3	0.6	-16.3	0.6	0.8	0.2
40' Ship		-	-27.8	0.8	-9.8	0.8	-4.3	0.2
Bobtail	Blue Cascadia	Bobtail	-25.1	1.8	-17.1	1.8	1.8	0.3
53' Box		40' Ship	-28.4	1.4	-6.5	1.4	-0.4	0.6
Doubles		40' Ship	-29.7	1.1	-5.9	1.1	-1.1	0.2
Doubles		53' Box	-30.0	0.3	-6.2	0.3	0.7	0.2

Boxplots for the HV front to RV front range at LCW alert onset and offset are shown in Figure 23. For alert onset (left subplot), the HV with trailer conditions had a greater negative value versus the HV bobtail conditions. As noted earlier, the HV with 40' Shipping Container and RV

= Honda Odyssey combination had a larger negative alert offset value (right subplot) when compared to the other combinations tested.



Alert Onset | Alert Offset

Figure 23: LCW-2 Boxplots of HV Front to RV Front Range at Alert Onset and Offset

Depictions of the HV and RV average relative positions at alert onset and alert offset are shown in Figure 24 and Figure 25 respectively. As was the case with the LCW-1 results, the relative position of the HV and RV in the figures shows that the WSU in the Cascadia trucks sets the blind zone onset for LCW further back than it was for the BSW results shown in the previous section (Figure 21).

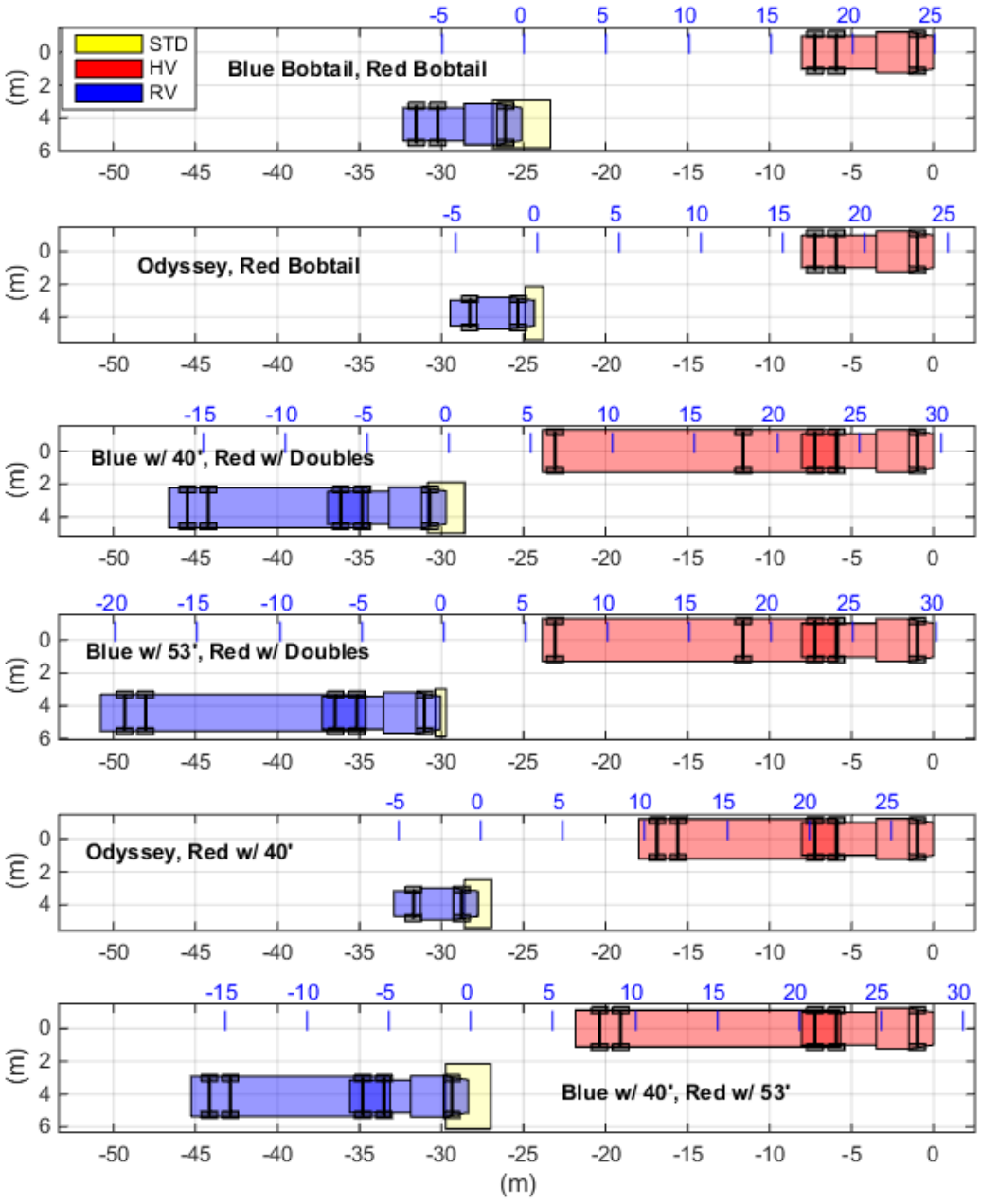


Figure 24: LCW-2 HV and RV Average Relative Position at Alert Onset

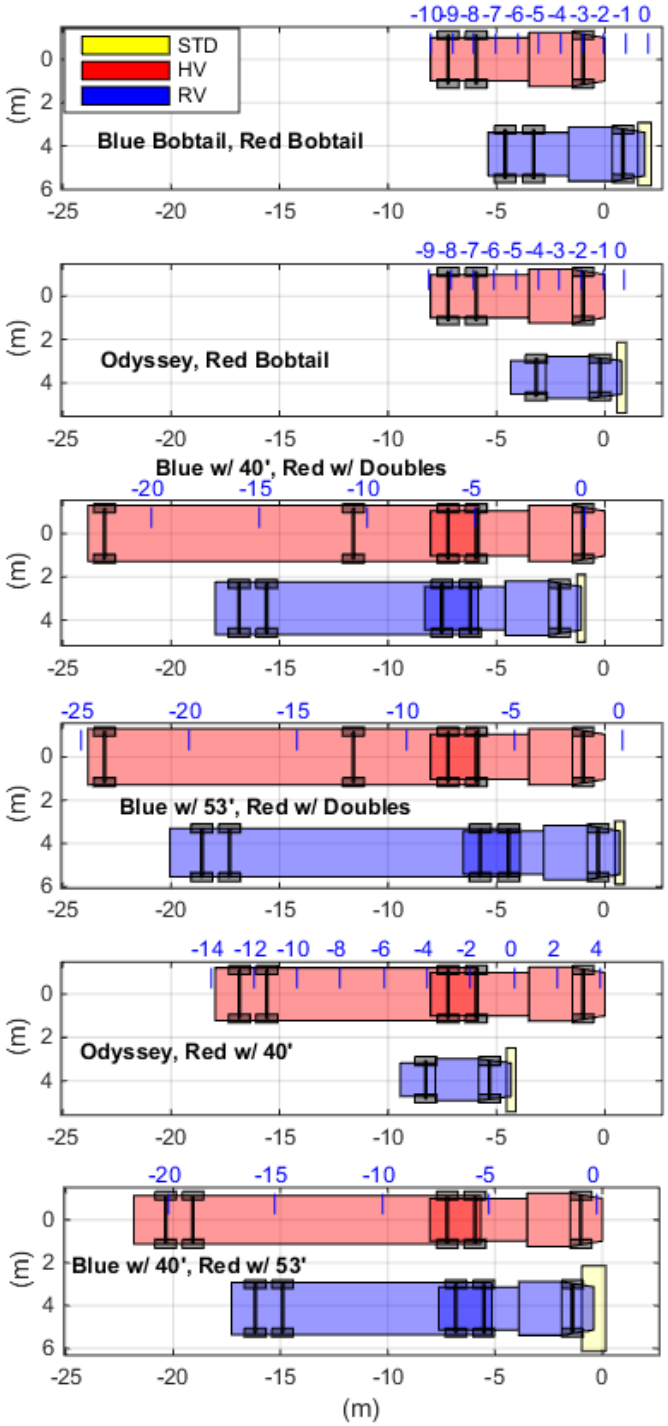


Figure 25: LCW-2 HV and RV Average Relative Position at Alert Offset

5.2.3 BSW to LCW Blind Zone Extension

The TTC for the BSW/LCW blind zone extension determination for each HV/RV combination evaluated for the BSW/LCW-2 test procedures are given in Table 14. The calculated TTC ranged from 5.0 to 5.1 seconds. The WSU data were used to calculate these values. These results are consistent with what was found for the BSW/LCW-1 results.

Table 14: BSW/LCW-2 Blind Zone Extension TTC Determination

HV Trailer	RV	RV Trailer	Avg. Long. Range		Avg. Delta Range (m)	Avg. Delta Speed (mph)	TTC_{ex} (sec)
			TS On	TS Off			
Bobtail	Honda Odyssey	-	-5.9	-16.3	10.4	4.7	5.0
40' Ship. Cont.		-	0.6	-9.8	10.4	4.7	5.0
Bobtail	Blue Cascadia	Bobtail	-5.5	-17.1	11.6	5.2	5.0
53' Box Trailer		40' Ship. Cont.	4.7	-6.5	11.2	5.1	5.0
Double 28'		40' Ship, Cont.	6.1	-5.9	12.0	5.4	5.0
Double 28'		53' Box Trailer	5.9	-6.2	12.1	5.3	5.1

Due to the blind zone extension that occurs when the turn signals are activated. The BSW/LCW-2 test procedure presented in Appendix A, Section A.9 has been modified to allow for both a BSW test and separate LCW test. Methods and calculations for determining the blind zone extension TTC are also now part of the test procedure.

5.3 BSW/LCW-3: HV Passes RV, Straight Road

For the BSW/LCW-3 test procedure, two vehicles travel along a straight roadway in adjacent lanes and in the same direction. While the leading RV travels at a constant velocity, the trailing HV moves at a higher rate of speed than the RV, which leads to the slower RV entering into the BSW/LCW application alert zone on either side of the trailing HV. The subject of this test was to determine the ability of the HV V2V-based BSW/LCW system to identify the vehicle in its blind zone and alert the HV driver of the threat in a timely manner as well as extinguish the alert when the threat has passed. Details for this test procedure can be found in Appendix A, Section A.10. The HV and RV initial speeds were 40 and 35 mph respectively for the tests conducted in this study. As was the case for the BSW/LCW-1 and -2 test procedures, the procedure was run twice: one set of tests with the turn signals off and one set with the turn signals on. Tests were conducted with the RV to the left of the HV and to the right of the HV, but not for every combination evaluated

The HV was the Red Cascadia and the RV was either the Honda Odyssey or Blue Cascadia. The vehicle-trailer combinations evaluated are presented in Table 15. The RV location relative to the HV during testing is also listed (L = Left, R = Right).

Table 15: BSW/LCW-3 Vehicle Combinations Evaluated

HV Trailer	RV	RV Trailer	RV Location
Bobtail	Honda Odyssey	-	L
40’ Shipping Container		-	L
Bobtail	Blue Cascadia	Bobtail	L
53’ Box Trailer		40’ Shipping Container	L & R(only LCW)
Double 28’		40’ Shipping Container	L & R
Double 28’		53’ Box Trailer	L & R

5.3.1 BSW-3 Results

The BSW-3 test alert summary is shown in Table 16. All but one combination had a BSW alert for every test. The HV Bobtail with RV = Honda Odyssey had 6 of 7 tests with BSW alerts.

Table 16: BSW-3 Test Alert Summary

HV Trailer	RV	RV Trailer	No. of Tests w/ BSW Alerts	
			RV on Left	RV on Right
Bobtail	Honda Odyssey	-	6 of 7	-
40’ Ship. Cont.		-	8 of 8	-
Bobtail	Blue Cascadia	Bobtail	5 of 5	-
53’ Box Trailer		40’ Ship. Cont.	7 of 7	-
Double 28’		40’ Ship, Cont.	5 of 5	5 of 5
Double 28’		53’ Box Trailer	5 of 5	5 of 5

The longitudinal and lateral range traces for the test with no BSW alert are shown in Figure 26. For this test the WSU lateral range was greater than 5.5 meters in the time frame when an alert would have been expected (18 to 25 seconds). The RT data shows that the HV and RV were closer laterally than what the WSU data shows. This test should have produced a BSW alert.

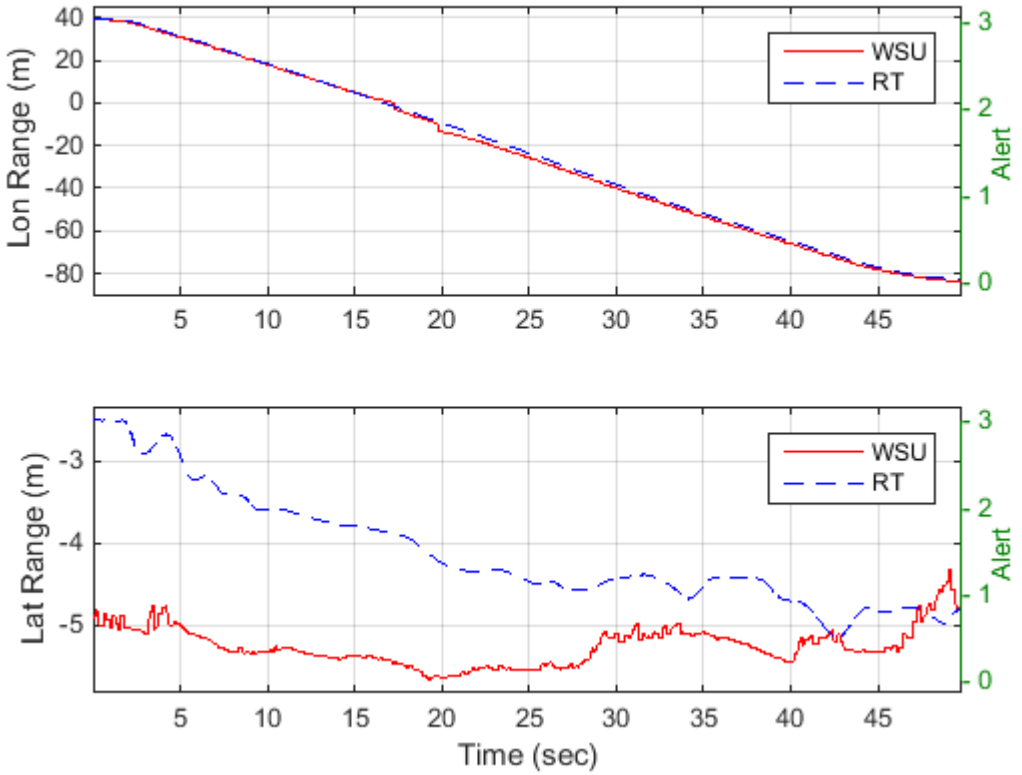


Figure 26: Longitudinal and Lateral Range for Test 774 – No BSW Alert (HV Bobtail With RV = Honda Odyssey)

Average and standard deviation of WSU data for the HV to RV ranges at alert onset and offset are shown in Table 17 for the RV on the Left tests and Table 18 for the RV on the Right tests. HV front bumper to RV front bumper at alert onset, HV front bumper to RV front bumper at alert offset, and HV rear bumper to RV front bumper at alert offset are listed. More complete data for each individual test is presented in Appendix B, Section B.3. WSU, RT, and GPS data are presented in the appendix.

For the RV Left of the HV tests, the HV front to RV front at onset average values ranged from -1.5 to -3.3 meters. The HV front to RV front at alert offset average values ranged from -16.6 to -24.3 meters with the HV bobtail conditions having lower magnitude values (-16.6 to -16.9 meters) and the HV with trailer conditions having larger values (-23.4 to -24.3 meters). The HV rear to RV front at offset ranged from -8.8 meters to 0.0 meters.

For the RV Right of the HV tests, the HV front to RV front at onset average values ranged from -1.8 to -4.0 meters. The HV front to RV front at alert offset average values ranged from -20.0 to -20.2 meters, which is 3 to 4 meters less than what was seen for the RV Left of the HV tests when a trailer was in place (-23.4 to -24.3 meters). The HV rear to RV front at offset ranged from 0.7 to 1.0 meters.

Table 17: BSW-3 RV Left of HV Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset – WSU Data

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Front to RV Front at Offset (m)		HV Rear to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Bobtail	Honda Odyssey	-	-1.8	0.2	-16.9	0.3	-8.8	0.3
40’ Ship		-	-3.3	0.6	-24.3	0.2	-6.4	0.2
Bobtail	Blue Cascadia	Bobtail	-1.5	0.1	-16.6	0.1	-8.5	0.1
53’ Box		40’ Ship	-1.5	0.2	-23.4	0.4	-1.6	0.4
Doubles		40’ Ship	-2.1	0.5	-23.9	0.2	0.0	0.2
Doubles		53’ Box	-2.1	0.0	-23.9	0.4	0.0	0.4

Table 18: BSW-3 RV Right of HV Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset – WSU Data

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Front to RV Front at Offset (m)		HV Rear to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Doubles	Blue Cascadia	40’ Ship	-4.0	0.3	-20.0	0.7	3.8	0.7
Doubles		53’ Box	-1.8	0.1	-20.2	1.0	3.6	1.0

Boxplots for the HV front to RV front range at BSW alert onset and offset are shown in Figure 27 for the RV to the left of the HV and in Figure 28 for the RV to the right of the HV. For the RV to the left of the HV results, there was not a large difference in HV to RV range at alert onset for the various HV and RV trailer conditions (right subplot). For alert offset (right subplot), the HV with trailer conditions had greater negative values versus those for the HV bobtail conditions. For the RV to the right of the HV results, there was a trailer in place for all the tests.

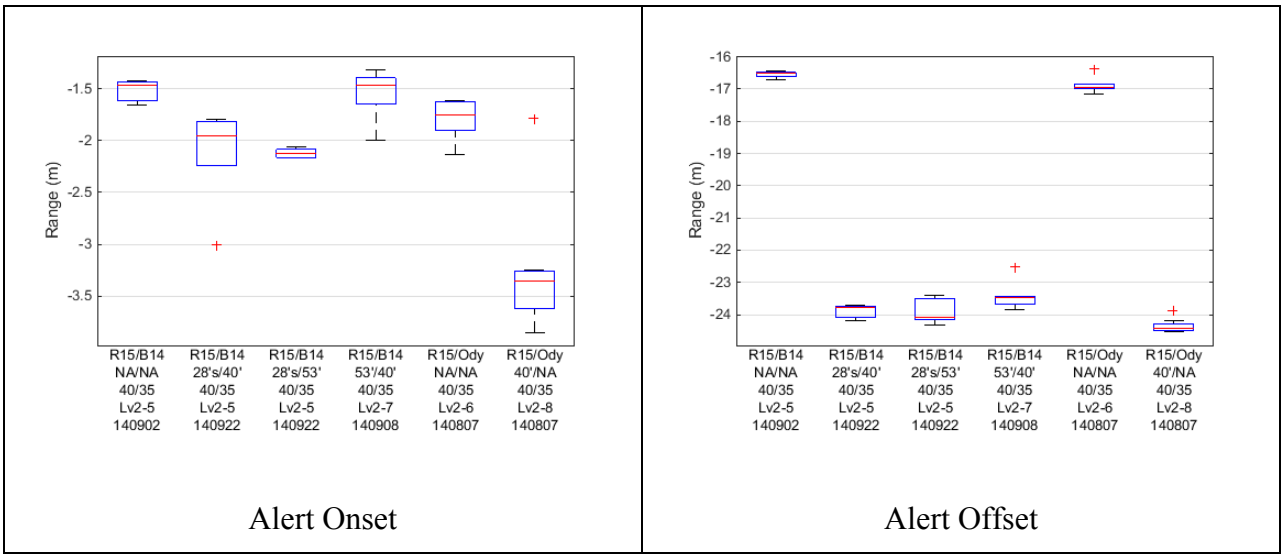


Figure 27: BSW-3 Boxplots of HV Front to RV Front Range at Alert Onset and Offset – RV to Left of HV Results

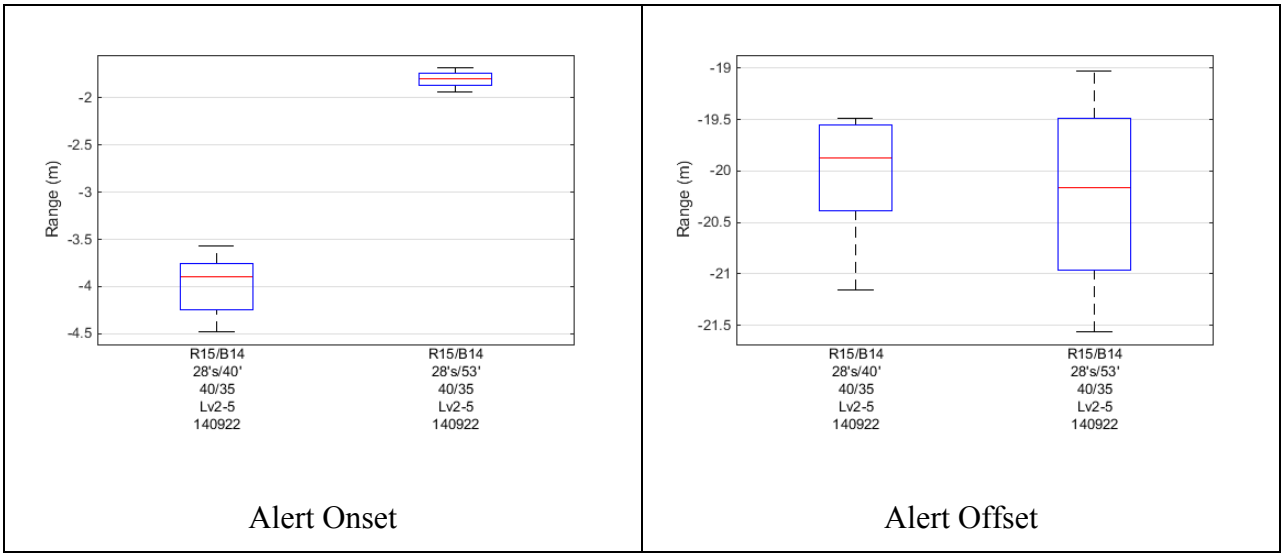


Figure 28: BSW-3 Boxplots of HV Front to RV Front Range at Alert Onset and Offset – RV to Right of HV Results

Depictions of the HV and RV average relative positions at alert onset and alert offset are shown in Figure 29 and Figure 30 respectively for the RV left of HV tests. The HV bobtail conditions are shown in the top two subplots and the HV with trailer conditions are shown in the bottom four subplots. From the results presented in Figure 29, the WSU determined blind zone onset does not appear to change with trailer condition and occurs when the HV is slightly ahead of the RV (HV has started to pass RV). From Figure 30, the relative position of the HV and RV in the figures suggests that the WSU in the Cascadia trucks sets the blind zone offset for BSW at one length for the bobtail condition and another for an attached trailer that does not change with trailer length. Similar data for the RV right of the HV tests are shown in Figure 31 and Figure 32.

