Connected Commercial Vehicles—Retrofit Safety Device Kit Project

Applications Performance and Functional Test Report

Publication No. FHWA-JPO-14-108 March 28, 2014

U.S. Department of Transportation
Federal Highway Administration

Notice

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The U.S. Government assumes no liability for the use of the information contained in this document.

The U.S. Government does not endorse products or manufacturers. Trademarks or manufacturers' names appear in this report only because they are considered essential to the objective of the document.

Quality Assurance Statement

The Federal Highway Administration provides high quality information to serve Government, industry, and the public in a manner that promotes public understanding. Standards and policies are used to ensure and maximize the quality, objectivity, utility, and integrity of its information. FHWA periodically reviews quality issues and adjusts its programs and processes to ensure continuous quality improvement.

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-JPO-14-108		

4. Title and Subtitle	5. Report Date
Connected Commercial Vehicles—Retrofit Safety Device Kit Project: Applications Performance and Functional Test Report	March 28, 2014
	6. Performing Organization Code 100005986
7. Author(s) Scott Bogard and David LeBlanc	8. Performing Organization Report No. 100005986-405
9. Performing Organization Name And Address University of Michigan Transportation Research Institute (UMTRI) 2901 Baxter Road Ann Arbor, MI 48109-2150 Battelle 505 King Avenue Columbus, OH 43201	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-11-D-00014/T11001
12. Sponsoring Agency Name and Address Federal Highway Administration 1200 New Jersey Avenue, S.E. Washington, DC 20590	13. Type of Report and Period Covered Task Report 9/1/2011 to 3/30/2014 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Connected vehicle wireless data communications can enable safety applications that may reduce injuries and fatalities. Cooperative vehicle-to-vehicle (V2V) safety applications will be effective only if a high fraction of vehicles are equipped. Deployment of V2V technology will be enabled if it is available not only for manufacturing in new vehicles but also for retrofit to existing vehicles. The objective of the Connected Commercial Vehicles—Retrofit Safety Device (CCV-RSD) Kit Project was to develop complete hardware and software that can be used in various brands and models of heavy trucks. The RSD kits provide the functionality needed for cooperative V2V and vehicle-to-infrastructure (V2I) safety applications to support the Model Deployment and other USDOT connected vehicle projects. This project included testing and documentation needed for installation, operation, enhancement, and maintenance of the units. These retrofit kits were built so they could be installed in existing class 6, 7, or 8 trucks. The RSD kits achieved a V2V and V2I functionality similar to that of the Connected Commercial Vehicles—Integrated Truck vehicles, where onboard equipment was integrated with newly manufactured truck tractors.

This report documents tests on the functionality of the safety applications on a closed course. More than 20 scenarios were developed to verify safety application performance in both typical and challenging pre-crash conditions. Most scenarios tested whether a warning was displayed to the driver at the appropriate time, and some tested whether the system would withhold a warning when it was not warranted. Several test runs were conducted for each scenario. The system passed all of the tests that were run.

17. Key Words	18. Distribution Statement
Commercial vehicle, connected vehicle, commercial motor vehicle, CMV, dedicated short-range communication, DSRC, V2V	Distribution unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	78	

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

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACRONYMS AND ABBREVIATIONS

BSM	Basic Safety Message
BSW	Blind Spot Warning
CAN	Controller Area Network
CSW	Curve Speed Warning
DAS	Data Acquisition System
DSRC	Dedicated Short Range Communications
DVI	Driver-Vehicle Interface
EEBL	Emergency Electronic Brake Lights
FCW	Forward Collision Warning
GPS	Global Positioning System
GUI	Graphical User Interface
HV	Host Vehicle
HVT	Host Vehicle Truck
IMA	Intersection Movement Assist
LCW	Lane Change Warning
MITRP	Michigan Technical Resource Park
NHTSA	National Highway Traffic Safety Administration
OEM	Original Equipment Manufacturers
OTA	Over the Air
RqAx	Required Deceleration [to avoid a forward collision]
RSD	Retrofit Safety Device
RvAx	Acceleration of the RV

RV	Remote Vehicle (a.k.a. RV1)
RVL	Remote Vehicle – Light Vehicle
RVT	Remote Vehicle – Truck
SAE	SAE International
TIM	Traveler Information Message
TTC	Time-To-Collision
UMTRI	University of Michigan Transportation Research Institute
USDOT	United States Department of Transportation
V2V	Vehicle-to-Vehicle
WSU	Wireless Safety Unit

EXECUTIVE SUMMARY

The Connected Commercial Vehicles—Retrofit Safety Device (CCV-RSD) Kit Project involved the development, validation, and field testing of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) safety applications for commercial vehicles. These safety applications were built in a kit by the contractor team, and the kit was installed on a truck tractor by staff from the U.S. Department of Transportation using instructions from the contractor team.

This report presents test results from a series of objective performance tests of four applications: Emergency Electronic Brake Lights, Forward Crash Warning, Blind Spot Warning and Lane Change Warning, and Intersection Movement Assist.

Several runs were made in each of 25 test scenarios on a closed course. The purpose was to verify that the safety application performance was consistent with design intentions in both typical and challenging pre-crash scenarios. The system passed all 25 scenarios.

This project demonstrated that the safety applications can be retrofit on existing truck tractors.

CHAPTER 1. INTRODUCTION

The Connected Commercial Vehicles—Retrofit Safety Device (CCV-RSD) Kit Project involved the development, validation, and field testing of vehicle-to-vehicle and vehicle-to-infrastructure safety applications. The RSD technologies provide information or warnings to drivers to help them avoid or reduce the severity of crashes associated with several specific pre-crash situations. The safety applications are implemented using prototype equipment that uses data from the host vehicle, inertial sensors, global positioning system (GPS), and signals received over the air from one or more nearby vehicles that are broadcasting a defined set of information.

The purpose of the testing described in this report is to verify that that the alerts generated by the RSD safety applications are consistent with the intended function and operational performance of the system. This document is a companion to another report, Safety Application Performance and Functional Test Plan and Procedure,[(2)] which defined the test scenarios that were addressed in this report.

The results are from testing conducted from October 30 to November 2, 2012.

Following instructions written by the team, staff from the U.S. Department of Transportation (USDOT) staff installed the kits.

Chapter 2 of this document provides a brief overview of the test scenarios, the test facility, and the test equipment. Chapter 3 presents the results for each of the test scenarios, and chapter 4 summarizes the results and provides summary statements about the results.

CHAPTER 2. OVERVIEW OF TESTS

Four safety applications have been developed to take advantage of the capabilities of vehicle-to-vehicle (V2V) communication. Several scenarios were developed to test the applications for proper functioning. Two tractors equipped with CCV-IT and one light vehicle were used to drive these scenarios. This chapter describes the applications, the scenarios, the vehicles, and the test facility.

SAFETY APPLICATIONS FOR CONNECTED COMMERCIAL VEHICLES

The Connected Commercial Vehicle Retrofit Safety Device system includes five safety applications, as described in RSD Applications Requirement Document:(1)

- Electronic Emergency Brake Lights (EEBL)
- Forward Collision Warning (FCW)
- Blind Spot and lane Change Warning (BS+LCW)
- Intersection Movement Assist (IMA)
- Curve Speed Warning (CSW)

The test plan(2) defined test scenarios and associated procedures for executing those tests. In each scenario, the OBE is expected to issue (or is expected not to issue) an alert to the driver. The test plan also contained requirements on the test vehicles, wireless data exchange, data collection, testing conditions, and the test facility itself. Throughout this current report on the results of running these tests, frequent reference will be made to the test procedures document, including notes when it was necessary to execute the tests in a manner that was different from the test plan.

When the OBE detects a potentially dangerous situation, it alerts the driver of the nature and severity of the situation. A visual icon indicates which of the applications is issuing the alert (that is, which of the collisions is developing), and most are accompanied by an audible component through the tractor's speakers. An "inform" alert indicates a lower level of severity, and a "warn" alert is a higher level requiring immediate action of the driver.

The term *application* is used commonly within the V2V community to refer to one of the safety functions listed above. Within this report, *scenario* refers to a sequence of maneuvers of two or three vehicles that might trigger a warning from one of the applications. Each scenario was repeated several times, and each repetition was called a *run*. A series of runs of a certain scenario constituted a *test*. Each run had a criterion for success, and an application passed a test if the required number of runs were executed successfully.

SCENARIOS TO TEST THE APPLICATIONS

There were several scenarios to test each of the several applications, and each test was repeated a number of times. Table 1 lists the tests by application. The code on each row contains the application name and test number. The name is a brief description of the scenario. The scenario is illustrated and described more fully in the test results in chapter 3, and complete instructions for executing each test are in the test plan. The abbreviation HV means host vehicle (the vehicle being tested and in which the alert is to be issued). Each test had one or two remote vehicles. A remote vehicle is designated RVT if it is another truck or RVL if it is a light vehicle.

The final column of table 1 indicates where there were variations between the planned test and how it was executed. One test, the Curve Speed Warning, was not executed. The Curve Speed Warning application depends on traveler information messages (TIMs) broadcast by roadside equipment (RSE), which was not available at the time of testing. The table lists 21 scenarios that were performed counting the variations in the IMA scenarios. Table 22 has the results of 25 scenarios.

There were two types of tests. A true positive test was expected to elicit a warning message from the application. A false positive test put the vehicles in a situation that was close to a warning condition but where a warning would have been inappropriate. The success criterion for some of the false positive tests was that the vehicles remained in the prescribed situation for a certain time period without a warning being issued. A “false positive” type scenario was judged to be a success if no alert was issued to the driver after a certain number of attempts or a minimum amount of time driving in the specified conditions. Runs in a “true positive” scenario were judged to be successful if the alert was issued under the proper circumstances.