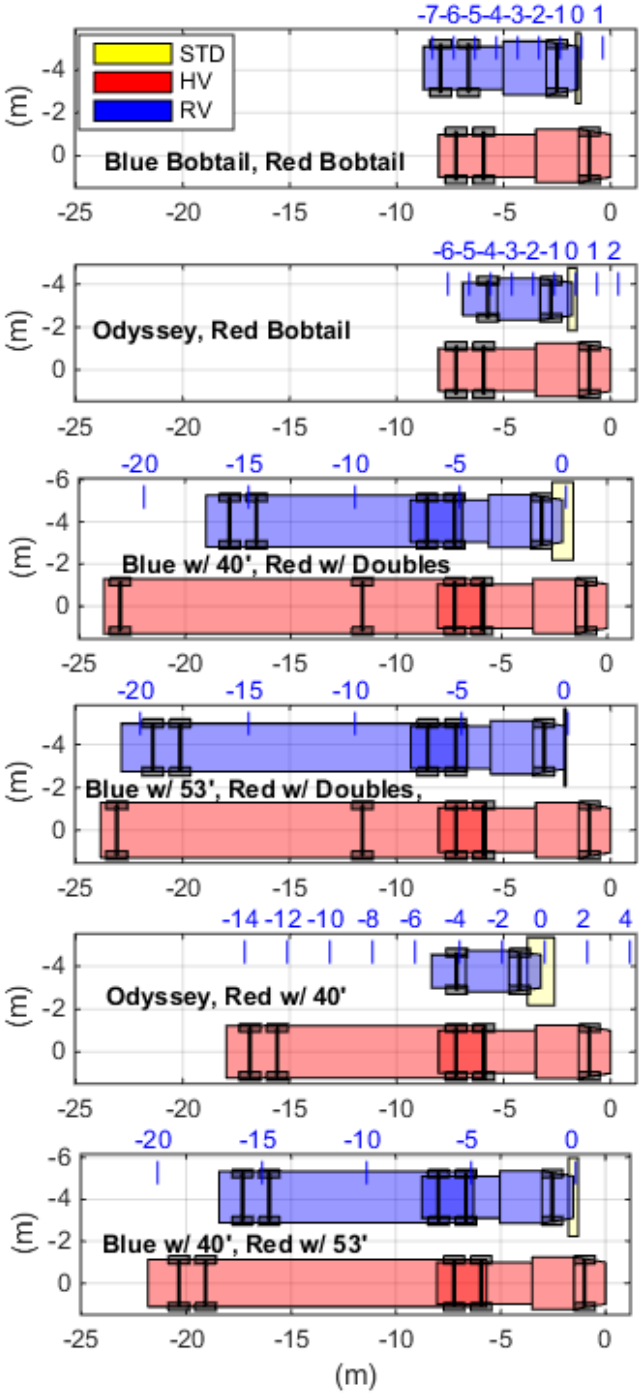


Figure 29: BSW-3 HV and RV Average Relative Position at Alert Onset – RV Left of HV

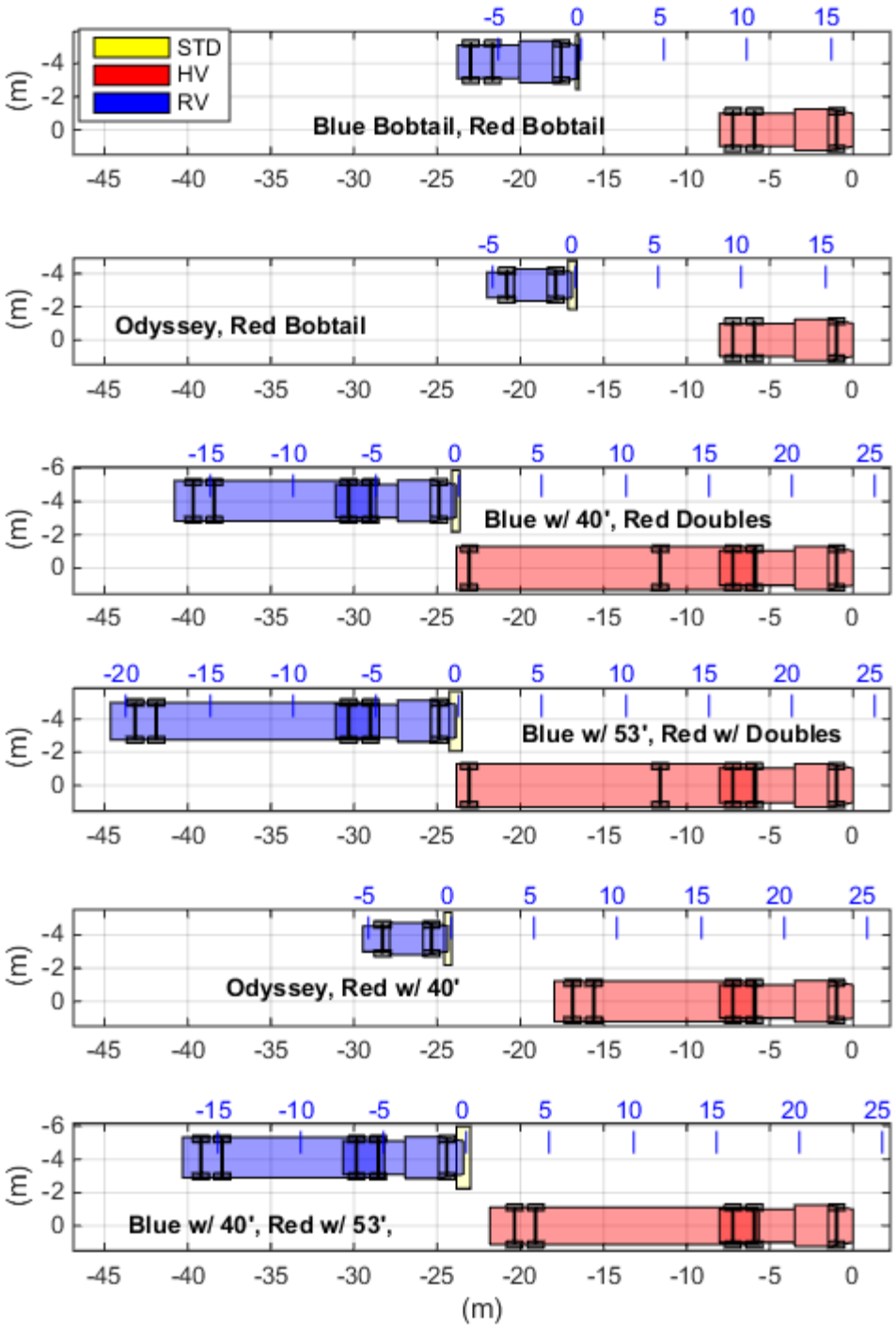


Figure 30: BSW-3 HV and RV Average Relative Position at Alert Offset – RV Left of HV

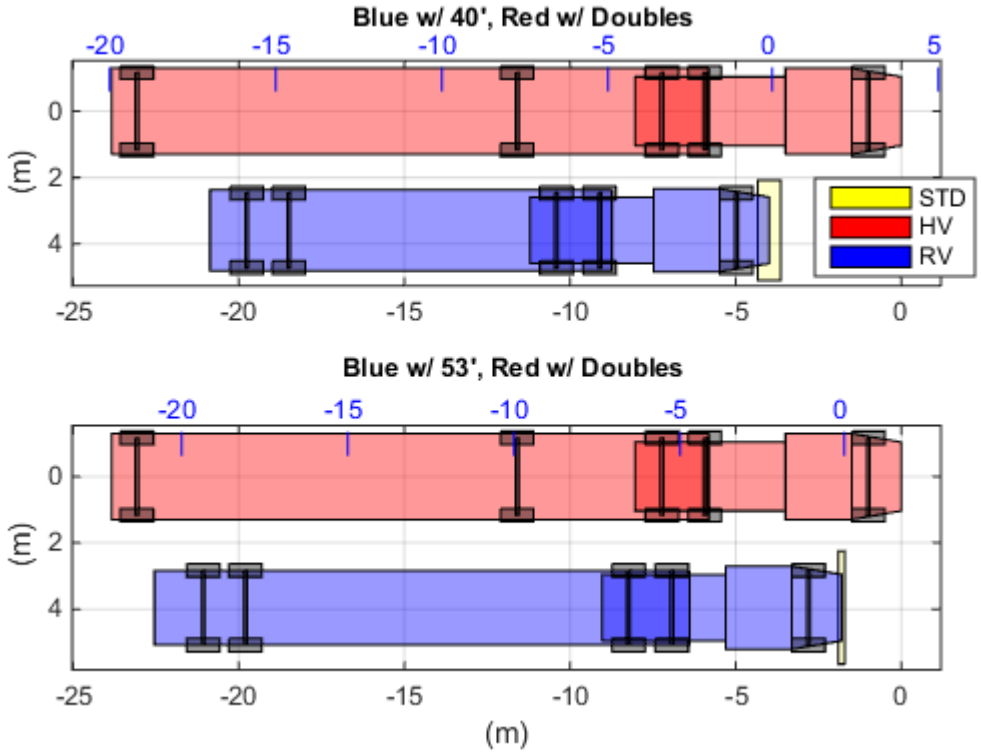


Figure 31: BSW-3 HV and RV Average Relative Position at Alert Onset – RV Right of HV

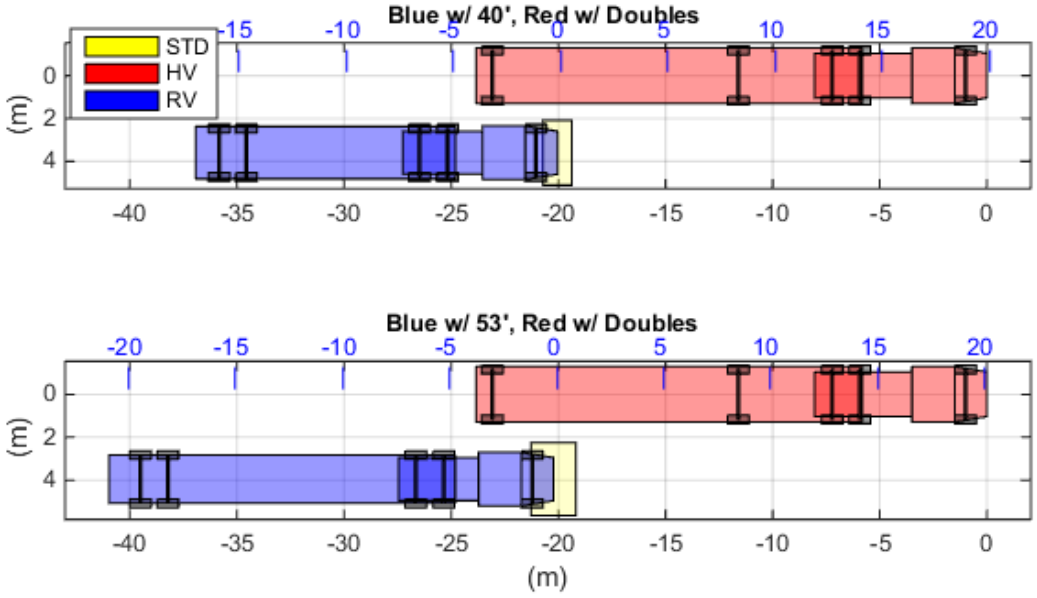


Figure 32: BSW-3 HV and RV Average Relative Position at Alert Offset – RV Right of HV

5.3.2 LCW-3 Results

The LCW-3 test procedure is essentially the same as the BSW-3 test procedure except tor the LCW-3 test procedure the HV driver used the turn signal to indicate intent to change lanes. The turn signal was activated prior to the RV entering the WSU determined blind zone. The LCW-3 test alert summary is shown in Table 19. All vehicle combinations had an LCW alert for every test.

Table 19: LCW-3 Test Alert Summary

HV Trailer	RV	RV Trailer	No. of Tests w/ BSW Alerts	
			RV on Left	RV on Right
Bobtail	Honda Odyssey	-	5 of 5	-
40' Ship. Cont.		-	8 of 8	-
Bobtail	Blue Cascadia	Bobtail	5 of 5	-
53' Box Trailer		40' Ship. Cont.	5 of 5	6 of 6
Double 28'		40' Ship, Cont.	5 of 5	5 of 5
Double 28'		53' Box Trailer	5 of 5	7 of 7

Average and standard deviation of WSU data for HV to RV ranges at alert onset and offset are shown in Table 20 for the RV on the Left tests and Table 21 for the RV on the Right tests. HV front bumper to RV front bumper at alert onset, HV front bumper to RV front bumper at alert offset, and HV rear bumper to RV front bumper at alert offset are listed. More complete data for each individual test are presented in Appendix B, Section B.3. WSU, RT, and GPS data are presented in the appendix.

For the RV Left of the HV tests, the HV front to RV front at onset average values ranged from -1.5 to -4.0 meters. The HV front to RV front at alert offset average values ranged from -15.4 to -24.4 meters with the HV bobtail conditions having lower magnitude values (-15.4 to -16.3 meters) and the HV with trailer conditions having larger values (-23.5 to -24.4 meters). The HV rear to RV front at offset ranged from -8.3 meters to 0.1 meters.

For the RV Right of the HV tests, the HV front to RV front at onset average values ranged from -1.7 to -3.7 meters. The HV front to RV front at alert offset average values ranged from -19.7 to -20.2 meters, which is 3 to 4 meters less than what was seen for the RV Left of the HV tests when a trailer was in place (-23.5 to -24.4 meters). The HV rear to RV front at offset ranged from 2.1 to 4.0 meters.

Table 20: LCW-3 RV Left of HV Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset – WSU Data

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Front to RV Front at Offset (m)		HV Rear to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Bobtail	Honda Odyssey	-	-1.8	0.2	-15.4	3.4	-7.4	3.4
40’ Ship		-	-4.0	1.1	-24.4	0.6	-6.4	0.6
Bobtail	Blue Cascadia	Bobtail	-3.9	5.4	-16.3	0.2	-8.3	0.2
53’ Box		40’ Ship	-1.5	0.1	-23.5	0.3	-1.7	0.3
Doubles		40’ Ship	-1.8	0.1	-23.7	0.4	0.1	0.4
Doubles		53’ Box	-2.1	0.1	-23.7	0.1	0.1	0.1

Table 21: LCW-3 RV Right of HV Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset – WSU Data

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Front to RV Front at Offset (m)		HV Rear to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
53’ Box	Blue Cascadia	40’ Ship	-2.9	0.3	-19.7	0.2	2.1	0.2
Doubles		40’ Ship	-3.7	0.1	-20.2	0.4	3.6	0.4
Doubles		53’ Box	-1.7	0.2	-19.9	1.4	4.0	1.4

The standard deviations for the range values listed in the tables above were generally 0.4 meters or less with some notable exceptions. For the RV Left of HV results, the HV bobtail and RV = Honda Odyssey at alert offset (3.4 meters), the HV with 40’ shipping container and RV = Honda Odyssey at alert onset (1.1 meters), and the HV bobtail and RV = Blue Cascadia bobtail at alert onset (5.4 meters) had high standard deviation values. For the RV Right of HV results, the HV with doubles and the RV = Blue Cascadia with 53’ box trailer at alert offset values also had a high standard deviation (1.4 meters). For each of these sets of tests, there was one test that either had a delayed alert onset or an early alert offset. The most notable case was the test for the HV Bobtail and RV = Blue Cascadia bobtail combination. The longitudinal and lateral ranges for this test (Test 1021) are shown in Figure 33 along with the LCW alert. From the top subplot, the alert onset for this test occurs at approximately -20 meter longitudinal range which corresponds to a -13.5 meter HV Front to RV Front bumper range. The other tests for this vehicle combination had alerts occur at HV Front to RV Front bumper ranges of -1.4 to -1.5 meters. This delayed alert onset occurs due to the WSU determined lateral range being greater than -5.4 meters. From the lower subplot, the alert comes on when the lateral range increases from -5.5 meters to -5.4 meters a little past 38 seconds. The GPS measured lateral range shows the vehicles being 0.5 meters closer (-5 meters) at the time the alert should have occurred. The other combinations listed above with the higher standard deviation values also have a test that had a delayed alert onset or early alert offset due to the WSU determined lateral range being greater than

approximately 5.4 meters for some portion of the test. The GPS and/or RT data shows that the vehicles are within this 5.4 meter range.

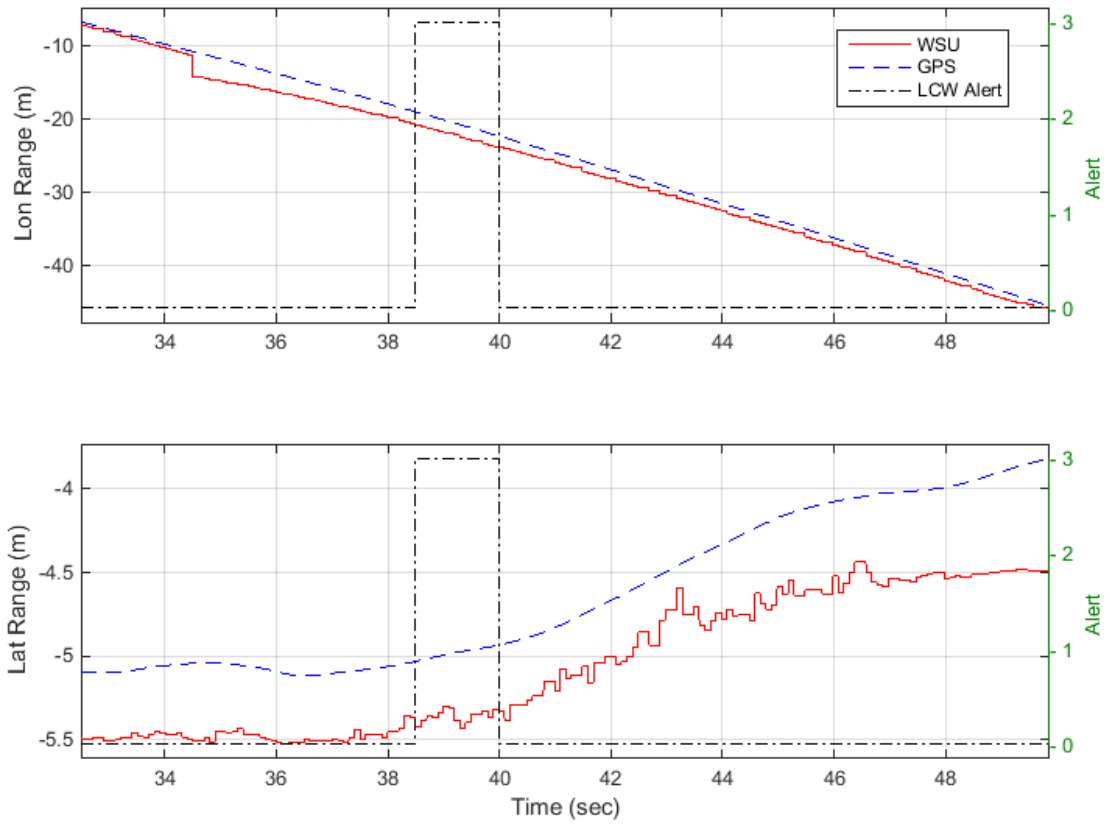


Figure 33: Longitudinal and Lateral Range for Test 1021 - HV = Red Cascadia Bobtail, RV= Blue Cascadia Bobtail

Boxplots for the HV front to RV front range at BSW alert onset and offset are shown in Figure 34 for the RV to the left of the HV results and in Figure 35 for the RV to the right of the HV results. For the RV to the left of the HV results, there was not a large difference in HV to RV range at alert onset for the various HV and RV trailer conditions (left subplot). For alert offset (right subplot), the HV with trailer conditions had greater negative values versus those for the HV bobtail conditions. For the RV to the right of the HV results, there was a trailer in place for all the tests.

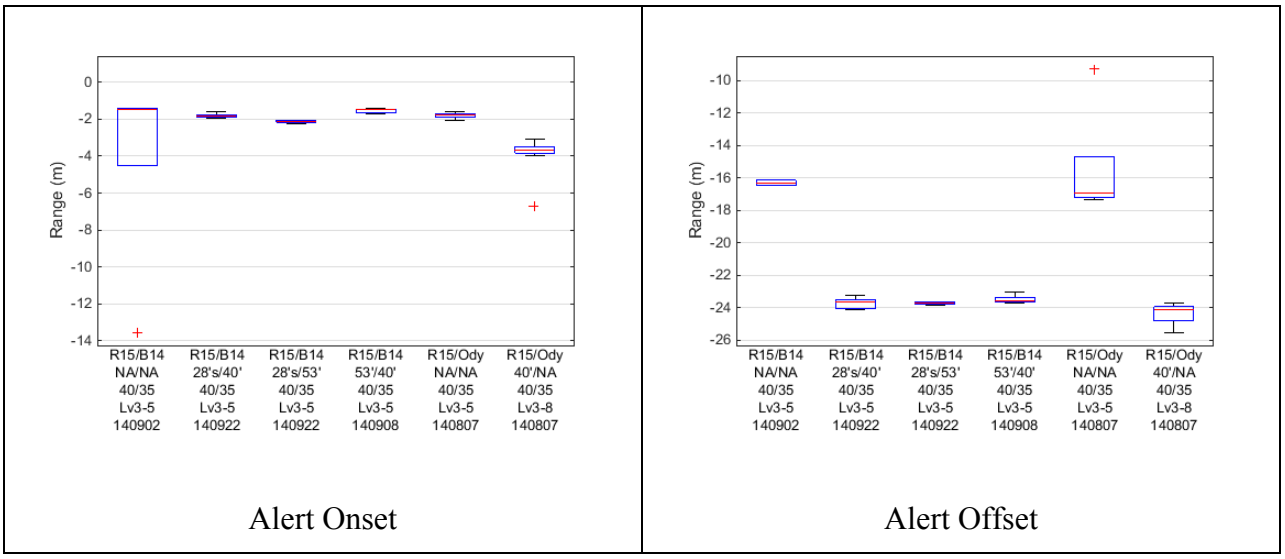


Figure 34: LCW-3 Boxplots of HV Front to RV Front Range at Alert Onset and Offset – RV to Left of HV Results

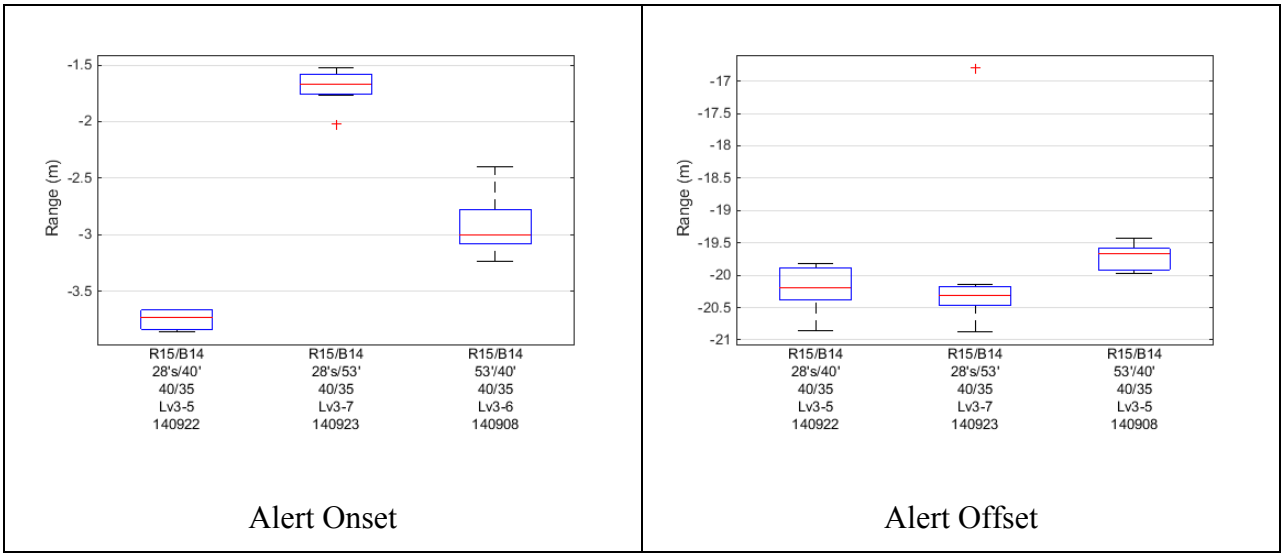


Figure 35: LCW-3 Boxplots of HV Front to RV Front Range at Alert Onset and Offset – RV to Right of HV Results

Depictions of the HV and RV average relative positions at alert onset and alert offset are shown in Figure 36and Figure 37 respectively for the RV left of HV tests. The HV bobtail conditions are shown in the top two subplots and the HV with trailer conditions are shown in the bottom four subplots. From the results presented in Figure 36, the WSU determined blind zone onset does not appear to change with trailer condition and occurs when the HV is slightly ahead of the RV (HV has started to pass RV). From Figure 37, the relative position of the HV and RV in the figures suggests that the WSU in the Cascadia trucks sets the blind zone offset for LCW at one length for the bobtail condition and another for an attached trailer that does not change with trailer length. Similar data for the RV right of the HV tests are shown in Figure 38 and Figure 39.