The test plan specified a criterion for the success of the runs within each test. Typically, a warning was to be issued at the proper moment in 6 of 8 runs of a scenario. Each scenario had one of three metrics:

- Latency. The simplest metric to understand is latency. Latency is the time delay between when a warning condition is met (such as a driver applying the brakes) and when the warning was actually issued by the DVI. The success criterion in these scenarios was that the latency be less than 0.5 s in some scenarios and less than 0.6 s in others.

- Time to Collision (TTC). If the HVT and RVL continue at their current speed and path, they are on a collision course. If the HVT is on a collision course with another vehicle, the driver must be warned of the situation not too soon and not too late. The time to collision is the time that would elapse between the moment a warning is issued and when the two vehicles would collide if they both maintained their speed. One low-speed scenario had a success criterion that the TTC be 5.0 ± 1.0 s. Other scenarios had criteria of 6.0 ± 1.0 s or 7.0 ± 1.0 s.

- Required Acceleration (RqAx). The deceleration required of the HVT to avoid a collision with the RVL. When both vehicles are decelerating (as in Test FCW-4), this is more appropriate than TTC.

The descriptions of the scenarios in chapter 3 identify the criteria. The master summary of results, table 22, also lists the criterion for each scenario.

The pass-fail criterion of a small number of the tests was changed, from the test plan, based on experiences during the application development period and the pre-testing rehearsals at the test track with the tractors. These are:

- Runs for tests FCW-1, FCW-2, FCW-5, and FCW-7 were evaluated using a time to collision (TTC) criterion of 6.5 ± 1.0 s, instead of the test plan range criterion of 85.2 ± 7.5 m. The metric was changed for two reasons. First, the TTC metric better accommodates the slight variations in kinematics conditions of individual test runs. That is, if the actual speeds are very slightly different than the ideal test speed, the TTC metric is only slightly different. This approach is more consistent with most vehicle-level objective tests, such as the NHTSA New Car Assessment Program (NCAP) tests. Secondly, the TTC criterion corresponds to a longer range than was in test plan, to account for the longer stopping distances of heavy trucks.

- Test FCW-4 was evaluated using a required deceleration (RqAx). This metric allows for slight variations in actual testing trials, in the same manner as TTC was used for vehicles that are not decelerating.

- Test IMA-1, where two moving vehicles were approaching each other was to be evaluated by the distance and speed separating the vehicle at the moment of warning. The criterion used was the TTC of the HVT assuming the RVL would crash with the HVT in the center of the HVT lane. In these tests, the vehicles approach at a 90-degree angle. Hence, the measured range and range-rate are the un-resolved hypotenuse between the vehicles. To evaluate the timeliness of the warnings in these scenarios, geometry was used to solve for HVT distance to crash. This distance and the speed of the HVT at the time of warning were used to determine the TTC for the pass/fail criterion.

Table 1. Test scenario table.

Scenario Code	Name	Type	Performed
EEBL-1	HVT Drives Behind Braking RVL	True positive	✓
EEBL-2	HVT Drives Behind RVT Which Drives Behind Braking RVT	True positive	✓
EEBL-3	HVT Drives Behind Mild Braking RVT	True positive	✓
EEBL-4	HVT Drives Behind Braking RVT in Left Adjacent Lane	False positive	✓
FCW-1	HVT Drives Behind Stopped RVL	True positive	✓
FCW-2	HVT Drives Behind RVT Which Drives Behind Stopped RVL	True positive	✓
FCW-3	HVT Tailgates RVT	False positive	✓
FCW-4	HVT Drives Behind Braking RVT	True positive	✓
FCW-5	HVT Changes Lanes Behind Stopped RVT	True positive	✓
FCW-6	HVT Passes a Stopped RVT on a Curve	False positive	✓
FCW-7	HVT Drives on a Curve Behind RVT Stopped in the Curve	True positive	✓
FCW-8	HVT Drives Behind Moving RVT in Left Adjacent Lane and Passes it in a Curve	False positive	✓
BSW+LCW-1	RVL Passes HVT on the Left	True positive	✓
BSW+LCW-2	RVL Passes HVT on the Right	True positive	✓
BSW+LCW-3	Two RVLs Pass HVT on the Left and Right	True positive	✓
BSW+LCW-4	HVT Passes RVL on the Left and Pauses	True positive	✓
BSW+LCW-5	RVT Tailgates HVT	False positive	✓
BSW+LCW-6	RVT and HVT Separated by One Lane	False positive	✓
BSW+LCW-7	RVT Passes HVT in a Curve	True positive	✓
IMA-1	Approaches with Moving HVT and RVL	True positive	✓
IMA-2	Stopped HVT, Moving RVL	True positive	✓
CSW	Curve Speed Warning Test	True positive	no

Source: UMTRI

TEST VEHICLES

The host vehicle (HV) used in the testing was an RSD tractor, as shown in figure 1 along with the 40-foot modular container trailer. The HVT was hitched to this trailer for the BSW/LCW scenarios, and it ran bobtail (without a trailer) for all of the other scenarios.