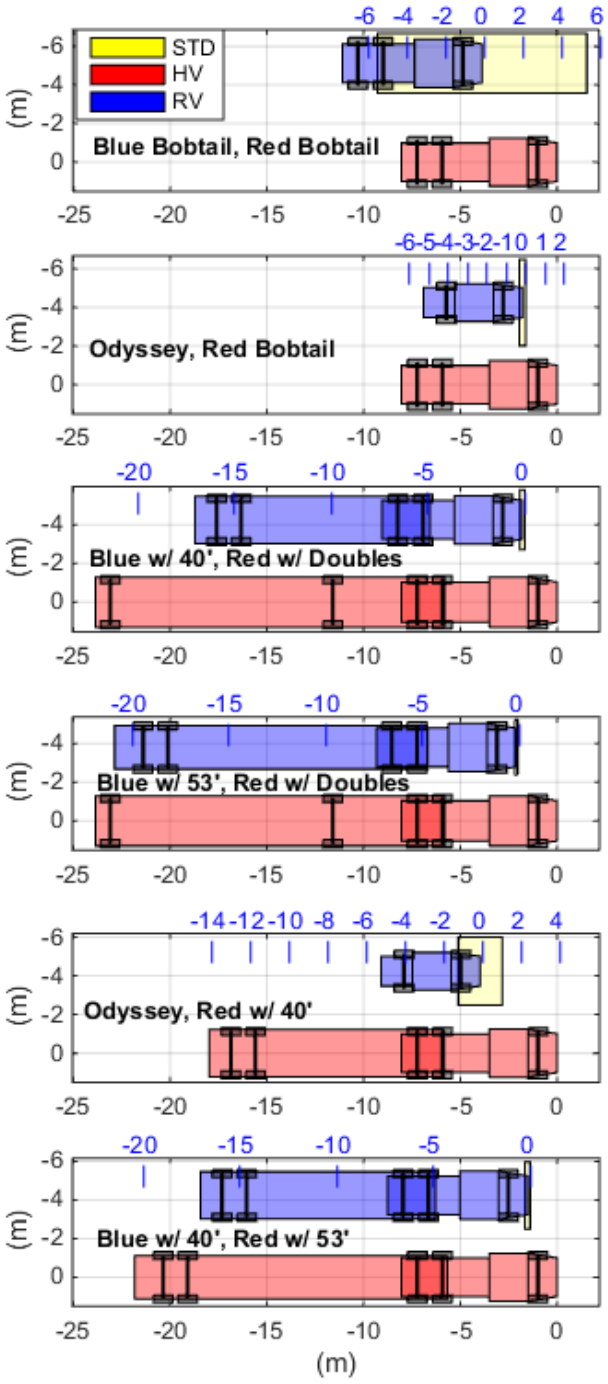


Figure 36: LCW-3 HV and RV Average Relative Position at Alert Onset – RV Left of HV

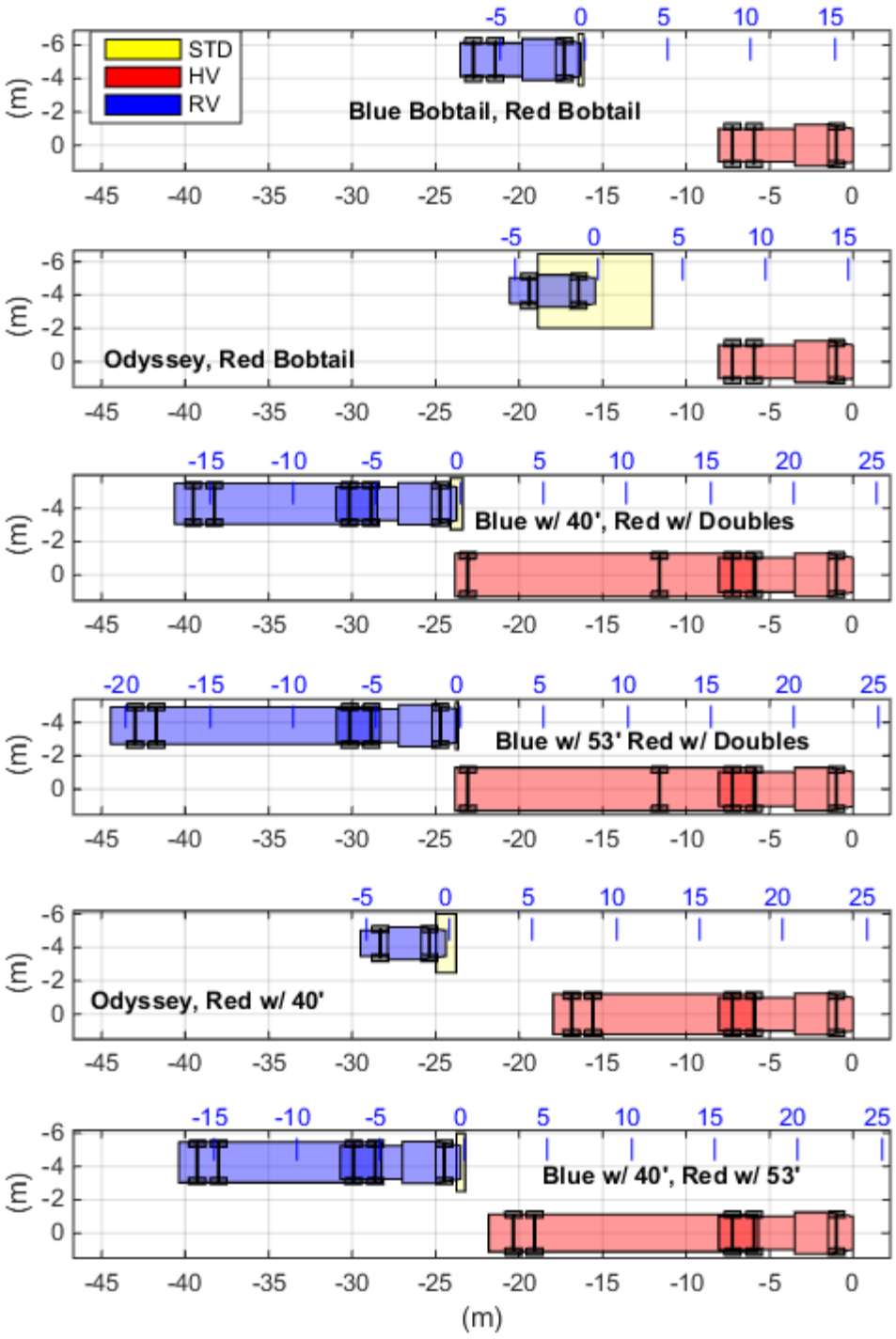


Figure 37: LCW-3 HV and RV Average Relative Position at Alert Offset – RV Left of HV

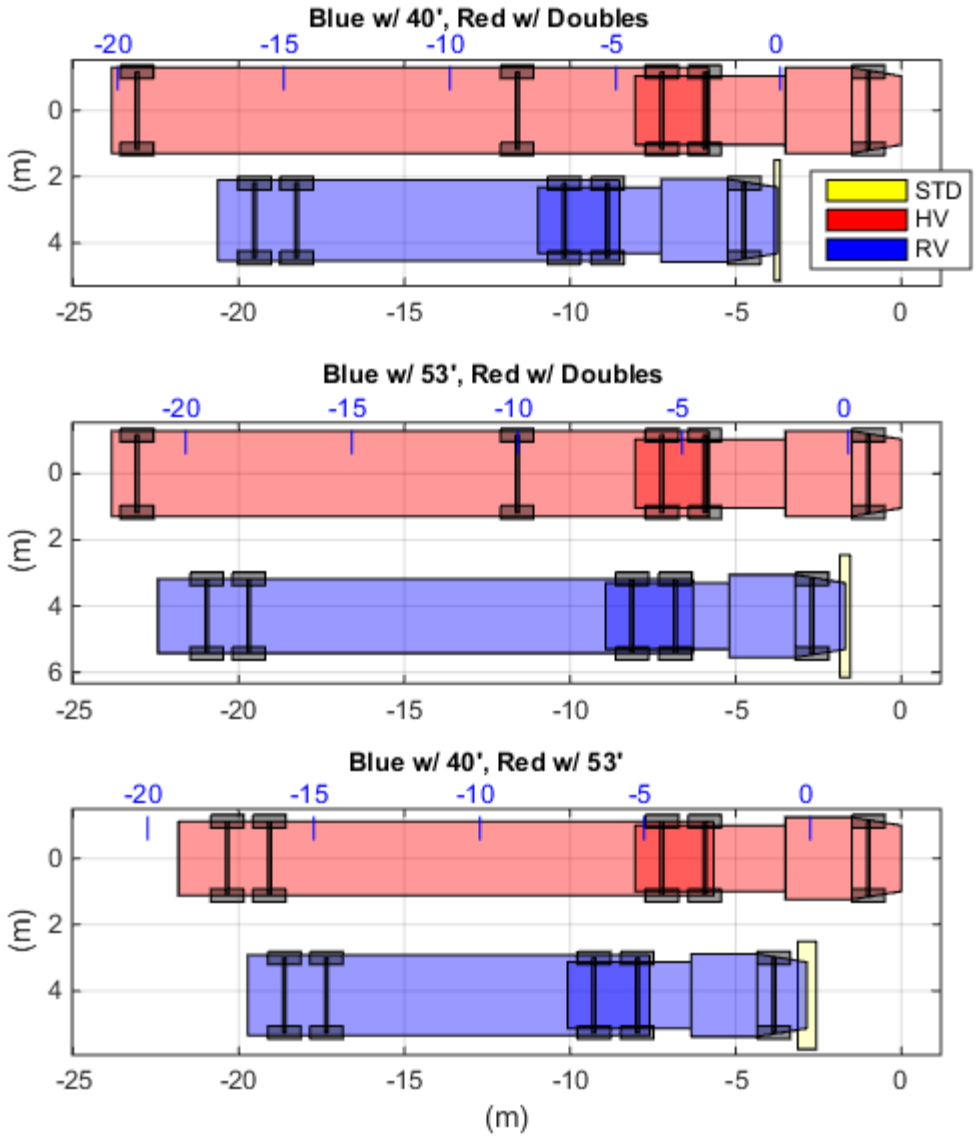


Figure 38: LCW-3 HV and RV Average Relative Position at Alert Onset – RV Right of HV

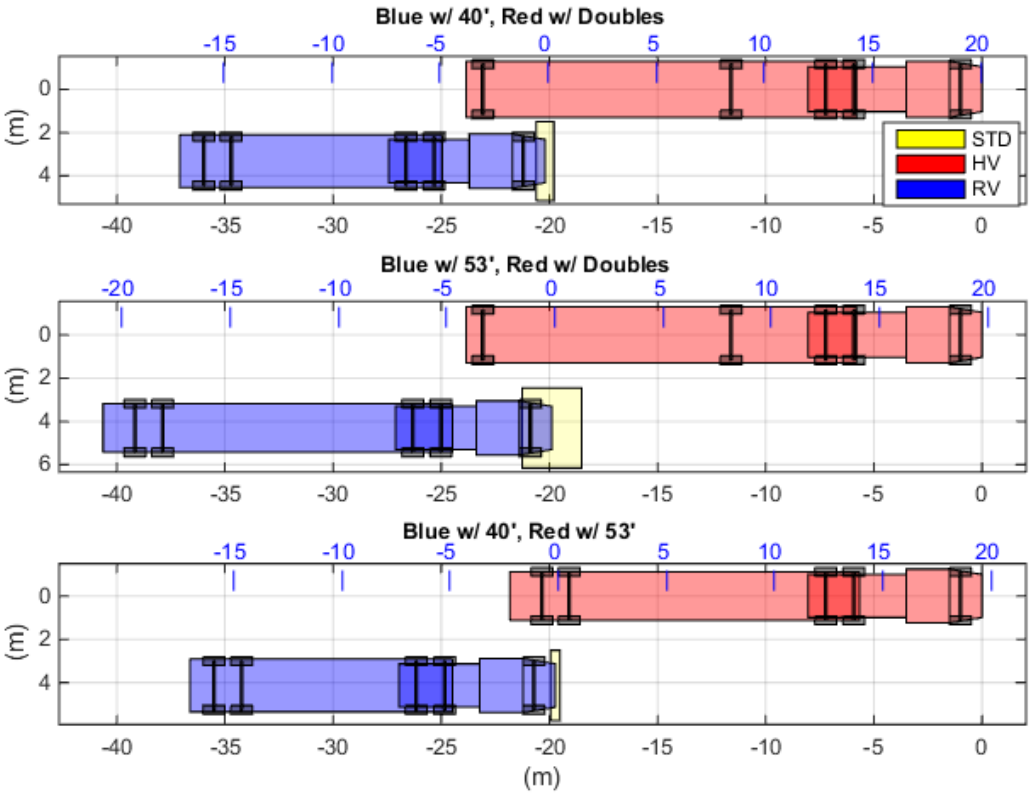


Figure 39: LCW-3 HV and RV Average Relative Position at Alert Offset – RV Right of HV

5.3.3 Comparison of BSW-3 and LCW-3 Results

The BSW/LCW-1 and -2 test procedures produced very different HV Front to RV Front range values for the BSW condition versus the LCW condition due to the Blind Zone Extension of 5 seconds. In those tests the RV is approaching/passing the HV. For the BSW/LCW-3 test procedure the HV is approaching, passing, and then pulling away from the RV and therefore there is no need for a blind zone extension.

The average HV Front to RV front range at alert onset and offset (WSU data) for the BSW-3 and LCW-3 test conditions are listed in Table 22 for each HV/RV combination evaluated. The difference between the BSW and LCW average values were generally 0.3 meters or less. The larger differences for the HV Bobtail, RV = Honda Odyssey at offset (1.5 meters) and the HV Bobtail, RV = Blue Cascadia Bobtail (2.4 meters) are primarily due to one test for each combination that had a delayed alert onset or early alert offset (as discussed in the previous section). If the one early offset LCW test for the HV Bobtail, RV = Honda Odyssey combination was removed, the average value for the LCW results would be -17 meters, which is only 0.1 meter different than the BSW results (-16.9 meters). If the one delayed onset LCW test for the HV Bobtail, RV = Blue Cascadia Bobtail was removed, the average value for the LCW results would be -1.5 meters, which is the same as the BSW results.

Table 22: BSW/LCW-3 Average HV to RV Ranges at Alert Onset and Offset – WSU Data

RV Location	HV Trailer	RV	RV Trailer	Avg. HV Front to RV Front at Onset (m)			Avg. HV Front to RV Front at Offset (m)		
				BSW	LCW	Diff.	BSW	LCW	Diff.
Left	Bobtail	Honda Odyssey	-	-1.8	-1.8	0.0	-16.9	-15.4	1.5
	40’ Ship		-	-3.3	-4.0	0.7	-24.3	-24.4	0.1
	Bobtail	Blue Cascadia	Bobtail	-1.5	-3.9	2.4	-16.6	-16.3	0.3
	53’ Box		40’ Ship	-1.5	-1.5	0.0	-23.4	-23.5	0.1
	Doubles		40’ Ship	-2.1	-1.8	0.3	-23.9	-23.7	0.2
	Doubles		53’ Box	-2.1	-2.1	0.0	-23.9	-23.7	0.2
Right	53’ Box	Blue Cascadia	40’ Ship	-	-2.9	-	-	-19.7	-
	Doubles		40’ Ship	-4.0	-3.7	0.3	-20.0	-20.2	0.2
	Doubles		53’ Box	-1.8	-1.7	0.1	-20.2	-19.9	0.3

These results show that there is no need to run the BSW/LCW-3 test procedure twice (one set with the turn signal on and one set with the turn signal off). Instead the turn signal can simply be turned on and off once the BSW alert is issued to check and see if the alert will switch to an LCW when the HV driver indicates an intention to switch lanes.

5.4 BSW/LCW-4: RVs Pass HV on Left and Right, Straight Road

For the BSW/LCW-4 test procedure, three vehicles travel along a straight roadway in three adjacent lanes and in the same direction, with the vehicle in the center lane (the HV) ahead of the other two. While the leading HV maintains a constant velocity in the center lane, the two trailing RVs travel at a higher velocity in the two outside lanes and enter into the BSW/LCW application’s alert zone on both sides of the HV. Upon notification of a BSW alert with vehicles in both the left and right blind zone, the HV driver cycles the turn signal to the left and then to the right to see if the BSW alert switches to an appropriate left and then right LCW alert due to the turn signal application. Details for this test procedure can be found in Appendix A, Section A.11. The HV and RV initial speeds were 35 and 40 mph respectively for the tests conducted in this study.

One vehicle combination was evaluated: HV = Red Cascadia with 53’ box trailer, RV1 = Mack with 53’ box trailer, and RV2 = Blue Cascadia with 53’ box trailer. Five tests were conducted. The HV received BSW and LCW alerts for 5 of 5 tests from RV1, but only 4 of 5 tests from RV2. Example results for a test with all the appropriate alerts are shown in Figure 40. The longitudinal range is shown in the top subplot along with the BSW (Level 2) and LCW (Level 3) alerts for each RV. Both WSU (solid line) and GPS (dashed line) longitudinal ranges are shown. The lateral ranges are shown in the lower subplot along with the alerts and turn signal (dash-dot green trace). A turn signal to the left is indicated by the lower plateau in the trace and a turn to the right is indicated by the higher plateau. When both the RV1 and RV2 BSW alerts are at

Level 2, the displays shows a BSW alert with an RV on each side of the vehicle. When the turn signals are applied to the left the BSW alert on RV2 goes to an LCW (Level 2 to Level 3) and when the turn signals are applied to the right the BSW alert on RV1 goes to an LCW (Level 2 to Level 3). When the BSW changes to an LCW, the I-Pad display shows an LCW alert on the side of the HV that the turn signal is applied.

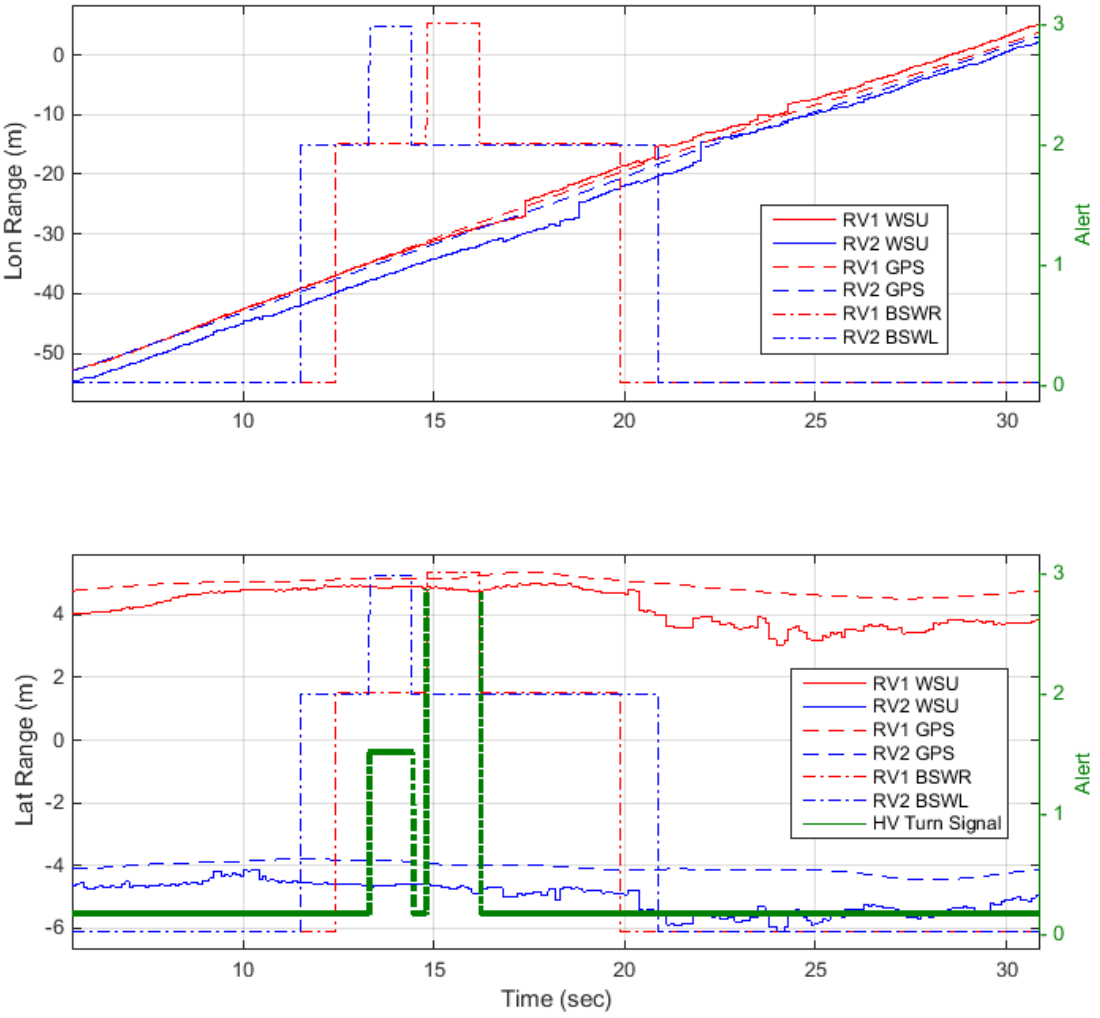


Figure 40: Example BSW/LCW-4 Test Results – Longitudinal and Lateral Range for Test 1667

Results for the test that did not produce alerts from the RV2 are shown in Figure 41 (Test 1669). The HV driver applied the turn signals to the left multiple times to try and get the LCW alert indication from RV2. No alert was obtained from RV2 due to the WSU determined lateral range. From the lower subplot, the RV2 WSU determined lateral range (solid blue trace) was below -5.5 meter for the entire time when the RV2 would be expected to elicit a BSW/LCW alert on the HV. The RV2 GPS determined lateral range was in the -4 to -4.5 meter range during this time frame and therefore the V2V equipment on the HV should have issued alerts for the RV2.