The RSD HVT was equipped with the safety applications being tested, as well as an UMTRI data acquisition system (DAS) shown in figure 2. The DAS in the HVT was outfitted with a live display of DAS data for use by the test engineer driving the tractor (figure 3). This display was useful for establishing proper test conditions, such as headway distance.

The primary remote vehicle (RVL) was a 2006 Honda Accord SE equipped with a DENSO miniWSU, as shown in figure 4. In tests that required a second remote vehicle, the 2005 Subaru Outback shown in figure 5 was used. The DENSO MiniWsu onboard equipment broadcasted basic safety messages (BSMs) outlined in the SAE J2735 standard throughout testing [3]. The test procedures called for several remote vehicles (RVs), however, with the revisions of tests, as discussed in chapter 3, only a second remote vehicle passenger (RVL) was used. That system was also equipped with a portable DENSO WSU device to allow testing with three interacting vehicles for specific scenarios.

Source: UMTRI

Figure 1. Photo. Host vehicle: International ProStar 8600 Day Cab with the 40-ft modular container that was attached for some tests.

Source: UMTRI

Figure 2. Photo. UMTRI Gen5 DAS.

Source: UMTRI

Figure 3. Photo. Interface for HVT driver.

Source: UMTRI

Figure 4. Photo. Remote vehicle outfitted with a newer GEN5 DAS and a DENSO miniWsu.

Source: UMTRI

Figure 5. Photo. Second remote vehicle outfitted with a DENSO MiniWsu.

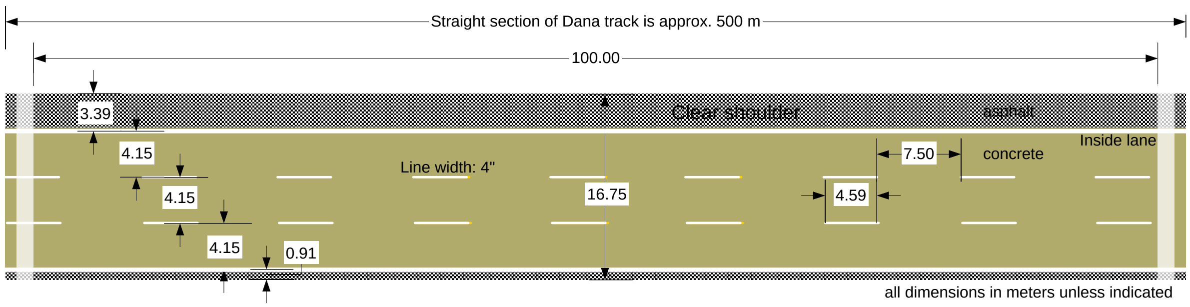
TEST TRACK

Testing was conducted at the Michigan Technical Research Park (MITRP) in Ottawa Lake, Michigan. MITRP includes an oval test track and associated proving grounds encompassing 330 acres and a wide range of test surfaces (see figure 6). Only the oval test track and its staging area were used for RSD testing.

Source: UMTRI

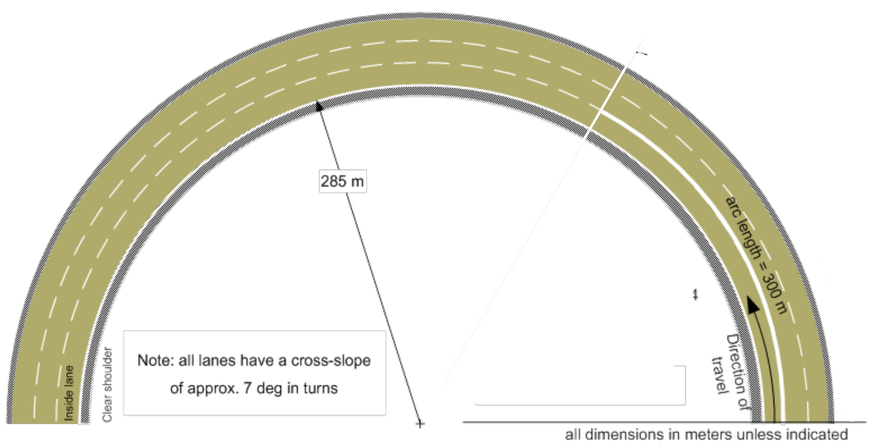
Figure 6. Photo. MITRP oval test track.

The track is a 3-lane, 1.75 -mile track with 14 to 15 ft. lane widths of Portland concrete with asphalt berm. The boundary and pavement type layout for the test track is shown in figure 7. The figures shows a clear shoulder on the inside of the track that is 3.4 m (10 ft) wide and is bounded by a with continuous 4 inch line around the entire oval. In the straight section of track the lane widths are a minimum of 4.15 m (13.6 ft) but become wider in the center and outer lanes until they reach as wide as 5.0 m (16.4 ft) in the curves. The outer boundary of the outside lane is also a 4-in. continuous white line around the entire track. An asphalt shoulder that is 0.91 m (2.9 ft) bounds the outside of the outer lane. Both the eastern and western curves also have a continuous metal guard rail outside the shoulder.



Source: UMTRI

Figure 7. Illustration. Boundary and pavement type drawing for the test track.



Source: UMTRI

Figure 8. Illustration. MITRP eastern curve.

CHAPTER 3. TEST RESULTS BY SCENARIO

This chapter presents the testing results for each scenario. The scenarios are grouped by application and presented in the same order as they were in table 1. A brief description and illustration of each scenario is presented, followed by the expected results and a table of actual results.

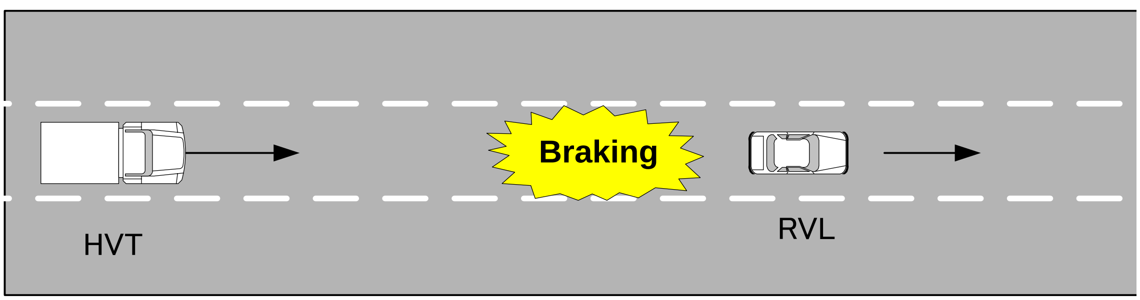
Chapter 4 provides a summary table of these results and a discussion of the overall conclusions regarding the RSD system performance.

EMERGENCY ELECTRONIC BRAKE LIGHTS (EEBL) TESTS

As described in the test plan, the goal of EEBL is to warn the driver that a vehicle ahead in traffic is braking hard, even when the host vehicle driver's view is obstructed by other vehicles or bad weather conditions.

EEBL-1: HVT Drives Behind Braking RVL

This test is to verify that the EEBL system will issue a warning when a vehicle ahead brakes abruptly. The application is to warn the driver when the instantaneous braking of the RVL exceeds the EEBL braking threshold of 0.4 g. This is shown in figure 9, where the HVT is shown bobtail (without a trailer) as was planned.



Source: UMTRI

Figure 9. Illustration. HVT drives behind braking RVL.

The initial conditions for the test are shown in table 2, with the HVT running bobtail (without a trailer), as designed. The RVL was a light vehicle.

The test was conducted on a straight section of track. When the initial conditions for the test were satisfied, the test conductor instructed the driver of the RVL to brake hard. The criterion for a successful test was a latency of less than 0.6 s, where latency is defined as the amount of time between the RVL reaching the EEBL acceleration threshold and the warning being given to the HVT driver.

The conditions and results of the test are shown in table 2. Five runs were conducted, and the system performed with a satisfactory latency of 0.10 s on all runs. The system passed this test.

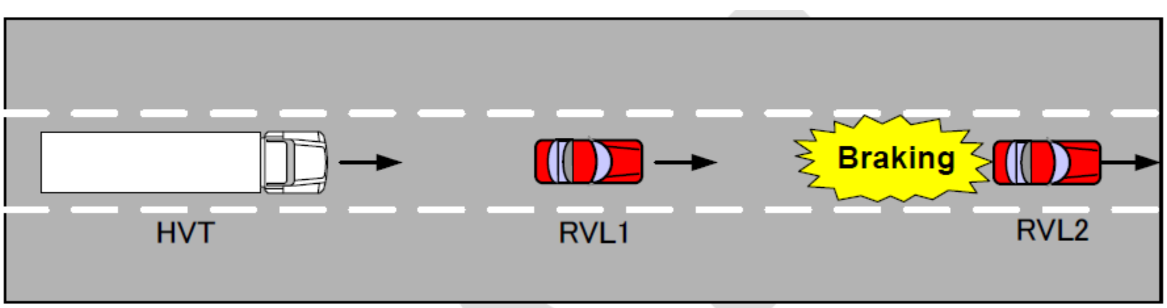
Table 2. EEBL-1: HVT drives behind RVL when RVL brakes hard.

	HvSpeed, m/s	RvSpeed, m/s	Range, m	Latency, s	Pass/Fail
Design Conditions	**15.7 (35 mph)**	**15.7 (35 mph)**	**>125**	**< 0.6**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1	14.0	15.9	156.8	0.10	Pass
Run 2	12.7	15.8	128.4	0.10	Pass
Run 3	16.0	15.9	143.4	0.10	Pass
Run 4	14.4	15.8	137.4	0.10	Pass
Run 5	14.1	15.8	130.1	0.10	Pass
Average	14.3	15.8	139.2	0.10	--
Stdev	1.1	0.1	10.3	0.00	--
Minimum	12.7	15.8	128.4	0.10	--
Maximum	16.0	15.9	156.8	0.10	--
Requirement: 4 of 5 runs are successful. Result: 5 of 5 were successful.					**Pass**

Source: UMTRI

EEBL-2: HVT Drives Behind RVT Which Drives Behind Braking RVL

This test is nearly identical to EEBL-1. It differs in that the driver of HVT1 cannot see RVL2 because the view is obstructed by a third vehicle, RVT1, as shown in figure 10.