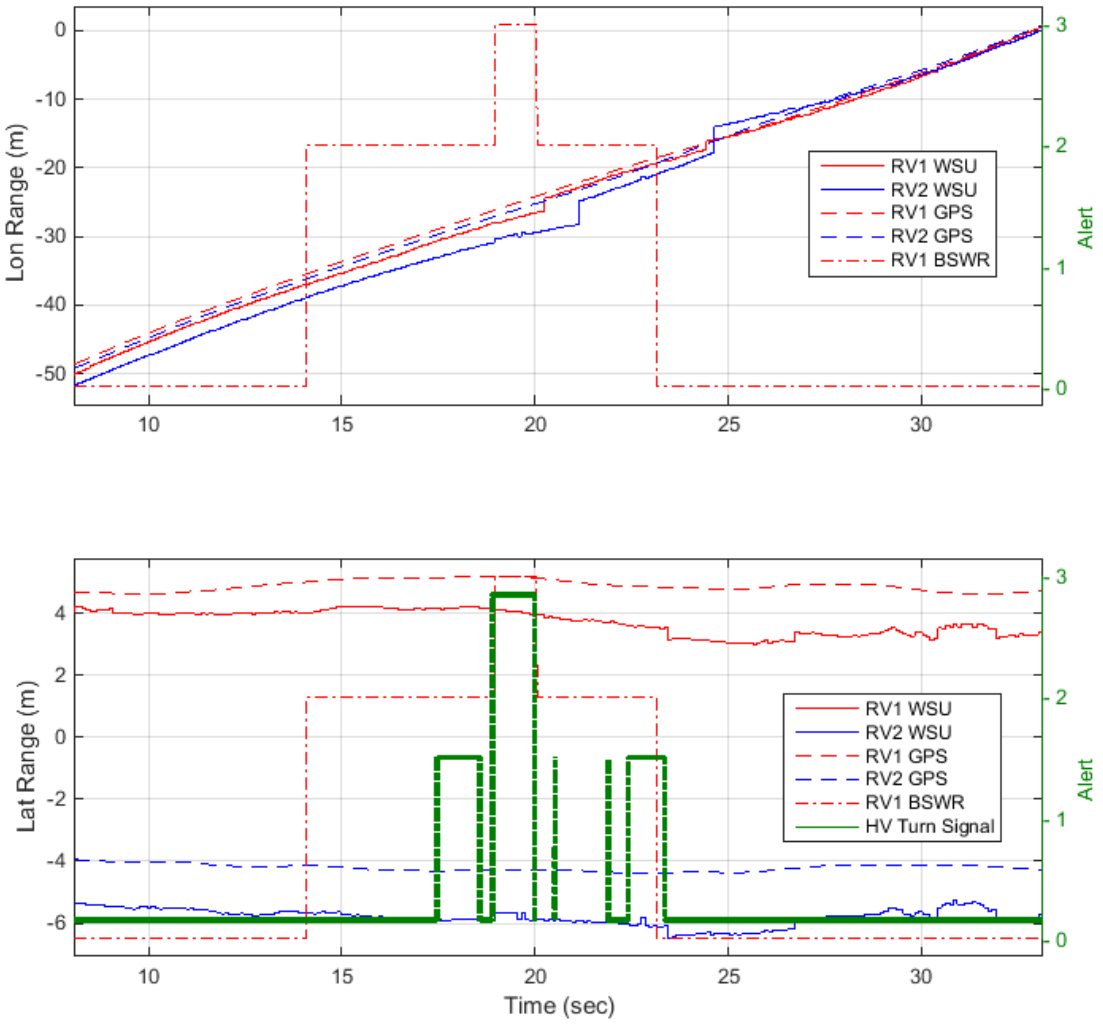


Figure 41: Example BSW/LCW-4 Test Results – Longitudinal and Lateral Range for Test 1669 – No Alerts from RV2

The WSU determined longitudinal ranges between HV and RVs at the RV1 BSW Alert onset and offset are listed in Table 23. Similar values at the RV2 BSW alert onset and offset are given in Table 24. More complete data for each individual test are presented in Appendix B, Section B.4. WSU, RT, and GPS data are presented in the appendix. In Table 23, the HV to RV2 ranges are given to provide an indication of how closely aligned the RVs were with each other as they approached the HV. This is the same reason the RV1 ranges are included in Table 24. The average HV Front to RV1 Front at BSW RV1 onset was -17.0 meters with a standard deviation of 0.1 meters. The average HV Front to RV2 Front at BSW RV2 onset was -21.2 meters with a standard deviation of 0.1 meters. While there is no direct comparison for this set of tractor/trailer combinations to tests conducted for the BSW-1 and BSW-2 maneuvers, these average values are consistent with the BSW-1 (RV on Right) and BSW-2 (RV on Left) average longitudinal range

values when a trailer was present (-17.2 to -17.9 meters for BSW-2 results and -20.7 to -21.4 meters for BSW-1 results).

Table 23: Longitudinal Range Between HV and RVs at RV1 BSW Alert Onset and Offset for HV = Red Cascadia w/ 53' Box, RV1 = Mack w/ 53' Box, RV2 = Blue Cascadia w/ 53' Box

Test No.	HV Front to RV1 Front at Onset (m)	HV Front to RV2 Front at Onset (m)	HV Front to RV1 Front at Offset (m)	HV Front to RV2 Front at Offset (m)
1665	-17.0	-15.7	1.3	2.2
1666	-17.0	-15.4	0.2	1.5
1667	-17.0	-19.0	1.0	-1.7
1668	-17.1	-16.6	1.5	1.9
1669	-17.1	-18.1	0.5	-0.3
Ave.	-17.0	-17.0	0.9	0.7
Std.	0.1	1.6	0.5	1.7

Table 24: Longitudinal Range Between HV and RVs at RV2 BSW Alert Onset and Offset for HV = Red Cascadia w/ 53' Box, RV1 = Mack w/ 53' Box, RV2 = Blue Cascadia w/ 53' Box

Test No.	HV Front to RV1 Front at Onset (m)	HV Front to RV2 Front at Onset (m)	HV Front to RV1 Front at Offset (m)	HV Front to RV2 Front at Offset (m)
1665	-22.3	-21.2	0.0	1.0
1666	-22.8	-21.2	-0.3	1.0
1667	-19.2	-21.1	4.6	0.5
1668	-21.9	-21.1	0.5	1.0
Ave.	-21.5	-21.2	1.2	0.9
Std.	1.6	0.1	2.3	0.3

The average relative position for the HV and RVs at the BSW alert onsets and offsets are shown in Figure 42. The average relative positions at alert onset are shown on the left and at alert offset on the right. The top subplot in each figure is for when the HV V2V equipment determines the alert onset/offset for the BSW for RV1 and the bottom subplot is for when the HV determines the alert onset/offset for the BSW for RV2.

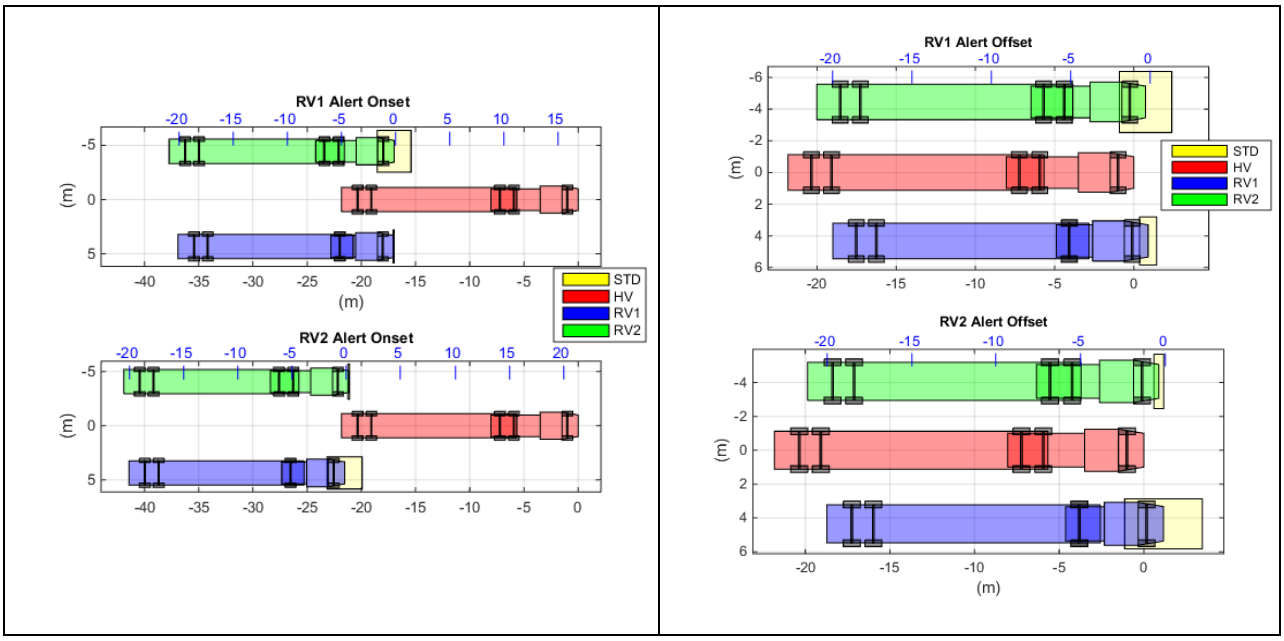


Figure 42: BSW-4 HV and RV Relative Average Positions at BSW Alert Onset and Offset

5.5 BSW/LCW-5: RV Tailgates HV, Straight Road

For the BSW/LCW-5 test procedure, two vehicles travel along a straight roadway in the same lane and in the same direction. While the leading HV maintains a constant velocity, the trailing RV tailgates the HV, which could create a scenario where a false positive BSW/LCW alert may occur. A false positive BSW/LCW alert is a BSW/LCW alert that is given when no imminent crash threat is present. Tailgating could be an imminent crash situation, but not from a BSW/LCW perspective. Tailgating crash situations should be addressed by Forward Collision Warning systems or safety applications. Details for this test procedure can be found in Appendix A, Section A.12.

From the BSW/LCW-1 and -2 results, it was found that there was very little longitudinal range between the HV and the RV when the BSW alerts would occur when the HV was in the bobtail condition and that there was actually some overlap (RV next to HV) of the vehicles when the HV had a trailer attached. It was intended that the BSW/LCW-5 test procedure be evaluated with a trailer in place. Given that the alerts did not occur until there was overlap in the vehicles, this could not be performed as intended. Instead tests were conducted with a "faux" trailer, which was accomplished by simply setting the HV I-Pad display trailer settings to a trailer setting even though no trailer was physically in place (HV run bobtail).

The results of these tests were initially documented in *Commercial Connected Vehicle Test Procedure Development and Test Results – Forward Collision Warning* [12] in the FCW-8 Tailgate section. For the FCW-8 tests, the HV tailgates the RV, so to use the results from these tests for this BSW/LCW-5 test procedure, the RV in the FCW-8 tests is treated as the HV and vice versa.

For the FCW-8 tests, the HV was the Red Cascadia and the RV was the Blue Cascadia and therefore the HV was the Blue Cascadia and the RV was the Red Cascadia for the purposes of examining the results as BSW/LCW-5 tests. The HV trailer combinations evaluated are

presented in Table 25 along with the number of tests for each speed evaluated. As noted above the HV was run 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 RV to get closer to the HV while reducing the chance of contact with the actual trailer.

Table 25: BSW/LCW-5 HV Trailer and HV/RV Speeds Evaluated

HV Trailer	HV and RV Speed	
	25 mph	55 mph
Faux 53'	2 sets of 5	2 sets of 5

The HV V2V equipment did not issue any false positive BSW alerts during the course of testing although as documented in the FCW report, there were false positive FCW alerts on the Red Cascadia and therefore the HV was not driven to the point of "overlap" with the trailer, but the longitudinal ranges between the vehicles were typically as close as 1 to 5 meters.

5.6 BSW/LCW-6: HV and RV Separated by One Lane, Straight Road

For the BSW/LCW-6 test procedure, two vehicles travel along a straight roadway in the same direction, separated by one empty lane. While the leading HV is driven at a constant velocity in the first lane, the trailing RV travels at a higher velocity in the third lane and gradually passes the HV, which produces a scenario where a false positive BSW/LCW alert might occur. The goal of this test is to characterize the ability of the HV's system to determine that the RV was not in the adjacent empty lane. Details for this test procedure can be found in Appendix A, Section A.13. The HV and RV initial speeds were 35 and 40 mph respectively for the tests conducted in this study.

The HV was the Red Cascadia bobtail and the RV was the Blue Cascadia bobtail for the BSW/LCW-6 tests. Five tests were conducted and none of the tests produced a false positive result.

5.7 BSW/LCW-7: RV Passes HV on Right, Curved Road

For the BSW/LCW-7 test procedure, two vehicles travel clockwise along a curved roadway in adjacent lanes and in the same direction. While the leading HV travels at a constant velocity in the left lane, the trailing RV travels faster in the right lane and passes the HV on its right side; therefore, entering into the HV's BSW/LCW application's right side alert zone. The goal of this scenario is to determine the ability of the HV's system to identify the vehicle in its blind zone and alert the HV's driver of the threat in a timely manner as well as extinguish the alert when the threat has passed while both vehicles traversed a curved roadway. Details for this test procedure can be found in Appendix A, Section A.14. The HV and RV initial speeds were 35 and 40 mph respectively for the tests conducted in this study.

The HV was the Red Cascadia and the RV was the Honda Odyssey. The vehicle combinations evaluated are presented in Table 26. Unlike the other test procedures, no tests were conducted with an HV trailer in place. This was an oversite.

Table 26: BSW/LCW-7 Vehicle Combinations Evaluated

HV Trailer	RV	RV Trailer
Bobtail	Honda Odyssey	-

5.7.1 BSW-7 Results

The BSW-2 test alert summary is shown in Table 27. Every test had a BSW alert. There were no issues with delayed alert onset or early alert offset for the BSW-7 tests. As noted previously, no tests were conducted with a trailer in place for this maneuver and therefore issues related to a trailer in place that were seen in other maneuvers have not been evaluated for this maneuver in this phase of testing.

Table 27: BSW-7 Test Alert Summary

HV Trailer	RV	RV Trailer	No. of Tests w/ BSW Alerts
Bobtail	Honda Odyssey	-	5 of 5

Average and standard deviation of WSU data for HV to RV ranges at alert onset and offset are shown in Table 28. More complete data for each individual test are presented in Appendix B, Section B.5. WSU, RT, and GPS data are presented in the appendix. The HV front to RV front at onset average value was -13.9 meters, which is consistent with what was found in the BSW-2 maneuver testing with the HV bobtail conditions having values ranging from -13.5 to -14.0 meters. The HV rear to RV front at onset average value was -5.8 meters. The HV front to RV front at offset average value was 1.2 meters.

Table 28: BSW-7 Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Rear to RV Front at Onset (m)		HV Front to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Bobtail	Honda Odyssey	-	-13.9	0.0	-5.8	0.0	1.2	0.4

5.7.2 LCW-7 Results

The LCW-7 test procedure is essentially the same as the BSW-3 test procedure except tor the LCW-7 test procedure the HV driver used the turn signal to indicate intent to change lanes. The turn signal was activated prior to the RV entering the WSU determined blind zone. The LCW-7 test alert summary is shown in Table 29. Every test had an LCW alert. There were no issues with delayed alert onset or early alert offset for the BSW-7 tests.

Table 29: LCW-7 Test Alert Summary

HV Trailer	RV	RV Trailer	No. of Tests w/ BSW Alerts
Bobtail	Honda Odyssey	-	5 of 5

Average and standard deviation of WSU data for HV to RV ranges at alert onset and offset are shown in Table 30. More complete data for each individual test are presented in Appendix B, Section B.5. The HV front to RV front at onset average value was -25.0, which is consistent with what was found in the LCW-2 maneuver testing with the HV bobtail conditions having values ranging from -24.3 to -25.1 meters. The HV rear to RV front at onset average value was -17.0 meters. The HV front to RV front at offset average value was 1.2 meters, which is the same as the BSW-7 results.

Table 30: LCW-7 Average and Standard Deviation of HV to RV Ranges at Alert Onset and Offset

HV Trailer	RV	RV Trailer	HV Front to RV Front at Onset (m)		HV Rear to RV Front at Onset (m)		HV Front to RV Front at Offset (m)	
			Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
Bobtail	Honda Odyssey	-	-25.0	0.7	-17.0	0.7	1.2	0.3

5.7.3 BSW to LCW Blind Zone Extension

Depictions of the HV and RV average relative positions at alert onset for the BSW-7 and LCW-7 tests are shown in Figure 43. The BSW-7 average relative position is shown in the top subplot and the LCW-7 average relative position is shown in the bottom subplot. The LCW alert occurred much earlier than the BSW alert due to the WSU determined blind zone extension, which is discussed in more detail in Section 5.1.3.

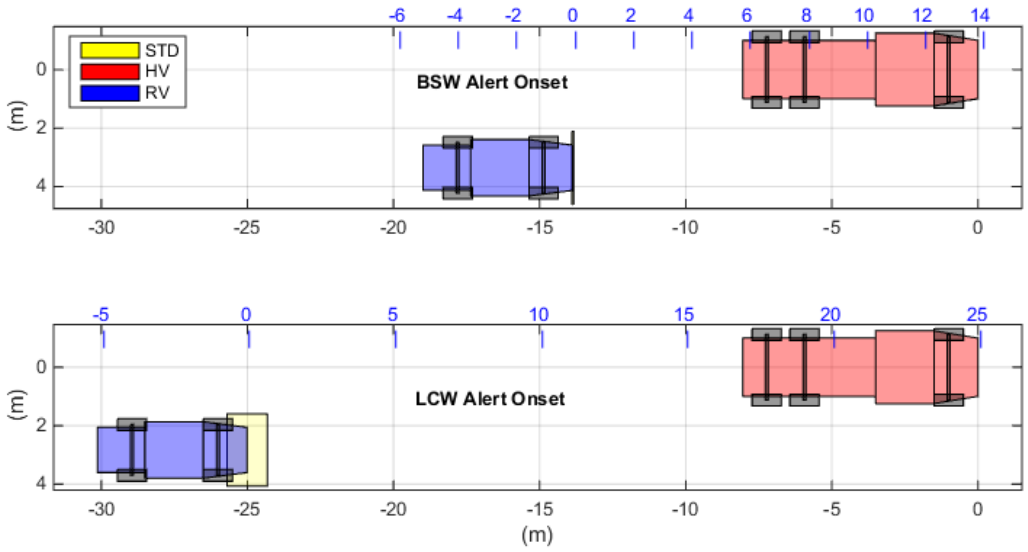


Figure 43: BSW-7 and LCW-7 HV and RV Average Relative Position at Alert Onset

The TTC for the BSW/LCW blind zone extension determination for the BSW/LCW-7 test results is given in Table 31. The calculated TTC was 4.9 seconds. The WSU data were used to calculate these values. These results are consistent with what was found for the BSW/LCW-1 and -2 maneuver results.

Table 31: BSW/LCW-7 Blind Zone Extension TTC Determination

HV Trailer	RV	Avg. Long. Range		Avg. Delta Range (m)	Avg. Delta Speed (mph)	TTC_{BX} (sec)
		TS On	TS Off			
Bobtail	Honda Odyssey	-13.9	-25.0	11.1	5.1	4.9

Due to the blind zone extension that occurs when the turn signals are activated. The BSW/LCW-7 test procedure presented in Appendix A, Section A.14 has been modified to allow for both a BSW test and separate LCW test. Methods and calculations for determining the blind zone extension TTC are also now part of the test procedure.

5.8 BSW/LCW-8: RV Passes Slow Moving HV on Left, Straight Road

For the BSW/LCW-8 test procedure, two vehicles travel along a straight roadway in adjacent lanes and in the same direction. The leading HV travels at a constant velocity in the left lane, but at a rate below the threshold speed of the BSW/LCW application. The trailing RV then passes the HV on the right. A range of test velocities may be specified to characterize the threshold velocity differential below or above which the subject V2V equipment is designed to suppress BSW/LCW alerts. This procedure characterized the HV's threshold speed of the BSW/LCW application. Details for this test procedure can be found in Appendix A, Section A.15.

The HV was the Red Cascadia and the RV was either the Honda Odyssey or Blue Cascadia. The vehicle-trailer combinations evaluated are presented in Table 32. The Odyssey was driven on the right side of the HV and the Cascadia was driven on the left side of the HV.

Table 32: BSW/LCW-8 Vehicle Combinations Evaluated

HV Trailer	RV	RV Trailer
Bobtail	Honda Odyssey	-
Bobtail	Blue Cascadia	Bobtail

The RV speed was set at 35 mph and the HV speed was started at a low value and increased until the HV V2V equipment started to issue BSW alerts. The commanded speed, maximum speed in the Blind Spot Zone, and the speed at alert onset (if there was an alert) are listed in Table 33. The HV V2V equipment started to issue BSW alerts when the HV speed was between 22 and 23 mph.

Table 33: BSW/LCW-8 – Commanded Speed, Maximum Speed, and Speed at Alert Onset

RV	Test No.	BSW Alert	Event Level	Command Speed (mph)		Max. Speed in BSW Range (mph)		Alert Onset		
								Speed (mph)		WSU Lon. Range (m)
				HV	RV	HV	RV	HV	RV	
Odyssey	932	No		10	35	10.0	33.9			
	933	No		15	35	15.0	33.7			
	934	No		20	35	20.0	33.8			
	937	No		22	35	21.9	34.4			
	940	BSW_R	2	23	35	23.0	34.4	23.0	34.2	-20.4
	938	BSW_R	2	23	35	23.1	34.4	23.1	34.3	-19.9
	939	BSW_R	2	23	35	23.5	34.4	23.0	34.3	-20.3
	936	BSW_R	2	25	35	24.8	34.4	24.7	34.3	-20.0
Blue Cascadia	1098	No		15	35	15.1	34.8			
	1099	No		20	35	20.0	34.7			
	1101	No		22	35	22.0	34.8			
	1102	BSW_L	2	23	35	22.9	36.0	22.8	35.9	-22.4
	1103	BSW_L	2	23	35	22.9	34.4	22.7	34.4	-19.7
	1104	BSW_L	2	23	35	23.2	34.4	23.2	34.4	-21.9
	1100	BSW_L	2	25	35	25.3	34.3	24.9	34.2	-22.4

5.9 BSW/LCW-9: HV Passes Slow Moving RV on Left, Straight Road

For the BSW/LCW-9 test procedure, two vehicles travel along a straight roadway in adjacent lanes and in the same direction. The leading RV travels at a constant velocity, but at a rate below the threshold speed of the HV's BSW/LCW application. The trailing HV travels at a higher rate of speed than the leading RV, which causes the leading RV to enter into the HV's BSW/LCW application alert zone on the respective side of the overtaking HV. A range of test velocities may be specified to characterize the threshold velocity differential below or above which the subject V2V equipment is designed to suppress BSW/LCW alerts. This procedure characterized the HV's threshold speed of the BSW/LCW application. Details for this test procedure can be found in Appendix A, Section A.16.

The HV was the Red Cascadia and the RV was either the Honda Odyssey or Blue Cascadia. The vehicle-trailer combinations evaluated are presented in Table 34. The Odyssey and the Blue Cascadia were driven on the right side of the HV.

Table 34: BSW/LCW-9 Vehicle Combinations Evaluated

HV Trailer	RV	RV Trailer
Bobtail	Honda Odyssey	-
Bobtail	Blue Cascadia	Bobtail

The RV speed was set at 35 mph and the HV speed was started at a low value and increased until the HV V2V equipment started to issue BSW alerts. The commanded speed, maximum speed in the Blind Spot Zone, and the speed at alert onset (if there was an alert) are listed in Table 35. The

HV V2V equipment started to issue BSW alerts when the RV speed was near 23 mph. This is consistent with what was found in the BSW/LCW-8 test results for the minimum HV speed.

Table 35: BSW/LCW-9 – Commanded Speed, Maximum Speed, and Speed at Alert Onset

RV	Test No.	BSW Alert	Event Level	Command Speed (mph)		Max. Speed in BSW Range (mph)		Alert Onset		
								Speed (mph)		WSU Lon. Range (m)
				HV	RV	HV	RV	HV	RV	
Odyssey	941			35	10	35.3	12.0			
	942			35	15	34.8	13.9			
	943			35	20	34.8	20.4			
	945			35	22	34.9	22.1			
	946	BSW_R	2	35	23	35.1	23.2	34.8	23.0	-7.6
	944	BSW_R	2	35	25	34.8	24.7	34.5	24.5	-9.3
Blue Cascadia	1105			35	20	35.0	20.1			
	1107			35	22	35.1	22.0			
	1108	BSW_R	2	35	23	34.7	23.3	34.7	23.0	-7.9
	1109	BSW_R	2	35	23	34.8	23.5	34.7	23.1	-6.8
	1106	BSW_R	2	35	25	35.0	24.9	34.6	24.9	-8.1

6 Conclusions and Recommendations

A series of BSW/LCW 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 BSW/LCW threats, but occasionally the equipment would not recognize that a vehicle was in the V2V equipment determined blind spot warning zone due to the systems error in estimating the lateral range between the vehicles.

For tests when the V2V equipment being evaluated is on the vehicle being overtaken, it is important to run BSW/LCW tests with the turn signals off and with the turn signals on prior to the passing vehicle entering the V2V equipment determined blind zone due to the blind zone extension. The blind zone extension occurs when the driver activates the turn signals. The V2V equipment pre-set blind zone used when the turn signals are off is increased based on the closing speed of the approaching vehicle. The blind zone is extended by a time-to-collision value based on the closing speed. The TTC value for the V2V equipment evaluated in this study was approximately 5 seconds. Due to the blind zone extension the BSW/LCW-1, -2, and -7 test procedures presented in Appendix A, have been modified to allow for both a BSW test and separate LCW test. Methods and calculations for determining the blind zone extension TTC are also now part of these test procedures.

For tests when the V2V equipment being evaluated is on a vehicle overtaking another vehicle, it is not important to test with the turn signals on and with the turn signals off prior to the vehicle being passed entering the blind zone because the V2V equipment determined blind zone does not need to be extended on a vehicle overtaking another vehicle. For these types of tests the turn signal can be applied briefly after the V2V equipped vehicle has started to pass the other vehicle

to make sure the V2V equipment changes from a BSW alert to an LCW alert when the turn signals are activated.