Source: UMTRI

Figure 10. Illustration. HVT drives behind RVT1 which drives behind RVL2.

The HVT was run without a trailer, the blocking RVT1 was a passenger car, and the remote vehicle that generated the alert, RVL2, was also a light vehicle. The test was conducted on a straight section of track with all vehicles traveling close to the test design conditions of 35 mph. The design distance from the HVT to RVL2 was at least 80 m. The driver of RVT1 was instructed to follow RVL2 with a time gap of at least 2 s.

When the initial conditions for the test were satisfied, the test conductor in the HVT instructed the driver of the RVL2 by radio to perform a hard braking event. A few moments after RVL2 applied the brakes, the driver of the blocking vehicle RVT1 would change lanes to avoid striking the RVL2. (See figure 11, which shows the two vehicles from a camera mounted in the HVT.)

Source: UMTRI

Figure 11. Photo. Picture of RVT1 (blocking vehicle on left) and RVL2 shortly after RVT1 changes lanes.

Table 3 lists the results of this test. The criterion for a run to pass is that the latency is less than 0.6 s. Six runs were conducted, and the average latency runs was 0.07 s, with a maximum of 0.10 s. This system passed this test.

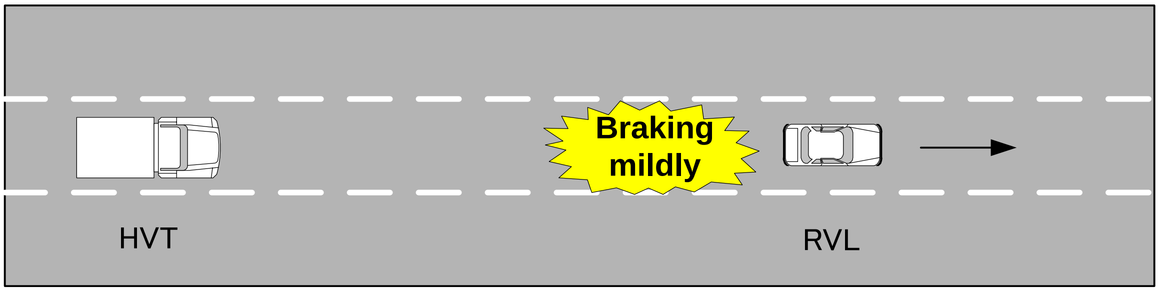
Table 3. EEBL-2: HVT drives behind RV1 and RV2 when RV2 brakes hard.

	HvSpeed, m/s	RvSpeed, m/s	Range, m	Latency, s	Pass/Fail
Design Conditions	**15.7 (35 mph)**	**15.7 (35 mph)**	**>80**	**< 0.6**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1	15.5	15.9	123.2	0.10	Pass
Run 2	15.6	15.9	126.5	0.10	Pass
Run 3	15.5	15.8	139.4	0.10	Pass
Run 4	15.2	15.9	133.0	0.00	Pass
Run 5	15.3	16.0	142.7	0.00	Pass
Run 6	15.2	15.9	153.6	0.10	Pass
Average	15.4	15.9	136.4	0.07	--
Stdev	0.2	0.0	11.2	0.05	--
Minimum	15.2	15.8	123.2	0.00	--
Maximum	15.6	16.0	153.6	0.10	--
Requirement: 4 of 5 runs are successful. Result: 6 of 6 were successful.					**Pass**

Source: UMTRI

EEBL-3: HVT Drives Behind Mild Braking RVT (False Positive)

This test is to verify that the system does not issue an EEBL warning when an RVL far ahead in the same travel lane decelerates mildly. This is classified as a "false positive" type test because any warning would be inappropriate when the RVL is decelerating less the warning threshold. The scenario is illustrated in figure 12.