The blind zone was different for each side of the vehicle evaluated in this study. It was shorter on the right side than it was on the left side. The blind zone was extended when a trailer was hitched to the tractor, but the blind zone did not extend based on trailer or trailer combination length. Instead a single length was set regardless of trailer or trailer combination length. The blind zone did not generally extend past the end of the trailers. When the turn signals were on, the blind zone extension did increase the blind zone to where it extended past the trailers.

The BSW/LCW test procedures are generally well developed and could be conducted with the V2V equipment evaluated in this study. The blind zone for commercial vehicles/tractor-trailers combinations needs to be further defined. There are several depictions of blind zones for commercial connected vehicles in the literature, but how far the blind zone extends past (or stays within) the length of the vehicle or vehicle combination needs to be addressed. The length of the blind zone directly affects when the BSW and LCW alerts should be issued during the tests conducted in this study.

References

[1] LeBlanc, D., Bogard, S., & Gilbert, M. (2014, January 31). *Connected Commercial Vehicle—Integrated Truck Project: Vehicle build and build test plan* (Final technical Report. Report No. 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

[3] Reed, M., Blower, D. F., & Flannagan, M. J. (2006, May). *Prioritizing improvements to truck driver vision* (Report No. UMTRI-2005–31). Ann Arbor, MI: University of Michigan Transportation Research Institute. Available at https://deepblue.lib.umich.edu/handle/2027.42/83927

[4] Bowman, D., Baker, S., Stone, S., Doerzaph, Z., & Hanowski, R. (2013, May). *Development of performance requirements for commercial vehicle safety applications* (Report No. DOT HS 811 772). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NVS/Crash%20Avoidance/Technical%20Publications/2013/811772.pdf

[5] Maile, M. (2009). *Vehicle Safety Communications – Applications (VSC-A) Project: Crash Scenarios and Safety Applications* (PowerPoint presentation). Available at www.sae.org/events/gim/presentations/2009/michaelmaile.pdf

[6] Ahmed-Zaid, F., Bai, F., Bai, S., Basnayake, C., Bellur, B., Brovold, S., ... & VanSickle, S. (2008, September). *Vehicle safety communications – Applications (VSC-A), First annual report – December 7, 2006 through December 31, 2007* (Report No. DOT HS 811 073). Washington, DC: National Highway Traffic Safety Administration. Available at www.nhtsa.gov/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2008/811073.pdf

[7] F. Ahmed-Zaid et al., *Vehicle Safety Communications – Applications (VSC-A), Final Report - Appendix C-1: Minimum Performance Requirements*, Cooperative Agreement Number DTNH22-05-H-01277, U.S. Department of Transportation, Washington, DC, August 2010.

[8] D. LeBlanc, D. Bezzina, T. Tiernan, K. Freeman, M. Gabel, and D. Pomerleau, *System Performance Guidelines for a Prototype Integrated Vehicle-Based Safety System (IVBSS) – Light Vehicle Platform* Cooperative Agreement Number DTNH22-05-H-01232, U.S. Department of Transportation, Washington, DC, March 2008.

[9] International Standards Organization, *Road Vehicles - Forward Vehicle Collision Warning System - Performance Requirements and Tests Procedures*, ISO/FDIS 15623, 2002.

[10] Bogard, S., & Peredo, G. (2014, January). *Connected Commercial Vehicle Integrated Truck Project: Applications performance and functional test report* (Report No. FHWA-JPO-13-108). Ann Arbor, MI: University of Michigan Transportation Research Institute.

[11] Wells, B., & Berg, R. (2012, January 31). *Connected Commercial Vehicle Retrofit Safety Device (CCV-RSD): Safety applications and development plan draft technical report* (Final Technical Report). Vista, CA: DENSO International America, Inc. Final report published by the Federal Highway Administration , March 28, 2014, as Report No. FWA-JPO-14-106 and available at http://ntl.bts.gov/lib/54000/54500/54590/401_safetyapps.pdf

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

Appendix A – BSW/LCW 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 BSW/LCW procedures.

A.2 Source Documents

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

[1] National Highway Traffic Safety Administration, Office of Vehicle Safety, Office of Crash Avoidance Standards. (2013, February). "Forward Collision Warning System Confirmation Test." 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. Available 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, September 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 packages are the vehicle platform-mounted elements of V2V-based collision avoidance systems. Variants of V2V-based OBE are the integrated safety system, the retrofit safety device, the aftermarket safety device, and the vehicle awareness device.

A.3.2 Integrated Safety System

An ISS is a V2V-based collision warning system that is an integral element of a V2V-equipped production vehicle. An ISS 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 is a V2V-based collision warning system designed for use in commercial vehicles. It is retrofitted to a finished production vehicle. A RSD 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 is a V2V-based collision warning system designed for use in light vehicles. It is retrofitted to a finished production vehicle. An ASD 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 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 is a vehicle that carries the ISS or RSD that is the test subject.

A.4.2 Remote Vehicle

A remote vehicle 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 the experimenter could confirm its operation during each test. The experimenter records both test conditions and test trial notes, and judges apparent test trial validity. The experimenter might also operate the data acquisition system and other test equipment.

The HV driver would be skilled in the operation of the HV. The HV driver would also be familiar with the operation of the collision warning system's driver-vehicle interface 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 BSW/LCW 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 test course is comprised of two or more adjacent lanes. One of the two adjacent lanes will be the primary test lane in which the HV will be driven. The other lane will be used by the RV to pass the HV. The only exceptions to this are the curved road BSW/LCW tests where the roadway is curved instead of straight.

All of the curved roadway tests will be performed in the berm lanes in the South Loop of the Vehicle Dynamics Area at the Transportation Research Center. 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.

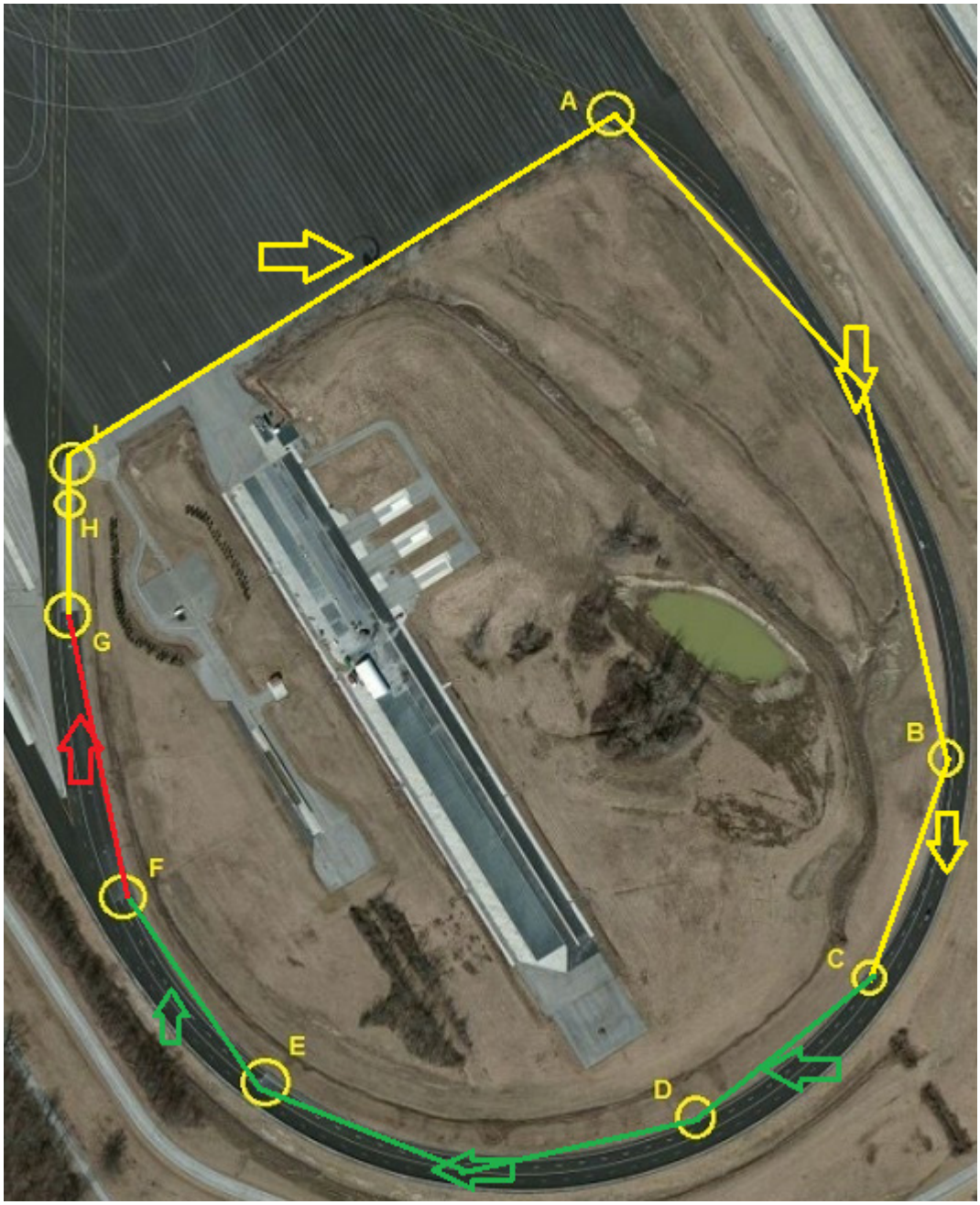


Figure A-1: Curved Road Testing on South Loop Berms Lanes of the Vehicle Dynamics Area at the Transportation Research Center.

A.8 BSW/LCW-1 - RV Passes HV on Left, Straight Road

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

A.8.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in adjacent lanes and in the same direction. The leading vehicle is a commercial truck equipped with a V2V system that features a BSW/LCW application. The trailing vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The trailing vehicle is moving at a higher rate of speed than the leading vehicle and therefore enters into the BSW/LCW application's left side alert zone of the leading vehicle.

A.8.2 Test Subject and Purpose

The subject of this test is the V2V-based BSW/LCW system of the HV. The test determines the ability of the HV's system to identify the vehicle in its blind zone and alert the HV's driver of the threat in a timely manner as well as extinguish the alert when the threat has passed.

A.8.3 Initial Condition

A.8.3.1 Test Velocities

For tests of V2V-based BSW/LCW systems, the velocities of the HV and RV are specified for each trial or set of trials. A minimum velocity differential may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity for each vehicle—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 differential below or above which the subject ISS or RSD is designed to suppress BSW/LCW alerts.

A.8.4 Execution of Procedure

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.

BSW Procedure:

1. The vehicles get into position with the HV in the right lane and the RV in the left lane 5 seconds behind the HV.
2. The vehicles accelerate to their respective test speeds.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds while the RV begins to pass the HV.
5. Once an "Inform Left" alert occurs, the driver of the HV cycles the turn signals. First activating the left turn signal, followed by activating the right turn signal.
6. Each trial ends once the alert extinguishes or the RV completes the pass of the HV to a specified headway.

LCW Procedure:

1. The vehicles get into position with the HV in the right lane and the RV in the left lane 10 seconds behind the HV.
2. The vehicles accelerate to their respective test speeds.

3. Once the vehicles are at speed, the experimenter arms the data acquisition system and the HV driver activates the left turn signal. The turn signal needs to be activated prior to the RV entering the LCW blind zone extension. No alert should occur when the turn signal is initially activated. If an alert does occur, then the HV driver waited too long to activate the turn signal and the test should be repeated.
4. The vehicles then hold their speeds while the RV begins to pass the HV. A "Warning Left" will occur as the RV begins to pass the HV.
5. Each trial ends once the alert extinguishes or the RV completes the pass of the HV to a specified headway.

A.8.5 Trial Validity

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

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

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

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

A BSW trial is successful if the HV OBE initiates a BSW alert when the RV enters the blind zone and extinguishes that alert once the RV is clear of the HV. A trial is unsuccessful if the HV OBE does not initiate a BSW alert when the RV is in the HV's blind zone, or the alert persists after the RV has moved out of the HV's blind zone. When the driver activates the turn signal to the left, the BSW alert should change to an LCW alert and when the turn signal is shut off the alert type should change back to a BSW. When the driver activates the turn signal to the right, the BSW alert should not change to an LCW alert and should remain a BSW alert.

A LCW trial is successful if the HV OBE initiates an LCW alert when the RV enters the blind zone and extinguishes that alert once the RV is clear of the HV. A trial is unsuccessful if the HV OBE does not initiate an LCW alert when the RV is in the HV's blind zone, or the alert persists after the RV has moved out of the HV's blind zone.

If both the BSW and LCW test are performed, the time-to-collision for the BSW/LCW blind zone extension can be calculated as follows:

$$TTC_{EX} = \frac{(S_{TsOn} - S_{TsOff})}{V_{HV} - V_{RV}}$$

Where:

TTC_{EX} ≡ TTC for blind zone extension when turn signal is on

S_{TsOn} ≡ Distance HV Rear to RV Front (range) at warning onset when turn signal is on

S_{TsOff} ≡ Distance HV Rear to RV Front at warning onset when turn signal is off

V_{Hv} ≡ HV Speed

V_{Rv} ≡ RV Speed

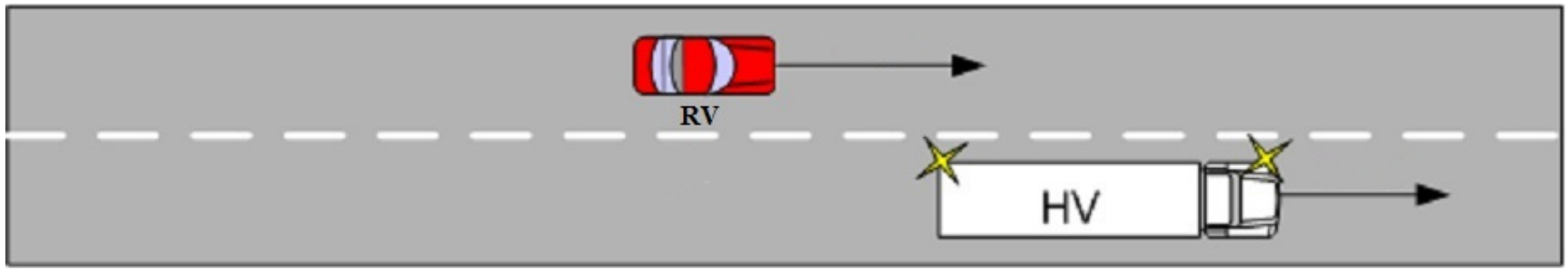


Figure A-2: BSW/LCW-1 Test Course Graphic (not to scale)

A.9 BSW/LCW-2 - RV Passes HV on Right, Straight Road

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

A.9.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in adjacent lanes and in the same direction. The leading vehicle is a commercial truck equipped with a V2V system that features a BSW/LCW application. The trailing vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The trailing vehicle is moving at a higher rate of speed than the leading vehicle and therefore enters into the BSW/LCW application's right side alert zone of the leading vehicle.

A.9.2 Test Subject and Purpose

The subject of this test is the V2V-based BSW/LCW system of the HV. The test determines the ability of the HV's system to identify the vehicle in its blind zone and alert the HV's driver of the threat in a timely manner as well as extinguish the alert when the threat has passed.

A.9.3 Initial Condition

A.9.3.1 Test Velocities

For tests of V2V-based BSW/LCW systems, the velocities of the HV and RV are specified for each trial or set of trials. A minimum velocity differential may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity for each vehicle—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 differential below or above which the subject ISS or RSD is designed to suppress BSW/LCW alerts.

A.9.4 Execution of Procedure

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-3.

BSW Procedure:

1. The vehicles get into position with the HV in the left lane and the RV in the right lane 5 seconds behind the HV.
2. The vehicles accelerate to their respective test speeds.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds while the RV begins to pass the HV.
5. Once an "Inform Right" alert occurs, the driver of the HV cycles the turn signals. First activating the right turn signal, followed by activating the left turn signal.

6. Each trial ends once the alert extinguishes or the RV completes the pass of the HV to a specified headway.

LCW Procedure:

1. The vehicles get into position with the HV in the left lane and the RV in the right lane 10 seconds behind the HV.
2. The vehicles accelerate to their respective test speeds.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system and the HV driver activates the right turn signal. The turn signal needs to be activated prior to the RV entering the LCW blind zone extension. No alert should occur when the turn signal is initially activated. If an alert does occur, then the HV driver waited too long to activate the turn signal and the test should be repeated.
4. The vehicles then hold their speeds while the RV begins to pass the HV. A "Warning Right" will occur as the RV begins to pass the HV.
5. Each trial ends once the alert extinguishes or the RV completes the pass of the HV to a specified headway.

A.9.5 Trial Validity

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

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

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

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

A BSW trial is successful if the HV OBE initiates a BSW alert when the RV enters the blind zone and extinguishes that alert once the RV is clear of the HV. A trial is unsuccessful if the HV OBE does not initiate a BSW alert when the RV is in the HV's blind zone, or the alert persists after the RV has moved out of the HV's blind zone. When the driver activates the turn signal to the right, the BSW alert should change to an LCW alert and when the turn signal is shut off the alert type should change back to a BSW. When the driver activates the turn signal to the left, the BSW alert should not change to an LCW alert and should remain a BSW alert.

A LCW trial is successful if the HV OBE initiates an LCW alert when the RV enters the blind zone and extinguishes that alert once the RV is clear of the HV. A trial is unsuccessful if the HV OBE does not initiate an LCW alert when the RV is in the HV's blind zone, or the alert persists after the RV has moved out of the HV's blind zone.

If both the BSW and LCW test are performed, the time-to-collision for the BSW/LCW blind zone extension can be calculated as follows:

$$TTC_{ex} = \frac{(S_{TsOn} - S_{TsOff})}{V_{Hv} - V_{Rv}}$$

Where:

TTC_{ex} ≡ TTC for blind zone extension when turn signal is on

S_{TsOn} ≡ Distance HV Rear to RV Front (range) at warning onset when turn signal is on

S_{TsOff} ≡ Distance HV Rear to RV Front at warning onset when turn signal is off

V_{Hv} ≡ HV Speed

V_{Rv} ≡ RV Speed

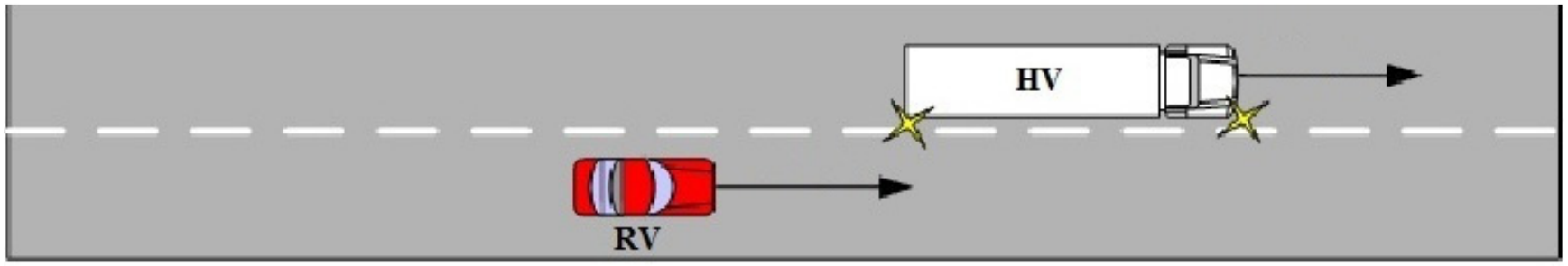


Figure A-3: BSW/LCW-2 Test Course Graphic (not to scale)

A.10 BSW/LCW-3 - HV Passes RV, Straight Road

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

A.10.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in adjacent lanes and in the same direction. The leading vehicle is a light vehicle or commercial truck equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The trailing vehicle is a commercial vehicle equipped with a V2V system that features a BSW/LCW application. The trailing vehicle is moving at a higher rate of speed than the leading vehicle and therefore causes the leading vehicle to enter into the BSW/LCW application's alert zone on either side of the trailing vehicle.

A.10.2 Test Subject and Purpose

The subject of this test is the V2V-based BSW/LCW system of the HV. The test determines the ability of the HV's system to identify the vehicle in its blind zone and alert the HV's driver of the threat in a timely manner as well as extinguish the alert when the threat has passed.

A.10.3 Initial Condition

A.10.3.1 Test Velocities

For tests of V2V-based BSW/LCW systems, the velocities of the HV and RV are specified for each trial or set of trials. A minimum velocity differential may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity for each vehicle—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 differential below or above which the subject ISS or RSD is designed to suppress BSW/LCW alerts.

A.10.4 Execution of Procedure

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-4.

1. The vehicles get into position with the RV initially in the left lane and the HV initially in the right lane some distance behind the RV.
2. The vehicles accelerate to their respective test speeds.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds while the HV begins to pass the RV.
5. Once an "Inform" alert occurs, the driver of the HV cycles the turn signals. First activating the left turn signal, followed by activating the right turn signal.

6. Each trial ends once the alert extinguishes or the HV completes the pass of the RV to a specified headway.
7. The procedure is then repeated with the RV in the right lane and the HV in the left lane.

A.10.5 Trial Validity

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

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

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

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

A trial is successful if the HV OBE initiates a BSW alert when the RV enters the blind zone and extinguishes that alert once the RV is clear of the HV. A trial is unsuccessful if the HV OBE does not initiate a BSW alert when the RV is in the HV's blind zone, or the alert persists after the RV has moved out of the HV's blind zone. When the driver activates the turn signal to the left, the BSW alert should change to an LCW alert and when the turn signal is shut off the alert type should change back to a BSW. When the driver activates the turn signal to the right, the BSW alert should not change to an LCW alert and should remain a BSW alert.

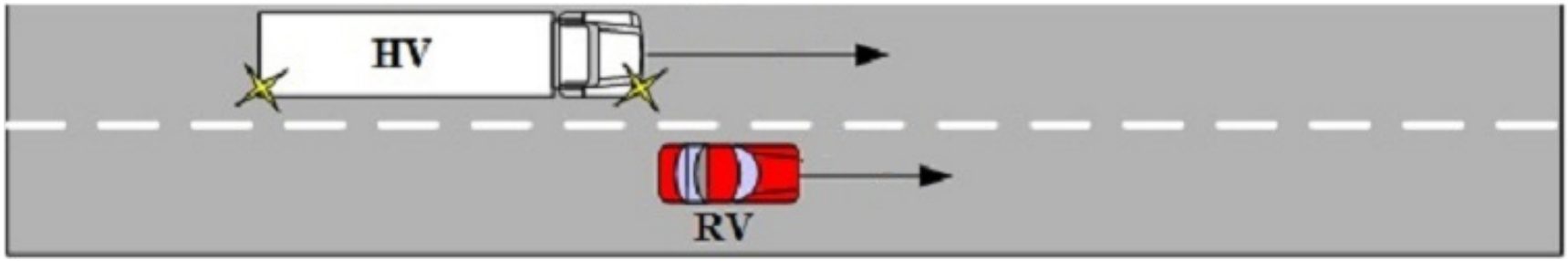


Figure A-4: BSW/LCW-3 Test Course Graphic (not to scale)

A.11 BSW/LCW-4 - RVs Pass HV on Left and Right, Straight Road

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

A.11.1 Pre-Crash Scenario

Three vehicles travel along a straight roadway in adjacent lanes and in the same direction with one vehicle ahead of the two others. The leading vehicle is a commercial truck equipped with a V2V system that features a BSW/LCW application. The trailing vehicles are equipped with V2V systems that broadcast their position, speed, direction of travel, and path history. The trialing vehicles are moving at a higher rate of speed then the leading vehicle and therefore enter into the BSW/LCW application's alert zone on both sides of the leading vehicle.

A.11.2 Test Subject and Purpose

The subject of this test is the V2V-based BSW/LCW system of the HV. The test determines the ability of the HV's system to identify vehicles in both of its blind zones simultaneously and alert the HV's driver of the threats in a timely manner as well as extinguish the alerts when the threats have passed.

A.11.3 Initial Condition

A.11.3.1 Test Velocities

For tests of V2V-based BSW/LCW systems, the velocities of the HV and RV are specified for each trial or set of trials. A minimum velocity differential may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity for each vehicle—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 differential below or above which the subject ISS or RSD is designed to suppress BSW/LCW alerts.

A.11.4 Execution of Procedure

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-5.