Source: UMTRI

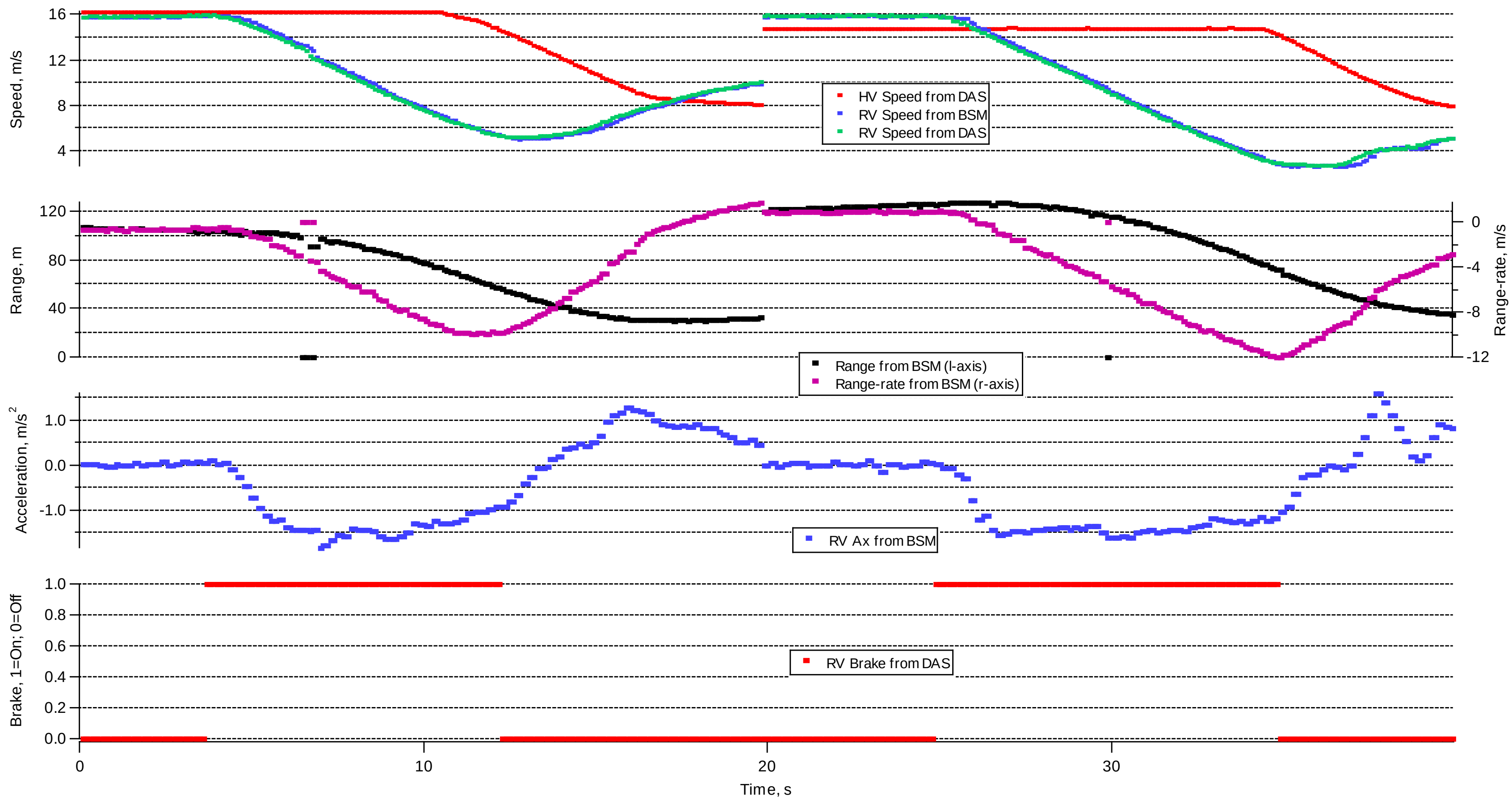
Figure 12. Illustration. HVT drives behind mild braking RVT.

The test plan calls for this test to be run with both vehicles driving at 35 mph, separated by at least 3 s (47 m). The RVL is to at any level more mild than -0.4 g. Two valid runs were conducted at those speeds and initial ranges of between 110 and 120 m, with deceleration values of approximately -0.15 g. None of the runs resulted in an EEBL warning, so the system passed this test.

A time history of the two runs is shown in figure 13. The time histories of the individual runs are combined in the figure by concatenating them along the horizontal time axis, from left to right. (The runs actually happen up to a minute or more apart.) The top pair of traces in the figure shows HVT and RVL speeds. The HVT speed is from the J1939 vehicle data bus, as captured on the DAS. Two RVL speeds are shown. One is from the basic safety message (BSM) broadcast from the RVL and received on the HVT and recorded on its DAS. The second speed was read from the RVL OEM CAN bus, as logged on the DAS on the RVL. The agreement between these RVL speed traces is very good. The speed traces show the RVL slowing in response to the application of the brake pedal (see the bottom trace in the figure). This is followed by HVT deceleration to avoid collision with the RVL.

The second row of traces shows range (distance) and the time derivative of range, or “range rate,” as derived from the GPS locations of the RVL and HVT captured by their DAS.

RVL acceleration is shown in the third row of traces in the figure.