1. The vehicles get into position with the HV in the center lane and the RVs in the left and right lanes respectively.
2. The vehicles accelerate to their respective test speeds.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds while the RVs begin to pass the HV.
5. Once an "Inform" alert occurs, the driver of the HV cycles the turn signals. First activating the left turn signal, followed by activating the right turn signal.

6. Each trial ends once the alerts extinguish or the RVs complete their pass of the HV to a specified headway.

A.11.5 Trial Validity

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

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

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

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

A trial is successful if the HV OBE initiates a BSW both sides alert when the RVs enter the blind zone and extinguishes that alert once the RVs are clear of the HV. A trial is unsuccessful if the HV OBE does not initiate a BSW both sides alert when the RVs are in the HV's blind zone, or the alert persists after the RVs have moved out of the HV's blind zone. When the driver activates the turn signal to the left, the BSW alert should change to an LCW left side alert. When the driver activates the turn signal to the right, the BSW alert should change to an LCW right side alert. When the turn signal is shut off the alert type should change back to a BSW both sides alert.

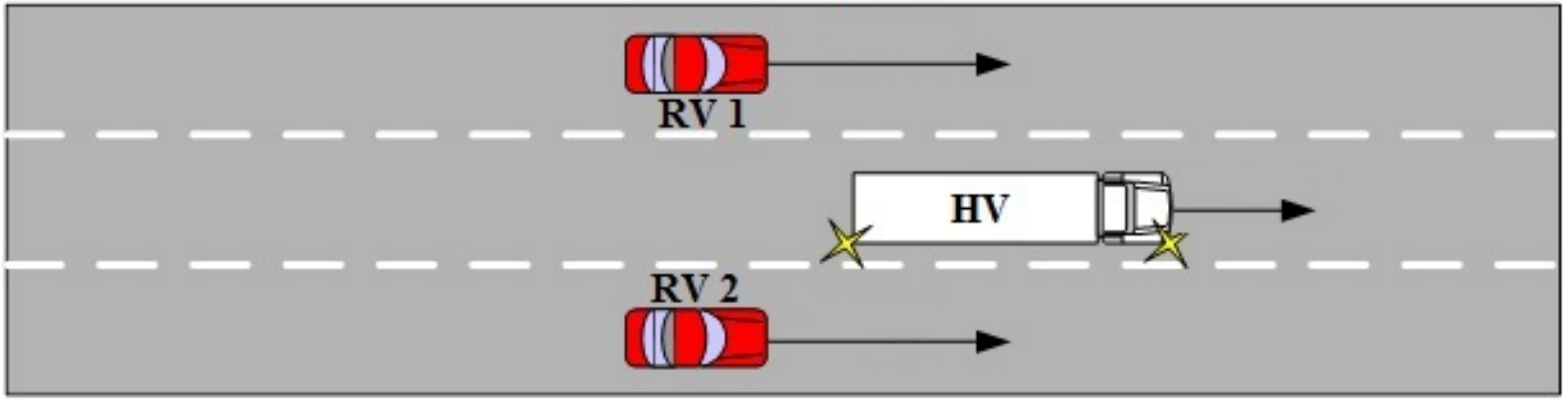


Figure A-5: BSW/LCW-4 Test Course Graphic (not to scale)

A.12 BSW/LCW-5 - RV Tailgates HV, Straight Road

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

A.12.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in the same lane and in the same direction. The leading vehicle is a commercial truck equipped with a V2V system that features a BSW/LCW application. The trailing vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The trailing vehicle is tailgating the leading vehicle creating a scenario where a false positive BSW/LCW alert may occur.

A.12.2 Test Subject and Purpose

The subject of this test is the V2V-based BSW/LCW system of the HV. The test determines the ability of the HV's system to differentiate that a vehicle tailgating the HV is not in an adjacent lane.

A.12.3 Initial Condition

A.12.3.1 Test Velocities

For tests of V2V-based BSW/LCW systems, the velocities of the HV and RV are specified for each trial or set of trials. A minimum velocity differential may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity for each vehicle—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 differential below or above which the subject ISS or RSD is designed to suppress BSW/LCW alerts.

A.12.4 Execution of Procedure

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-6.

1. The vehicles get into position with the RV positioned behind the HV in the center lane.
2. The vehicles accelerate to the test speed.
3. Once the vehicles are at speed, the HV holds speed while the RV holds a specified following distance.
4. Once the HV and RV are in position the experimenter starts the data collection.
5. Each trial ends once a specified amount of time has passed.

A.12.5 Trial Validity

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

1. The HV's and RV's velocities did not deviate from the specified velocity by more than ±1.0 mph.
2. The lateral distance between the centerline of the HV and the centerline of the RV did not exceed 2.0 ft.
3. The yaw rate of the HV did not exceed ±1 degree/second.

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

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

A trial is successful if the HV OBE does not initiate a BSW/LCW alert while the follows behind. A trial is unsuccessful if the HV OBE does initiate a BSW/LCW alert.

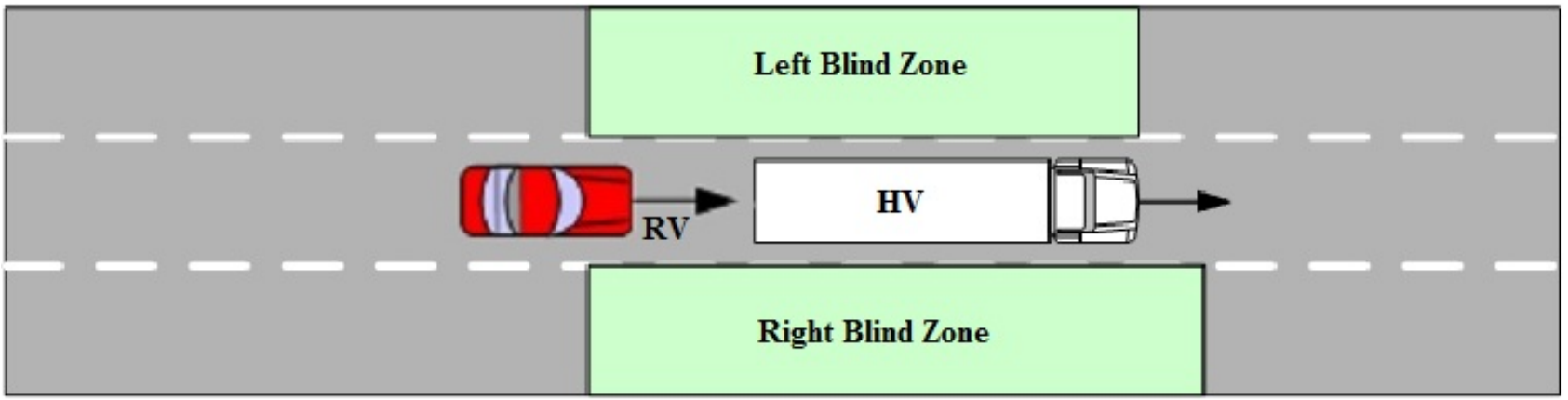


Figure A-6: BSW/LCW-5 Test Course Graphic (not to scale)

A.13 BSW/LCW-6 - HV and RV Separated by One Lane, Straight Road

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a scenario in which a BSW/LCW should not occur. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to avoid false positive alerts.

A.13.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in the same direction separated by one lane. A commercial truck equipped with a V2V system that features a BSW/LCW application is driven in one lane. The second vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The second vehicle travels two lanes over from the first vehicle in a position adjacent to the first vehicles blind zone, thus creating a scenario where a false positive BSW/LCW alert may occur.

A.13.2 Test Subject and Purpose

The subject of this test is the V2V-based BSW/LCW system of the HV. The test determines the ability of the HV's system to determine that the other vehicle is not in the adjacent lane.

A.13.3 Initial Condition

A.13.3.1 Test Velocities

For tests of V2V-based BSW/LCW systems, the velocities of the HV and RV are specified for each trial or set of trials. A minimum velocity differential may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity for each vehicle—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 differential below or above which the subject ISS or RSD is designed to suppress BSW/LCW alerts.

A.13.4 Execution of Procedure

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-7.

1. The vehicles get into position with the RV trailing the HV and separated by one lane.
2. The vehicles accelerate to their respective test speeds.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds for a specified amount of time while the RV holds position just outside the HV's blind zone.
5. Each trial ends once the specified period of time passes.

A.13.5 Trial Validity

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

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

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

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

A trial is successful if the HV OBE does not initiate a BSW/LCW alert. A trial is unsuccessful if the HV OBE does initiate a BSW/LCW alert.

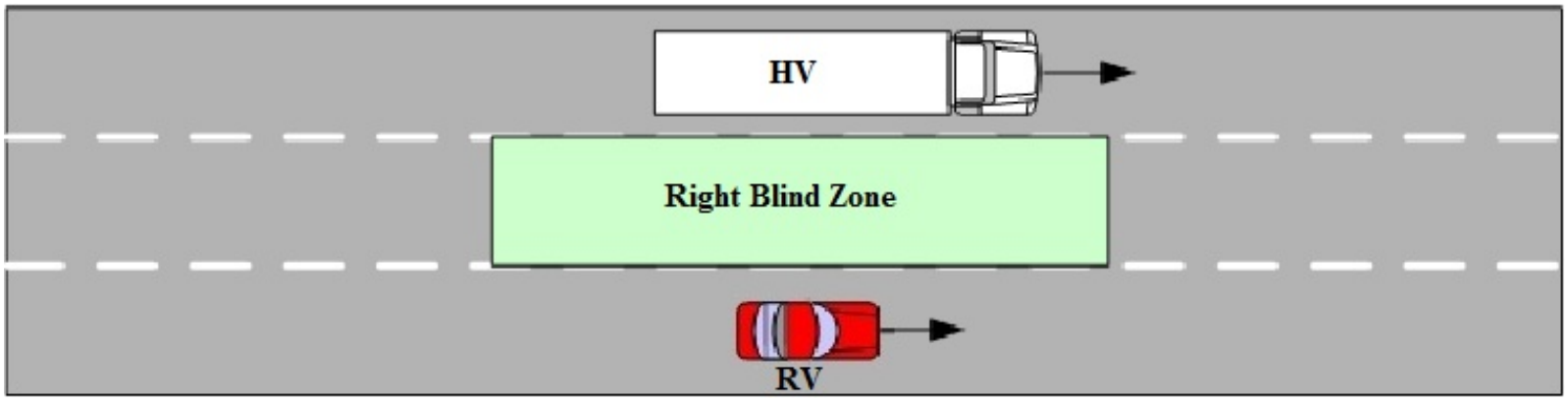


Figure A-7: BSW/LCW-6 Test Course Graphic (not to scale)

A.14 BSW/LCW-7 - RV Passes HV on Right, Curved Road

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

A.14.1 Pre-Crash Scenario

Two vehicles travel clockwise along a curved roadway in adjacent lanes and in the same direction. The leading vehicle is a commercial truck equipped with a V2V system that features a BSW/LCW application. The trailing vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The trailing vehicle is moving at a higher rate of speed than the leading vehicle and therefore enters into the BSW/LCW application's right side alert zone of the leading vehicle.

A.14.2 Test Subject and Purpose

The subject of this test is the V2V-based BSW/LCW system of the HV. The test determines the ability of the HV's system to identify the vehicle in its blind zone and alert the HV's driver of the threat in a timely manner as well as extinguish the alert when the threat has passed.

A.14.3 Initial Condition

A.14.3.1 Test Velocities

For tests of V2V-based BSW/LCW systems, the velocities of the HV and RV are specified for each trial or set of trials. A minimum velocity differential may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity for each vehicle—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 differential below or above which the subject ISS or RSD is designed to suppress BSW/LCW alerts.

A.14.4 Execution of Procedure

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-8.

BSW Procedure:

1. The vehicles enter the curve with the RV behind the HV.
2. Once the roadway widens to two lanes the HV merges into the outside lane and the RV stays in the inside lane.
3. The vehicles accelerate to their respective test speeds.
4. Once the vehicles are at speed, the experimenter arms the data acquisition system.
5. The vehicles then hold their speeds while the RV begins to pass the HV on the right.

6. Once an "Inform Right" alert occurs, the driver of the HV cycles the turn signals. First activating the right turn signal, followed by activating the left turn signal.
7. Each trial ends once the alert extinguishes or the RV completes the pass of the HV to a specified headway.

LCW Procedure:

1. The vehicles enter the curve with the RV behind the HV.
2. Once the roadway widens to two lanes the HV merges into the outside lane and the RV stays in the inside lane.
3. The vehicles accelerate to their respective test speeds.
4. Once the vehicles are at speed, the experimenter arms the data acquisition system and the HV driver activates the right turn signal. The turn signal needs to be activated prior to the RV entering the LCW blind zone extension. No alert should occur when the turn signal is initially activated. If an alert does occur, then the HV driver waited too long to activate the turn signal and the test should be repeated.
5. The vehicles then hold their speeds while the RV begins to pass the HV. A "Warning Right" will occur as the RV begins to pass the HV.
6. Each trial ends once the alert extinguishes or the RV completes the pass of the HV to a specified headway.

A.14.5 Trial Validity

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

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

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

A BSW trial is successful if the HV OBE initiates a BSW alert when the RV enters the blind zone and extinguishes that alert once the RV is clear of the HV. A trial is unsuccessful if the HV OBE does not initiate a BSW alert when the RV is in the HV's blind zone, or the alert persists after the RV has moved out of the HV's blind zone. When the driver activates the turn signal to the right, the BSW alert should change to an LCW alert and when the turn signal is shut off the alert type should change back to a BSW. When the driver activates the turn signal to the left, the BSW alert should not change to an LCW alert and should remain a BSW alert.

A LCW trial is successful if the HV OBE initiates an LCW alert when the RV enters the blind zone and extinguishes that alert once the RV is clear of the HV. A trial is unsuccessful if the HV OBE does not initiate an LCW alert when the RV is in the HV's blind zone, or the alert persists after the RV has moved out of the HV's blind zone.

If both the BSW and LCW test are performed, the time-to-collision for the BSW/LCW blind zone extension can be calculated as follows:

$$TTC_{ex} = \frac{(S_{TsOn} - S_{TsOff})}{V_{Hv} - V_{Rv}}$$

Where:

TTC_{ex} ≡ TTC for blind zone extension when turn signal is on

S_{TsOn} ≡ Distance HV Rear to RV Front (range) at warning onset when turn signal is on

S_{TsOff} ≡ Distance HV Rear to RV Front at warning onset when turn signal is off

V_{Hv} ≡ HV Speed

V_{Rv} ≡ RV Speed

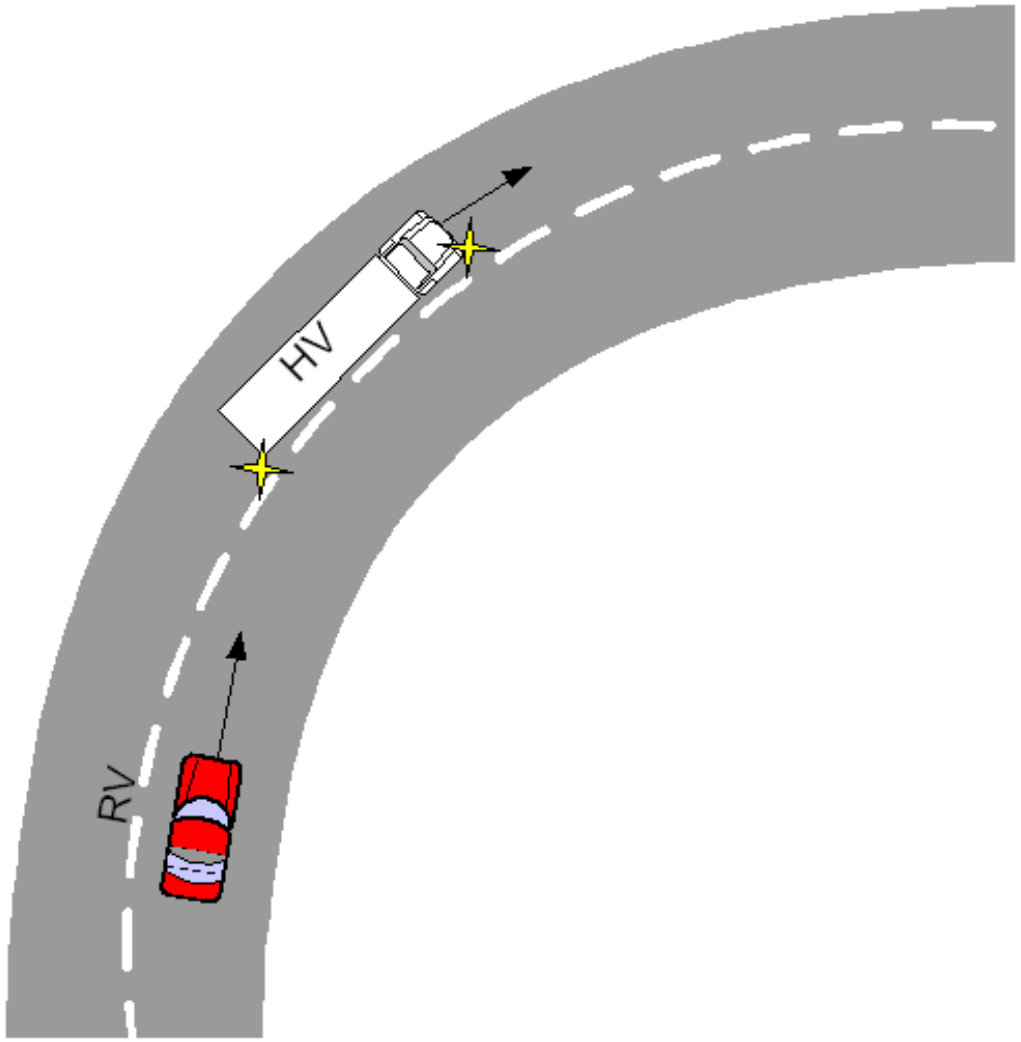


Figure A-8: BSW/LCW-7 Test Course Graphic (not to scale)

A.15 BSW/LCW-8 - RV Passes Slow Moving HV on Left, Straight Road

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a scenario in which a BSW/LCW should not occur. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to avoid false positive alerts.

A.15.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in adjacent lanes and in the same direction. The leading vehicle is a commercial truck equipped with a V2V system that features a BSW/LCW application. The trailing vehicle is equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The leading vehicle is moving at a low rate of speed below the threshold speed of the BSW/LCW application.

A.15.2 Test Subject and Purpose

The subject of this test is the V2V-based BSW/LCW system of the HV. This tests the HV threshold speed of the BSW/LCW application, the system should not produce an alert due to the low speed of the HV.

A.15.3 Initial Condition

A.15.3.1 Test Velocities

For tests of V2V-based BSW/LCW systems, the velocities of the HV and RV are specified for each trial or set of trials. A minimum velocity differential may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity for each vehicle—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 differential below or above which the subject ISS or RSD is designed to suppress BSW/LCW alerts.

A.15.4 Execution of Procedure

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-9.

1. The vehicles get into position with the HV in the right lane and the RV in the left lane trailing behind the HV.
2. The vehicles accelerate to their respective test speeds.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds while the RV begins to pass the HV.
5. Each trial ends once the RV completes the pass of the HV to a specified headway.

A.15.5 Trial Validity

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

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

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

A.15.6 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful in the HV OBE does not initiates a BSW/LCW alert when the RV enters the blind zone area. A trial is unsuccessful if the HV OBE does initiate a BSW/LCW alert when the RV is in the HV's blind zone.

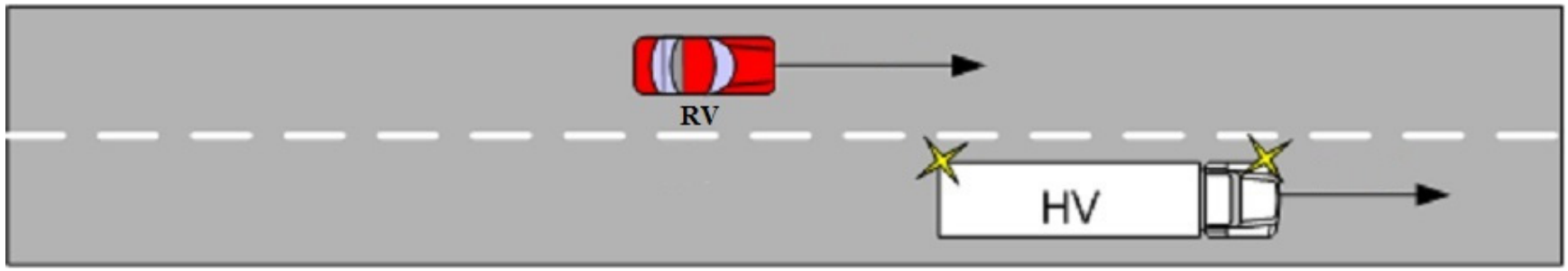


Figure A-9: BSW/LCW-8 Test Course Graphic (not to scale)

A.16 BSW/LCW-9 - HV Passes Slow Moving RV on Left, Straight Road

This procedure provides specifications for conducting a test to assess the performances of CCV crash avoidance systems when presented with a scenario in which a BSW/LCW should not occur. The procedure is used to evaluate the abilities of commercial vehicle-based V2V systems to avoid false positive alerts.

A.16.1 Pre-Crash Scenario

Two vehicles travel along a straight roadway in adjacent lanes and in the same direction. The leading vehicle is a light vehicle or commercial truck equipped with a V2V system that broadcasts the vehicle's position, speed, direction of travel, and path history. The trailing vehicle is a commercial vehicle equipped with a V2V system that features a BSW/LCW application. The trailing vehicle is moving at a higher rate of speed than the leading vehicle and therefore causes the leading vehicle to enter into the BSW/LCW application's alert zone on either side of the trailing vehicle. However, the leading vehicles low rate of speed should be below the threshold speed of the BSW/LCW application.

A.16.2 Test Subject and Purpose

The subject of this test is the V2V-based BSW/LCW system of the HV. This tests the threshold speed of the BSW/LCW application, the system should not produce an alert due to the low speed of the RV.

A.16.3 Initial Condition

A.16.3.1 Test Velocities

For tests of V2V-based BSW/LCW systems, the velocities of the HV and RV are specified for each trial or set of trials. A minimum velocity differential may be specified above which an ISS or RSD would issue an alert to produce a successful trial. A single, standard velocity for each vehicle—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 differential below or above which the subject ISS or RSD is designed to suppress BSW/LCW alerts.

A.16.4 Execution of Procedure

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-10.

1. The vehicles get into position with the RV in the right lane and the HV in the left lane some distance behind the RV.
2. The vehicles accelerate to their respective test speeds.
3. Once the vehicles are at speed, the experimenter arms the data acquisition system.
4. The vehicles then hold their speeds while the HV begins to pass the RV.
5. Each trial ends once the HV completes the pass of the RV to a specified headway.

A.16.5 Trial Validity

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

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

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

A.16.6 Evaluation Metrics (Performance Metrics - Pass/Fail Criteria)

A trial is successful in the HV OBE does not initiates a BSW/LCW during the pass of the RV. A trial is unsuccessful if the HV OBE does initiate a BSW/LCW alert when the RV is in the HV's blind zone.

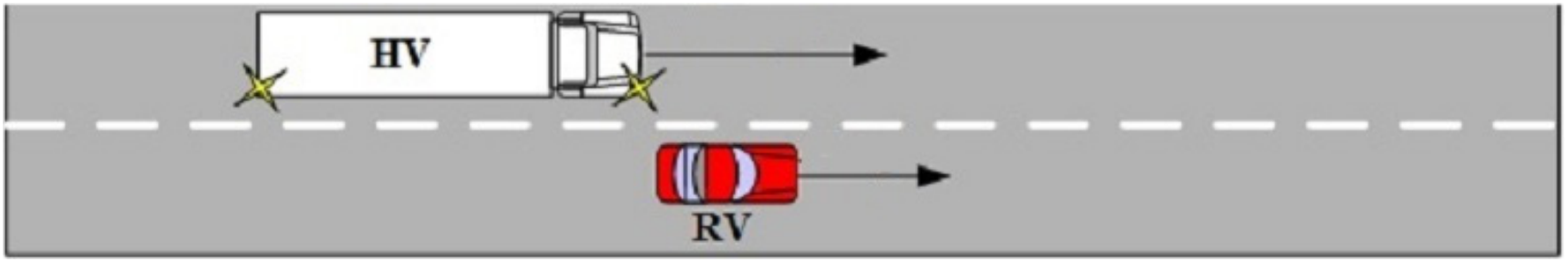


Figure A-10: BSW/LCW-9 Test Course Graphic (not to scale)

Appendix B - Tabulated Test Results

B.1 BSW/LCW-1 Tabulated Test Results

Table B-1: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
771	-16.4		-13.9	-8.3		-5.8	34.5	39.1	-1.5		0.9
773	-12.0		-14.2	-4.0		-6.1	34.7	38.7	1.8		0.8
778	-12.3		-14.0	-4.3		-5.9	34.7	39.3	1.7		0.6
780	-12.5		-13.9	-4.4		-5.8	34.8	38.7	1.0		0.4
782	-15.3		-14.1	-7.2		-6.1	34.3	38.7	-0.7		0.5
Ave.	-13.7		-14.0	-5.6		-6.0	34.6	38.9	0.5		0.6
Std.	2.0		0.1	2.0		0.1	0.2	0.3	1.5		0.2
C.V.%	14.6		1.0	35.3		2.2	0.5	0.7	316.5		35.4

Table B-2: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
784	-25.3		-25.9	-17.3		-17.8	34.8	40.3	1.1		1.3
786	-23.9		-24.3	-15.9		-16.2	34.6	39.2	0.7		0.7
788	-23.9		-24.4	-15.8		-16.3	34.9	39.6	1.1		0.6
790	-25.1		-25.6	-17.1		-17.6	34.7	40.0	1.5		1.1
792	-3.5		-2.2	4.5		5.8	34.7	39.7	-0.1		0.9
794	-24.6		-24.4	-16.5		-16.4	34.7	39.3	0.4		0.8
Ave.	-21.1		-21.1	-13.0		-13.1	34.7	39.7	0.8		0.9
Std.	8.6		9.3	8.6		9.3	0.1	0.4	0.6		0.3
C.V.%	41.0		43.9	66.3		70.9	0.3	1.0	73.5		31.1

Table B-3: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 40' Shipping Container, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
795	-24.8		-20.5	-6.9		-2.5	34.7	39.9	-4.8		0.9
797	-26.0		-21.0	-8.0		-3.0	34.7	39.2	-5.7		1.1
799	-25.9		-20.8	-7.9		-2.8	35.1	39.0	-6.1		0.4
801	-25.9		-20.8	-8.0		-2.8	34.6	39.9	-5.8		1.3
803	-26.2		-20.6	-8.3		-2.7	34.7	39.4	-6.3		1.3
805	-26.0		-20.9	-8.0		-2.9	34.5	39.2	-4.7		0.4
807	-25.7		-20.8	-7.7		-2.8	34.6	38.7	-6.0		0.1
809	-25.7		-20.8	-7.7		-2.9	34.6	39.5	-5.8		0.6
Ave.	-25.8		-20.8	-7.8		-2.8	34.7	39.4	-5.7		0.8
Std.	0.4		0.1	0.4		0.1	0.2	0.4	0.6		0.4
C.V.%	1.6		0.7	5.3		5.3	0.5	1.0	10.4		57.4

Table B-4: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 40' Shipping Container, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
811	-35.0		-29.6	-17.0		-11.7	35.0	38.9	-6.6		0.7
813	-35.8		-30.0	-17.8		-12.0	34.4	38.5	-7.0		0.6
815	-37.7		-32.3	-19.8		-14.3	34.8	40.0	-5.7		1.0
817	-36.6		-31.0	-18.7		-13.0	34.7	39.2	-6.7		0.3
819	-37.5		-31.8	-19.6		-13.9	34.5	39.5	-6.5		0.8
821	-35.8		-30.6	-17.8		-12.6	34.6	38.9	-6.5		0.3
823	-35.0		-29.5	-17.0		-11.5	34.6	38.4	-5.8		0.4
825	-33.9		-29.0	-15.9		-11.0	34.6	38.3	-16.6		-13.8
Ave.	-35.9		-30.5	-17.9		-12.5	34.7	39.0	-7.7		-1.2
Std.	1.3		1.2	1.3		1.2	0.2	0.6	3.6		5.1
C.V.%	3.7		3.8	7.5		9.3	0.6	1.5	47.3		415.8

Table B-5: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Blue Cascadia Bobtail

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
996		-8.3	-10.1		-0.2	-2.0	34.6	39.3		1.1	1.0
998		-12.2	-13.5		-4.2	-5.4	34.5	39.0		-0.8	-1.2
1002		-12.0	-13.5		-3.9	-5.4	34.6	38.8		1.6	1.0
1004		-11.9	-13.6		-3.9	-5.5	34.5	39.3		2.4	1.5
Ave.		-11.1	-12.6		-3.1	-4.6	34.6	39.1		1.1	0.6
Std.		1.9	1.7		1.9	1.7	0.1	0.2		1.4	1.2
C.V.%		16.9	13.7		61.4	37.5	0.2	0.6		126.5	199.1

- One test dropped from analysis due to GPS and WSU data suggesting that the HV and RV may have been more than one lane apart for a portion of the test

Table B-6: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Blue Cascadia Bobtail

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1018		-28.3	-28.2		-20.2	-20.2	34.5	41.0		0.8	1.6
1020		-25.4	-24.3		-17.3	-16.3	34.5	39.4		0.1	1.2
1022		-26.1	-23.8		-18.1	-15.8	34.7	39.5		-1.2	1.2
1024		-25.1	-23.2		-17.1	-15.1	34.7	39.0		-0.9	1.5
1026		-25.8	-24.0		-17.7	-15.9	34.6	39.3		-0.8	1.3
Ave.		-26.1	-24.7		-18.1	-16.7	34.6	39.6		-0.4	1.3
Std.		1.3	2.0		1.3	2.0	0.1	0.8		0.8	0.2
C.V.%		4.8	8.1		6.9	12.0	0.3	2.0		201.0	14.8

Table B-7: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 53' Box, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1172	-22.6	-21.8	-20.4	-0.8	0.1	1.4	35.0	40.4	-0.6	0.1	3.8
1174	-23.8	-22.8	-20.5	-1.9	-1.0	1.3	35.5	39.6	-1.5	-0.4	1.1
1176	-22.0	-22.7	-20.7	-0.1	-0.9	1.1	34.8	40.1	-0.2	-1.3	3.5
1178	-21.2	7.9	-20.7	0.6	29.7	1.1	34.8	40.6	0.4	22.3	3.4
1180	-22.0	-20.3	-20.4	-0.2	1.6	1.4	34.8	40.1	-0.7	-0.3	3.1
1182	-22.3	-21.7	-20.7	-0.5	0.1	1.1	34.8	40.0	0.0	0.7	4.3
1184	-24.4	-25.5	-21.4	-2.6	-3.6	0.4	34.7	39.6	-1.7	6.3	3.5
Ave.	-22.6	-18.1	-20.7	-0.8	3.7	1.1	34.9	40.1	-0.6	3.9	3.2
Std.	1.1	11.6	0.3	1.1	11.6	0.3	0.3	0.4	0.8	8.5	1.0
C.V.%	4.8	63.8	1.6	139.1	313.5	29.8	0.8	0.9	121.6	217.3	31.3

Table B-8: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 53' Box, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1162	-33.1	-31.9	-31.2	-11.3	-10.1	-9.3	34.9	39.6	-1.8	0.0	1.1
1164	-33.5	-32.1	-32.9	-11.6	-10.3	-11.1	34.8	40.4	-1.2	0.1	1.0
1166	-32.2	-22.3	-31.0	-10.4	-0.5	-9.2	34.9	39.6	0.8	13.1	3.6
1168	-34.3	-32.2	-33.0	-12.4	-10.3	-11.2	34.6	40.0	0.2	0.2	3.9
1170	-33.6	-39.8	-31.8	-11.7	-18.0	-10.0	34.9	39.9	0.0	1.1	4.2
Ave.	-33.3	-31.7	-32.0	-11.5	-9.8	-10.2	34.8	39.9	-0.4	2.9	2.8
Std.	0.7	6.2	0.9	0.7	6.2	0.9	0.1	0.4	1.1	5.7	1.6
C.V.%	2.2	19.6	2.9	6.5	63.1	9.2	0.4	0.9	280.1	197.2	57.6

Table B-9: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1372	-24.5	-22.3	-21.1	-0.6	1.5	2.7	34.7	40.5	-1.9	0.0	2.9
1374	-24.3	-22.4	-21.1	-0.5	1.5	2.7	34.8	40.5	-2.7	-0.8	2.0
1376	-22.2	-20.2	-21.1	1.7	3.6	2.8	34.9	40.6	-0.9	1.0	1.9
1378	-24.0	-22.0	-21.2	-0.1	1.9	2.7	35.5	40.5	-1.9	0.1	2.3
1380	-23.3	-21.2	-21.3	0.5	2.7	2.5	34.8	40.7	-1.3	0.6	2.8
Ave.	-23.7	-21.6	-21.2	0.2	2.2	2.7	34.9	40.6	-1.8	0.2	2.4
Std.	0.9	0.9	0.1	0.9	0.9	0.1	0.3	0.1	0.7	0.7	0.5
C.V.%	4.0	4.3	0.5	498.6	41.2	3.6	0.9	0.2	37.9	349.2	19.2

Table B-10: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1382	-36.0	-34.0	-33.9	-12.2	-10.1	-10.1	35.1	40.8	-1.3	0.7	2.7
1384	-34.6	-32.5	-32.4	-10.7	-8.7	-8.6	35.6	40.6	-1.5	0.4	2.8
1386	-34.8	-32.8	-32.9	-11.0	-9.0	-9.0	35.3	40.4	-0.9	1.0	2.9
1388	-33.6	-31.6	-33.6	-9.8	-7.8	-9.8	35.0	40.5	0.3	2.3	3.0
1390	-37.3	-35.1	-34.9	-13.4	-11.3	-11.0	34.6	40.5	-1.5	0.4	2.9
Ave.	-35.3	-33.2	-33.5	-11.4	-9.4	-9.7	35.1	40.6	-1.0	0.9	2.9
Std.	1.4	1.4	0.9	1.4	1.4	0.9	0.4	0.1	0.8	0.8	0.1
C.V.%	4.0	4.1	2.8	12.3	14.4	9.8	1.0	0.3	78.5	82.7	4.8

Table B-11: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 53' Box

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1412	-20.8	-20.8	-21.4	3.0	3.0	2.5	34.8	40.3	0.8	1.0	0.6
1414	-20.7	-20.7	-21.4	3.1	3.2	2.4	34.8	40.3	1.5	1.5	0.8
1417	-21.7	-21.8	-21.5	2.1	2.1	2.3	34.9	40.3	0.6	0.4	0.9
1419	-21.8	-21.7	-21.5	2.1	2.1	2.3	35.7	40.3	-0.1	-0.1	0.6
1421	-22.1	-22.0	-21.5	1.8	1.8	2.4	34.7	40.3	0.3	0.3	0.7
1423	-20.3	-20.2	-21.4	3.6	3.7	2.4	35.0	40.3	1.8	1.8	1.0
Ave.	-21.2	-21.2	-21.4	2.6	2.6	2.4	35.0	40.3	0.8	0.8	0.8
Std.	0.7	0.7	0.1	0.7	0.7	0.1	0.4	0.0	0.7	0.8	0.1
C.V.%	3.3	3.5	0.3	27.2	28.1	2.4	1.1	0.1	86.3	91.2	16.7

Table B-12: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 53' Box

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1425	-33.3	-33.0	-34.0	-9.4	-9.2	-10.2	34.7	40.3	0.7	0.8	0.6
1427	-33.2	-33.3	-33.7	-9.4	-9.5	-9.8	34.8	40.3	1.2	0.9	0.5
1431	-34.4	-34.4	-33.9	-10.6	-10.5	-10.1	34.8	40.3	-0.1	-0.2	0.8
1435	-33.9	-33.7	-34.2	-10.0	-9.8	-10.3	35.0	40.5	1.0	0.9	0.7
1437	-34.4	-34.3	-34.6	-10.5	-10.5	-10.8	34.6	40.6	0.0	0.2	0.6
Ave.	-33.8	-33.7	-34.1	-10.0	-9.9	-10.2	34.8	40.4	0.6	0.5	0.7
Std.	0.6	0.6	0.4	0.6	0.6	0.4	0.1	0.1	0.6	0.5	0.1
C.V.%	1.7	1.7	1.1	5.8	5.9	3.5	0.4	0.3	102.7	92.5	13.7

B.2 BSW/LCW-2 Tabulated Test Results

Table B-13: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
839	-16.1		-14.1	-8.1		-6.1	34.8	39.3	-1.9		0.8
841	-12.4		-13.9	-4.3		-5.8	34.6	39.4	1.8		0.9
843	-16.0		-14.0	-8.0		-6.0	34.9	39.3	-1.8		0.7
845	-15.4		-13.8	-7.3		-5.8	34.5	39.6	-1.4		1.0
847	-12.1		-14.0	-4.0		-5.9	35.2	39.1	1.8		0.5
849	-15.2		-13.9	-7.2		-5.8	34.1	39.4	-1.2		1.1
851	-15.7		-14.0	-7.6		-5.9	34.9	39.2	-1.5		0.8
Ave.	-14.7		-14.0	-6.6		-5.9	34.7	39.3	-0.6		0.8
Std.	1.7		0.1	1.7		0.1	0.3	0.2	1.7		0.2
C.V.%	11.7		0.8	25.9		1.8	1.0	0.4	281.5		23.1

Table B-14: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
853	-24.1		-24.9	-16.0		-16.8	34.8	39.8	1.6		1.0
855	-25.5		-23.5	-17.5		-15.5	34.6	38.8	-2.3		0.4
859	-22.0		-23.9	-13.9		-15.8	34.8	39.3	2.2		0.7
861	-27.4		-24.8	-19.4		-16.8	34.6	39.5	-2.1		0.9
863	-27.8		-24.7	-19.8		-16.7	34.6	39.5	-2.2		1.0
865	-22.9		-24.2	-14.8		-16.2	34.6	39.2	1.9		0.7
Ave.	-24.9		-24.3	-16.9		-16.3	34.7	39.3	-0.1		0.8
Std.	2.4		0.6	2.4		0.6	0.1	0.3	2.2		0.2
C.V.%	9.6		2.3	14.2		3.4	0.4	0.8	1489.2		27.3

Table B-15: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 40' Shipping Container, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
868	-19.1		-17.4	-1.1		0.5	34.6	39.4	-6.3		-4.2
870	-26.1		-17.5	-8.2		0.5	34.8	39.1	-13.3		-4.3
872	-19.9		-17.4	-1.9		0.6	34.4	39.2	-7.2		-4.1
874	-19.7		-17.4	-1.8		0.6	34.7	39.3	-6.9		-4.0
876	-23.4		-17.4	-5.4		0.6	34.6	39.3	-10.6		-4.2
Ave.	-21.6		-17.4	-3.7		0.6	34.6	39.3	-8.9		-4.2
Std.	3.0		0.1	3.0		0.1	0.1	0.1	3.0		0.1
C.V.%	14.0		0.4	82.3		11.9	0.4	0.3	33.7		2.8

Table B-16: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 40' Shipping Container, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
878	-31.6		-28.3	-13.6		-10.3	34.5	39.3	-8.2		-4.6
880	-30.2		-27.1	-12.2		-9.1	34.6	38.9	-8.0		-4.6
882	-35.5		-28.4	-17.5		-10.4	34.5	39.5	-11.0		-4.3
884	-32.2		-28.4	-14.3		-10.4	34.7	39.7	-8.3		-4.2
886	-30.6		-26.9	-12.6		-8.9	34.6	38.8	-8.2		-4.3
888	-33.6		-26.7	-15.6		-8.8	34.8	39.1	-11.4		-4.4
890	-33.1		-28.7	-15.2		-10.7	34.6	39.6	-8.5		-4.0
Ave.	-32.4		-27.8	-14.4		-9.8	34.6	39.3	-9.1		-4.3
Std.	1.8		0.8	1.8		0.8	0.1	0.3	1.4		0.2
C.V.%	5.7		3.0	12.8		8.4	0.4	0.9	15.9		5.0

Table B-17: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Blue Cascadia Bobtail

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1006		-12.0	-13.4		-4.0	-5.4	34.6	39.3		3.6	2.3
1008		-12.3	-13.6		-4.3	-5.5	34.5	39.1		2.6	1.7
1010		-12.9	-13.5		-4.8	-5.5	34.6	39.5		2.5	2.2
1012		-12.8	-13.5		-4.8	-5.5	34.7	38.8		2.0	1.9
1014		-12.7	-13.6		-4.6	-5.6	34.6	38.2		1.9	1.7
Ave.		-12.5	-13.5		-4.5	-5.5	34.6	39.0		2.5	2.0
Std.		0.4	0.1		0.4	0.1	0.1	0.5		0.7	0.3
C.V.%		2.9	0.5		8.0	1.2	0.3	1.3		27.2	13.8

Table B-18: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Blue Cascadia Bobtail

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1028		-26.0	-24.6		-18.0	-16.6	34.7	39.7		0.2	2.0
1033		-25.7	-24.6		-17.7	-16.6	34.7	39.9		0.5	1.9
1035		-24.7	-23.3		-16.7	-15.3	34.7	38.9		-1.1	1.4
1037		-25.9	-24.9		-17.9	-16.9	34.6	39.8		0.0	1.6
1039		-29.2	-28.0		-21.1	-20.0	34.3	40.9		0.8	2.2
Ave.		-26.3	-25.1		-18.3	-17.1	34.6	39.8		0.1	1.8
Std.		1.7	1.8		1.7	1.8	0.2	0.7		0.7	0.3
C.V.%		6.4	7.0		9.2	10.3	0.5	1.8		987.8	16.8

Table B-19: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w 53' Box, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1129	-17.9	-16.7	-16.8	4.0	5.2	5.1	35.0	40.6	-0.9	0.3	0.3
1131	-18.7	-17.9	-17.3	3.1	3.9	4.5	34.9	39.5	-2.3	-1.6	-0.6
1133	-18.2	-14.0	-17.2	3.7	7.8	4.6	34.8	40.4	-1.1	3.0	0.2
1135	-18.7	-16.1	-17.1	3.1	5.7	4.7	34.7	39.6	-2.7	-0.4	-0.5
1138	-18.6	-17.8	-17.2	3.2	4.0	4.6	34.4	38.9	-2.2	-1.4	-0.3
1140	-18.6	-17.4	-17.2	3.2	4.5	4.6	34.5	39.1	-2.1	-0.8	-0.6
1142	-18.4	-15.4	-17.1	3.4	6.4	4.8	34.7	40.5	-1.8	-6.2	0.1
1144	-18.4	-17.2	-17.2	3.4	4.6	4.7	34.7	39.7	-1.6	-0.3	0.0
1146	-18.8	-17.9	-17.2	3.1	3.9	4.6	34.9	40.2	-1.9	-1.1	0.1
1148	-19.6	-14.2	-17.3	2.3	7.7	4.6	35.0	40.2	-2.5	-1.6	0.0
Ave.	-18.6	-16.4	-17.2	3.2	5.4	4.7	34.8	39.9	-1.9	-1.0	-0.1
Std.	0.4	1.5	0.2	0.4	1.5	0.2	0.2	0.6	0.6	2.3	0.3
C.V.%	2.4	9.1	0.9	13.8	27.9	3.3	0.6	1.5	31.2	222.7	284.0

Table B-20: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w 53' Box, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1152	-29.4	-28.6	-27.7	-7.6	-6.8	-5.9	34.9	39.6	-2.0	-1.5	0.0
1154	-31.9	-30.6	-30.1	-10.1	-8.7	-8.3	34.8	40.6	-2.0	-0.7	-0.4
1156	-28.5	-27.8	-26.6	-6.7	-5.9	-4.8	34.9	39.2	-2.6	-1.9	-0.4
1158	-29.8	-24.5	-28.1	-8.0	-2.7	-6.3	34.8	39.7	-2.1	-3.9	0.2
1160	-31.6	-30.2	-29.4	-9.7	-8.4	-7.5	34.7	40.4	-2.7	-1.4	-1.3
Ave.	-30.2	-28.3	-28.4	-8.4	-6.5	-6.5	34.8	39.9	-2.3	-1.9	-0.4
Std.	1.4	2.4	1.4	1.4	2.4	1.4	0.1	0.6	0.4	1.2	0.6
C.V.%	4.7	8.6	4.9	17.1	37.4	21.1	0.2	1.4	15.5	64.0	140.3

Table B-21: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1362	-18.1	-16.1	-17.7	5.7	7.8	6.2	34.9	40.5	-1.8	0.2	-1.3
1364	-20.1	-18.1	-17.7	3.7	5.8	6.1	34.8	40.5	-3.3	-1.3	-0.4
1366	-20.2	-17.9	-17.6	3.7	5.9	6.2	34.7	40.6	-3.5	-1.5	-1.0
1368	-20.5	-18.4	-17.8	3.4	5.4	6.0	34.8	40.5	-3.8	-1.7	-0.7
1370	-19.7	-17.6	-17.8	4.1	6.2	6.0	34.9	40.6	-3.0	-0.9	-1.4
Ave.	-19.7	-17.6	-17.7	4.1	6.2	6.1	34.8	40.5	-3.1	-1.0	-1.0
Std.	0.9	0.9	0.1	0.9	0.9	0.1	0.1	0.0	0.8	0.8	0.4
C.V.%	4.8	5.2	0.5	22.9	14.7	1.4	0.3	0.1	25.5	74.8	41.7

Table B-22: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1392	-32.3	-30.1	-30.4	-8.5	-6.2	-6.6	34.6	40.4	-2.5	-0.2	-0.8
1394	-31.8	-29.7	-30.0	-7.9	-5.8	-6.2	35.0	40.5	-3.5	-1.3	-1.3
1396	-33.8	-31.7	-30.4	-9.9	-7.8	-6.5	34.7	40.4	-4.3	-2.2	-1.0
1398	-32.1	-29.9	-30.0	-8.2	-6.1	-6.2	35.0	40.5	-3.1	-1.0	-1.2
1400	-30.5	-28.4	-27.7	-6.6	-4.5	-3.9	35.2	39.6	-4.3	-2.1	-1.2
Ave.	-32.1	-29.9	-29.7	-8.2	-6.1	-5.9	34.9	40.3	-3.6	-1.4	-1.1
Std.	1.2	1.2	1.1	1.2	1.2	1.1	0.2	0.4	0.8	0.8	0.2
C.V.%	3.7	3.9	3.8	14.3	19.2	19.1	0.6	1.0	22.0	60.9	17.5

Table B-23: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 53' Box

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1402	-18.6	-18.4	-18.0	5.3	5.4	5.9	34.8	40.4	0.7	0.9	1.6
1404	-17.8	-17.6	-18.0	6.0	6.2	5.9	34.5	40.4	1.0	1.2	1.1
1406	-19.7	-19.5	-17.9	4.1	4.3	5.9	34.7	40.4	-0.9	-0.8	1.0
1408	-18.6	-18.3	-18.1	5.2	5.6	5.8	34.3	40.4	1.8	1.9	1.6
1410	-16.5	-16.3	-17.8	7.4	7.5	6.0	35.0	40.4	2.3	2.6	0.9
Ave.	-18.2	-18.0	-17.9	5.6	5.8	5.9	34.7	40.4	1.0	1.1	1.3
Std.	1.2	1.2	0.1	1.2	1.2	0.1	0.3	0.0	1.2	1.3	0.3
C.V.%	6.6	6.6	0.5	21.4	20.4	1.5	0.8	0.1	125.6	110.7	27.3

Table B-24: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 53' Box

Test No.	HV Front to RV Front at Onset (m)			HV Rear to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	HV	RV	RT	GPS	WSU
1441	-29.7	-29.5	-30.6	-5.9	-5.7	-6.7	35.2	40.7	1.6	1.7	0.7
1443	-30.8	-30.6	-29.7	-6.9	-6.8	-5.9	35.0	40.2	-0.8	-0.8	0.5
1445	-28.4	-28.2	-30.1	-4.6	-4.4	-6.2	34.9	40.1	2.2	2.3	0.4
1447	-31.5	-31.3	-30.0	-7.7	-7.5	-6.2	34.9	40.2	-0.4	-0.3	1.1
1449	-27.9	-27.8	-29.6	-4.1	-3.9	-5.7	35.0	40.2	2.4	2.5	0.6
1451	-31.9	-31.7	-30.3	-8.0	-7.8	-6.4	34.8	40.2	-0.8	-0.7	0.7
1453	-30.8	-30.6	-30.1	-6.9	-6.8	-6.2	34.9	40.2	-0.1	0.0	0.8
Ave.	-30.1	-30.0	-30.0	-6.3	-6.1	-6.2	35.0	40.3	0.6	0.7	0.7
Std.	1.5	1.5	0.3	1.5	1.5	0.3	0.1	0.2	1.4	1.5	0.2
C.V.%	5.0	5.1	1.1	23.9	24.8	5.3	0.4	0.5	242.4	212.8	31.6

B.3 BSW/LCW-3 Tabulated Test Results

Tests were conducted with the RV on the left and with the RV on the right. The tests with the RV on the left are presented first.

B.3.1 RV on the Left Results

Table B-25: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
770	-2.9		-1.9	39.8	34.1	-18.1		-17.0	-10.0		-8.9
772	-2.6		-1.8	39.5	34.4	-18.3		-17.2	-10.3		-9.1
777	-3.0		-1.7	39.5	34.4	-18.0		-16.4	-10.0		-8.3
779	0.1		-2.1	39.8	34.0	-14.5		-16.9	-6.5		-8.8
781	-2.5		-1.6	39.6	34.6	-17.6		-16.9	-9.6		-8.8
783	-2.8		-1.6	40.1	34.9	-18.4		-17.0	-10.4		-9.0
Ave.	-2.3		-1.8	39.7	34.4	-17.5		-16.9	-9.5		-8.8
Std.	1.2		0.2	0.2	0.3	1.5		0.3	1.5		0.3
C.V.%	52.1		11.1	0.6	0.9	8.4		1.6	15.6		3.0

Table B-26: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
785	-0.7		-1.6	39.7	34.1	-16.2		-17.3	-8.2		-9.3
787	-1.4		-1.7	39.9	34.4	-16.1		-17.1	-8.0		-9.1
789	0.0		-1.7	39.9	34.4	-15.4		-17.0	-7.4		-8.9
791	-1.3		-2.0	39.7	34.4	-15.2		-16.5	-7.2		-8.4
793	-1.2		-1.9	39.8	34.3	-6.6		-9.3	1.4		-1.3
Ave.	-0.9		-1.8	39.8	34.3	-13.9		-15.4	-5.9		-7.4
Std.	0.6		0.2	0.1	0.1	4.1		3.4	4.1		3.4
C.V.%	60.4		9.3	0.2	0.3	29.4		22.3	69.8		46.5

Table B-27: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 40' Shipping Container, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
796	-8.5		-3.7	39.9	34.5	-28.6		-24.5	-10.6		-6.5
798	-7.5		-3.6	39.7	34.6	-27.7		-24.2	-9.7		-6.2
800	-7.0		-1.8	40.0	34.3	-28.6		-24.5	-10.6		-6.5
802	-8.2		-3.4	39.6	34.3	-29.0		-24.4	-11.1		-6.5
804	-7.4		-3.3	39.6	35.2	-28.5		-24.4	-10.6		-6.5
806	-7.4		-3.2	39.9	34.2	-28.7		-24.5	-10.7		-6.5
808	-7.7		-3.4	39.7	34.6	-28.0		-24.4	-10.1		-6.4
818	-8.1		-3.8	39.7	34.4	-28.2		-23.9	-10.2		-5.9
Ave.	-7.7		-3.3	39.8	34.5	-28.4		-24.3	-10.5		-6.4
Std.	0.5		0.6	0.2	0.3	0.4		0.2	0.4		0.2
C.V.%	6.7		19.5	0.4	0.9	1.5		0.9	4.1		3.4

Table B-28: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 40' Shipping Container, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
810	-7.7		-3.6	39.7	34.8	-27.9		-23.9	-9.9		-6.0
812	-8.2		-3.7	39.6	34.1	-28.6		-24.3	-10.7		-6.3
814	-8.8		-3.7	39.7	34.4	-29.4		-24.0	-11.4		-6.1
816	-8.4		-4.0	39.9	33.9	-29.1		-24.8	-11.1		-6.8
820	-8.4		-3.4	39.6	34.4	-28.4		-23.7	-10.5		-5.8
822	-8.0		-3.1	39.5	33.7	-29.7		-24.8	-11.7		-6.8
824	-8.0		-3.7	39.7	33.8	-27.9		-24.0	-9.9		-6.0
826	-11.2		-6.7	40.0	33.7	-29.1		-25.5	-11.1		-7.6
Ave.	-8.6		-4.0	39.7	34.1	-28.8		-24.4	-10.8		-6.4
Std.	1.1		1.1	0.2	0.4	0.7		0.6	0.7		0.6
C.V.%	12.8		28.5	0.4	1.2	2.3		2.5	6.0		9.4

Table B-29: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Blue Cascadia Bobtail

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
997		-2.0	-1.5	39.6	34.3		-16.8	-16.5		-8.8	-8.5
999		-2.1	-1.7	39.7	34.2		-16.8	-16.7		-8.7	-8.7
1001		-1.8	-1.6	39.5	34.2		-16.3	-16.5		-8.3	-8.5
1003		-1.4	-1.4	39.6	34.2		-16.0	-16.4		-8.0	-8.4
1005		-1.6	-1.4	39.7	34.3		-16.4	-16.6		-8.4	-8.5
Ave.		-1.8	-1.5	39.6	34.2		-16.5	-16.6		-8.4	-8.5
Std.		0.3	0.1	0.1	0.0		0.3	0.1		0.3	0.1
C.V.%		17.0	7.0	0.2	0.1		2.0	0.6		3.9	1.2

Table B-30: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Blue Cascadia Bobtail

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1019		-1.2	-1.5	39.7	35.0		-15.5	-16.5		-7.5	-8.4
1021		-11.8	-13.5	39.9	35.1		-15.1	-16.5		-7.0	-8.4
1023		-0.7	-1.4	39.7	34.9		-14.7	-16.1		-6.6	-8.1
1025		-0.5	-1.4	39.8	35.0		-14.7	-16.2		-6.7	-8.1
1027		-2.0	-1.5	39.6	35.0		-16.2	-16.3		-8.2	-8.3
Ave.		-3.2	-3.9	39.8	35.0		-15.2	-16.3		-7.2	-8.3
Std.		4.8	5.4	0.1	0.0		0.6	0.2		0.6	0.2
C.V.%		149.1	140.1	0.3	0.1		4.2	0.9		8.9	1.9

Table B-31: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 53' Box, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1173	-3.2	-2.4	-1.7	39.6	34.6	-23.3	-21.4	-22.5	-1.5	0.4	-0.7
1175	-3.3	-1.6	-1.4	40.0	34.6	-25.2	-24.9	-23.5	-3.4	-3.1	-1.7
1177	-2.6	-0.6	-1.5	39.7	33.6	-24.8	-34.4	-23.9	-2.9	-12.6	-2.0
1179	-2.9	-0.1	-1.4	40.1	34.6	-24.1	-21.9	-23.4	-2.3	0.0	-1.6
1181	-2.8	-2.0	-1.3	39.9	34.6	-24.4	-22.9	-23.7	-2.6	-1.1	-1.9
1183	-4.6	-3.3	-2.0	39.7	34.7	-26.0	-24.5	-23.5	-4.1	-2.7	-1.6
1185	-2.2	4.2	-1.5	40.1	34.6	-23.7	-51.8	-23.4	-1.9	-30.0	-1.6
Ave.	-3.1	-0.8	-1.5	39.9	34.5	-24.5	-28.8	-23.4	-2.7	-7.0	-1.6
Std.	0.8	2.5	0.2	0.2	0.4	0.9	11.0	0.4	0.9	11.0	0.4
C.V.%	25.1	298.4	15.4	0.5	1.1	3.7	38.3	1.8	33.9	157.4	26.7

Table B-32: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 53' Box, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1163	-3.2	-1.6	-1.7	40.4	34.7	-25.1	-23.5	-23.7	-3.3	-1.6	-1.9
1165	-1.7	-9.0	-1.5	39.8	34.6	-22.9	-53.4	-23.1	-1.1	-31.6	-1.2
1167	-1.8	3.2	-1.6	40.0	34.6	-23.5	-21.7	-23.6	-1.7	0.1	-1.8
1169	-2.9	-0.1	-1.4	40.2	34.6	-24.9	-23.5	-23.6	-3.1	-1.7	-1.8
1171	-2.8	-1.7	-1.5	39.6	34.6	-24.8	-23.6	-23.5	-3.0	-1.8	-1.7
Ave.	-2.5	-1.9	-1.5	40.0	34.6	-24.2	-29.1	-23.5	-2.4	-7.3	-1.7
Std.	0.7	4.5	0.1	0.3	0.0	1.0	13.6	0.3	1.0	13.6	0.3
C.V.%	28.1	240.1	8.6	0.8	0.1	4.1	46.6	1.1	40.9	186.0	15.5

Table B-33: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1373	-4.2	-1.9	-1.8	39.8	35.5						
1375	-2.8	-0.5	-1.9	40.4	35.6	-24.9	-22.4	-24.2	-1.1	1.4	-0.3
1377	-3.0	-0.7	-2.0	40.2	35.4						
1379	-4.7	-2.3	-3.0	40.2	35.6	-26.4	-24.1	-23.8	-2.6	-0.2	0.1
1381	-2.7	-0.4	-1.8	40.3	35.7	-24.4	-21.9	-23.7	-0.5	2.0	0.1
Ave.	-3.5	-1.2	-2.1	40.2	35.6	-25.3	-22.8	-23.9	-1.4	1.0	0.0
Std.	0.9	0.9	0.5	0.2	0.1	1.1	1.1	0.2	1.1	1.1	0.2
C.V.%	26.3	77.1	24.0	0.5	0.3	4.2	5.0	1.0	75.9	110.3	580.3

Table B-34: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1383	-3.5	-1.2	-1.9	40.2	35.6	-25.2	-22.9	-24.1	-1.4	1.0	-0.2
1385	-3.1	-0.9	-1.8	40.1	35.6	-24.3	-22.0	-23.3	-0.5	1.8	0.6
1387	-2.8	-0.5	-1.6	39.9	35.6	-24.7	-22.5	-24.2	-0.9	1.4	-0.3
1389	-1.7	0.4	-1.9	40.2	35.6	-23.5	-21.0	-23.7	0.4	2.8	0.2
1391	-3.4	-1.2	-1.8	39.9	35.6	-24.9	-22.4	-23.6	-1.0	1.4	0.3
Ave.	-2.9	-0.7	-1.8	40.1	35.6	-24.5	-22.2	-23.7	-0.7	1.7	0.1
Std.	0.7	0.7	0.1	0.1	0.0	0.7	0.7	0.4	0.7	0.7	0.4
C.V.%	24.9	101.7	7.2	0.3	0.1	2.8	3.2	1.5	100.8	41.8	357.2

Table B-35: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 53' Box

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1413	-1.6	-1.3	-2.2	40.2	35.3	-23.3	-22.9	-24.1	0.5	0.9	-0.2
1416	-2.1	-1.7	-2.1	40.6	35.3	-22.2	-21.9	-24.3	1.6	2.0	-0.5
1418	-1.9	-1.4	-2.1	39.7	35.3	-22.9	-22.5	-23.5	1.0	1.3	0.3
1422	-0.9	-0.5	-2.2	40.0	35.3	-22.3	-21.7	-24.1	1.6	2.1	-0.2
1424	-0.7	-0.4	-2.1	39.9	35.4	-21.9	-21.5	-23.4	1.9	2.4	0.4
Ave.	-1.4	-1.1	-2.1	40.1	35.3	-22.5	-22.1	-23.9	1.3	1.7	0.0
Std.	0.6	0.6	0.0	0.3	0.1	0.6	0.6	0.4	0.6	0.6	0.4
C.V.%	43.4	55.9	2.0	0.9	0.1	2.5	2.7	1.6	43.4	34.3	972.6

Table B-36: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 53' Box

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1428	-1.4	-1.0	-2.0	39.9	35.5						
1430	-1.8	-1.3	-2.1	39.7	35.4	-22.9	-22.5	-23.7	0.9	1.3	0.2
1434	-2.3	-2.0	-2.1	40.8	35.6	-23.6	-23.3	-23.8	0.2	0.5	0.0
1436	-1.4	-0.9	-2.2	40.5	35.6	-22.9	-22.5	-23.6	0.9	1.3	0.2
1438	-2.7	-2.4	-2.1	39.9	35.7	-23.9	-23.5	-23.8	-0.1	0.3	0.1
Ave.	-1.9	-1.5	-2.1	40.1	35.6	-23.3	-23.0	-23.7	0.5	0.9	0.1
Std.	0.6	0.6	0.1	0.5	0.1	0.5	0.5	0.1	0.5	0.5	0.1
C.V.%	29.9	41.6	3.5	1.1	0.2	2.2	2.3	0.4	103.3	60.5	71.5

B.3.2 RV on the Right Results

Table B-37: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 53' Box, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1153	-4.9	-3.6	-3.0	39.9	34.6	-21.5	-20.1	-19.7	0.3	1.8	2.2
1155	-4.2	-3.3	-3.1	39.9	34.7	-20.3	-19.5	-19.4	1.5	2.3	2.4
1157	-4.1	-2.7	-2.8	39.9	34.6	-20.6	-19.7	-20.0	1.2	2.1	1.9
1159	-2.9	-0.7	-2.4	39.8	34.6	-20.1	-18.7	-19.6	1.8	3.2	2.2
1161	-4.5	-3.3	-3.0	39.8	34.7	-21.0	-19.7	-19.9	0.9	2.1	1.9
Ave.	-4.1	-2.7	-2.9	39.9	34.6	-20.7	-19.5	-19.7	1.1	2.3	2.1
Std.	0.7	1.1	0.3	0.1	0.0	0.6	0.5	0.2	0.6	0.5	0.2
C.V.%	18.0	42.3	9.7	0.1	0.1	2.8	2.7	1.1	51.3	22.9	10.3

Table B-38: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1363	-6.6	-4.3	-3.8	39.9	35.6	-22.3	-19.9	-19.9	1.5	3.9	4.0
1365	-5.3	-2.8	-3.6	39.9	35.5	-20.7	-18.2	-19.5	3.2	5.6	4.4
1367	-5.5	-3.1	-3.9	40.2	35.5	-20.1	-17.8	-19.6	3.7	6.1	4.3
1369	-5.3	-2.7	-4.5	40.1	35.6	-22.2	-19.8	-20.1	1.6	4.0	3.7
1371	-5.4	-3.0	-4.2	40.2	35.5	-21.3	-18.9	-21.2	2.5	5.0	2.7
Ave.	-5.6	-3.2	-4.0	40.1	35.5	-21.3	-18.9	-20.0	2.5	4.9	3.8
Std.	0.6	0.6	0.3	0.1	0.0	1.0	1.0	0.7	1.0	1.0	0.7
C.V.%	10.3	20.3	8.7	0.3	0.1	4.5	5.0	3.3	38.2	19.4	17.6

Table B-39: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 40' Shipping Container

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1393	-4.9	-2.5	-3.7	39.5	35.6	-21.1	-18.7	-19.8	2.7	5.1	4.0
1395	-6.2	-3.8	-3.9	39.9	35.6	-22.1	-19.6	-19.9	1.8	4.2	3.9
1397	-6.1	-3.5	-3.7	39.9	35.6	-23.2	-20.8	-20.9	0.6	3.0	3.0
1399	-4.6	-2.2	-3.7	40.2	35.6	-21.2	-18.7	-20.2	2.7	5.2	3.6
1401	-6.7	-4.2	-3.8	40.1	35.6	-22.6	-20.2	-20.2	1.3	3.6	3.7
Ave.	-5.7	-3.3	-3.7	39.9	35.6	-22.0	-19.6	-20.2	1.8	4.2	3.6
Std.	0.9	0.9	0.1	0.3	0.0	0.9	0.9	0.4	0.9	0.9	0.4
C.V.%	15.8	26.5	2.4	0.7	0.0	4.1	4.8	2.0	50.2	22.1	11.2

Table B-40: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 53' Box

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1403	-1.9	-1.3	-1.9	39.8	35.3	-20.0	-19.5	-20.4	3.8	4.4	3.5
1405	0.2	0.7	-1.8	40.2	35.5	-18.3	-17.8	-19.9	5.5	6.1	3.9
1407	-2.6	-2.2	-1.7	39.5	35.4	-21.2	-20.5	-21.6	2.7	3.4	2.3
1409	-0.2	0.3	-1.8	40.2	35.5						
1411	-0.5	-0.1	-1.8	39.8	35.3	-17.6	-17.1	-19.0	6.3	6.7	4.8
Ave.	-1.0	-0.5	-1.8	39.9	35.4	-19.3	-18.7	-20.2	4.6	5.1	3.6
Std.	1.2	1.2	0.1	0.3	0.1	1.6	1.5	1.0	1.6	1.5	1.0
C.V.%	119.4	227.2	5.3	0.7	0.3	8.4	8.3	5.2	35.4	30.2	29.0

Table B-41: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia w/ 28' Doubles, RV= Blue Cascadia w/ 53' Box

Test No.	HV Front to RV Front at Onset (m)			Speeds (mph)		HV Front to RV Front at Offset (m)			HV Rear to RV Front at Onset (m)		
	RT	GPS	WSU	HV	RV	RT	GPS	WSU	RT	GPS	WSU
1442	-3.1	-2.7	-2.0	39.8	35.2	-21.4	-21.0	-20.3	2.4	2.9	3.5
1444	-0.5	-0.1	-1.7	40.0	35.2	-18.6	-18.1	-20.3	5.3	5.8	3.5
1446	-3.6	-3.0	-1.8	40.1	35.2	-21.4	-20.9	-20.1	2.4	2.9	3.7
1448	-0.7	-0.3	-1.6	40.0	35.1	-19.1	-18.6	-20.5	4.7	5.2	3.3
1450	0.1	0.5	-1.7	40.1	35.1	-15.2	-14.8	-16.8	8.6	9.0	7.0
1452	-2.6	-2.2	-1.5	39.7	35.2	-21.2	-20.6	-20.2	2.6	3.3	3.6
1454	0.3	0.8	-1.6	39.8	35.2	-18.8	-18.1	-20.9	5.0	5.7	3.0
Ave.	-1.4	-1.0	-1.7	39.9	35.2	-19.4	-18.9	-19.9	4.4	5.0	4.0
Std.	1.6	1.6	0.2	0.1	0.0	2.2	2.2	1.4	2.2	2.2	1.4
C.V.%	111.3	157.5	9.6	0.4	0.1	11.5	11.7	6.9	50.1	44.3	34.9

B.4 BSW/LCW-4 Tabulated Test Results

Table B-42: Longitudinal Range Between HV and RVs at RV1 BSW Alert Onset and Offset for HV = Red Cascadia w/ 53' Box, RV1 = Mack w/ 53' Box, RV2 = Blue Cascadia w/ 53' Box

Test No.	HV Front to RV1 Front at Onset (m)			HV Front to RV2 Front at Onset (m)			HV Front to RV1 Front at Offset (m)			HV Front to RV2 Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU
1665	-15.4	-15.4	-17.0	-14.2	-15.1	-15.7	2.8	3.0	1.3	3.3	2.3	2.2
1666	-17.4	-17.2	-17.0	-16.1	-17.0	-15.4	-0.8	-0.6	0.2	0.6	-0.4	1.5
1667	-17.7	-17.1	-17.0	-16.0	-16.9	-19.0	0.2	0.2	1.0	1.0	0.1	-1.7
1668	-17.3	-17.0	-17.1	-16.6	-17.3	-16.6	0.6	1.1	1.5	1.9	0.9	1.9
1669	-15.7	-15.6	-17.1	-14.5	-15.5	-18.1	1.3	1.3	0.5	2.4	1.4	-0.3
Ave.	-16.7	-16.5	-17.0	-15.5	-16.4	-17.0	0.8	1.0	0.9	1.8	0.9	0.7
Std.	1.1	0.9	0.1	1.0	1.0	1.6	1.3	1.3	0.5	1.1	1.1	1.7
C.V.(%)	6.3	5.4	0.3	6.8	6.2	9.2	165.6	130.2	60.9	58.9	124.1	225.2

Table B-43: Longitudinal Range Between HV and RVs at RV2 BSW Alert Onset and Offset for HV = Red Cascadia w/ 53' Box, RV1 = Mack w/ 53' Box, RV2 = Blue Cascadia w/ 53' Box

Test No.	HV Front to RV1 Front at Onset (m)			HV Front to RV2 Front at Onset (m)			HV Front to RV1 Front at Offset (m)			HV Front to RV2 Front at Offset (m)		
	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU	RT	GPS	WSU
1665	-21.6	-20.6	-22.3	-19.9	-20.8	-21.2	1.7	1.7	0.0	2.1	1.2	1.0
1666	-23.2	-22.9	-22.8	-22.1	-23.0	-21.2	-1.3	-1.1	-0.3	0.1	-0.9	1.0
1667	-19.6	-19.3	-19.2	-18.1	-18.9	-21.1	2.5	2.5	4.6	3.4	2.5	0.5
1668	-21.9	-21.8	-21.9	-21.0	-22.0	-21.1	0.1	0.2	0.5	1.0	0.0	1.0
Ave.	-21.6	-21.2	-21.5	-20.3	-21.2	-21.2	0.7	0.8	1.2	1.6	0.7	0.9
Std.	1.5	1.6	1.6	1.7	1.7	0.1	1.7	1.6	2.3	1.4	1.4	0.3
C.V.(%)	7.0	7.4	7.5	8.5	8.1	0.4	227.3	198.0	197.0	86.3	211.4	32.8

B.5 BSW/LCW-7 Tabulated Test Results

Table B-44: Longitudinal Range Between HV and RV at BSW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)		HV Rear to RV Front at Onset (m)		Speeds (mph)		HV Front to RV Front at Offset (m)	
	RT	WSU	RT	WSU	HV	RV	RT	WSU
893	-13.2	-13.9	-5.1	-5.8	34.6	40.1	2.3	1.6
894	-13.2	-13.8	-5.2	-5.8	34.5	39.5	1.9	1.5
895	-13.4	-13.8	-5.4	-5.8	34.7	39.9	1.6	1.3
896	-14.0	-13.9	-5.9	-5.9	34.5	39.3	1.1	0.7
897	-13.4	-13.9	-5.3	-5.8	34.7	39.4	1.3	0.9
Ave.	-13.4	-13.9	-5.4	-5.8	34.6	39.6	1.6	1.2
Std.	0.3	0.0	0.3	0.0	0.1	0.4	0.5	0.4
C.V.(%)	2.4	0.2	5.9	0.5	0.3	0.9	30.6	31.1

Table B-45: Longitudinal Range Between HV and RV at LCW Alert Onset and Offset and Speeds for HV = Red Cascadia Bobtail, RV= Honda Odyssey

Test No.	HV Front to RV Front at Onset (m)		HV Rear to RV Front at Onset (m)		Speeds (mph)		HV Front to RV Front at Offset (m)	
	RT	WSU	RT	WSU	HV	RV	RT	WSU
898	-25.2	-25.2	-17.2	-17.2	34.7	39.7	1.7	1.4
899	-23.7	-24.1	-15.6	-16.1	34.6	39.1	1.4	0.8
900	-25.4	-25.1	-17.3	-17.1	34.2	39.5	1.8	1.5
901	-26.1	-25.9	-18.1	-17.9	34.4	40.0	1.7	1.3
902	-24.3	-24.6	-16.3	-16.6	34.6	39.5	2.1	1.3
Ave.	-24.9	-25.0	-16.9	-17.0	34.5	39.5	1.7	1.2
Std.	1.0	0.7	1.0	0.7	0.2	0.3	0.2	0.3
C.V.(%)	3.8	2.8	5.6	4.1	0.5	0.8	13.0	22.4

DOT HS 812 317
November 2016

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

12423-110116-v2