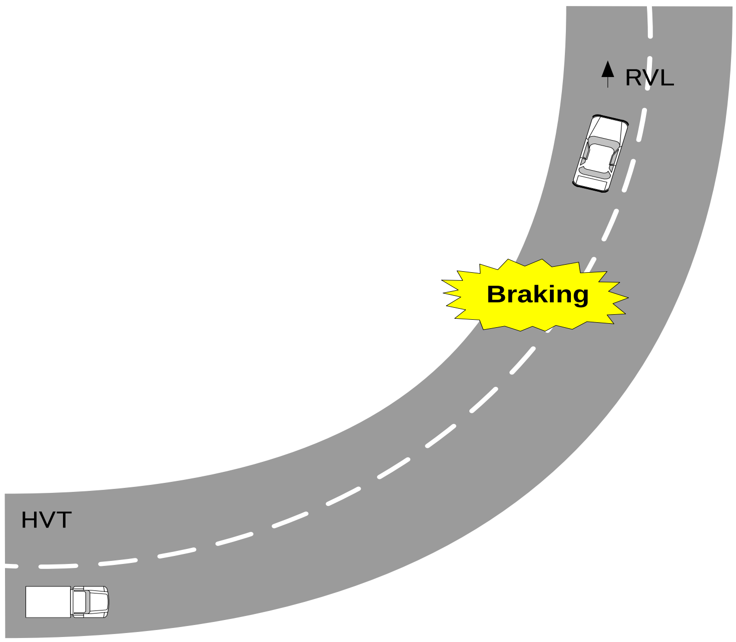


Source: UMTRI

Figure 13. Graph. Time history of EEBL-3: HVT drives behind RVL when RVL brakes moderately (false-positive scenario).

EEBL-4: HVT Drives Behind Braking RVT in Left Adjacent Lane

This test is similar to EEBL-1. The first difference is that the RVL is in a lane adjacent to the HVT. (The EEBL is to warn the driver of a threat vehicle ahead in its own lane or in either of the adjacent lanes, as specified in paragraph 3.4.3.4 (7) on page 20 of the CCV-IT Application Requirement.[(1)]) The second difference was that this test was conducted on a curve.



Source: UMTRI

Figure 14. Illustration. HVT drives behind braking RVT in adjacent left lane.

The test was conducted on curved section of track with the HVT running without a trailer and using a light vehicle RVL. When the initial conditions for the test were satisfied, the test conductor instructed the driver of the RVL to brake hard. The RVL's deceleration was to start at 0.4 g or greater and ramp up to at least 0.5 g.

The criterion for a successful run was a latency of less than 0.6 s. The system performed as intended on six runs, so it passed the test.

Table 4. EEBL-4: HVT drives behind RVL when RVL brakes hard in adjacent lane on curve.

	HvSpeed, m/s	RvSpeed, m/s	Range, m	Latency, s	Pass/Fail
Design Conditions	**15.7 (35 mph)**	**15.7 (35 mph)**	**> 3 s (> 47 m)**	**< 0.6**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1	14.9	15.9	100.1	0.10	Pass
Run 2	13.9	15.8	132.7	0.00	Pass
Run 3	13.7	15.9	123.1	0.20	Pass
Run 4	15.9	15.8	168.2	0.00	Pass
Run 5	15.3	16.0	142.3	0.00	Pass
Run 6	14.1	15.9	106.9	0.10	Pass
Average	14.8	15.9	128.1	0.1	--
Stdev	0.8	0.1	24.8	0.07	--
Minimum	13.7	15.8	100.1	0.0	--
Maximum	15.9	16.0	168.2	0.2	--
Requirement: 4 of 5 runs are successful. Result: 6 of 6 were successful.					**Pass**

Source: UMTRI

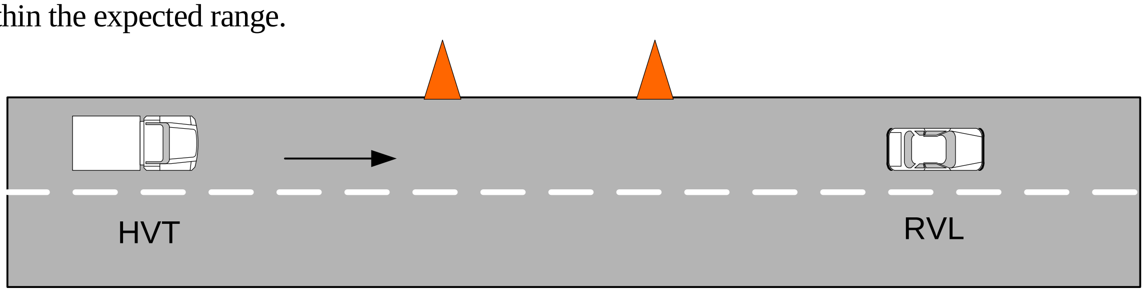
FORWARD COLLISION WARNING (FCW) TESTS

The Forward Collision Warning (FCW) application advises the driver of the HVT in case of an impending collision with a vehicle ahead in traffic in the same lane and direction of travel.

Most FCW test scenarios involve the HVT approaching a remote vehicle from a long range; however, one scenario involves the HVT changing lanes and encountering a slower RV.

FCW-1: HVT Drives Behind Stopped RVL

This test is to verify that the FCW system will issue a warning to the HVT driver when there is a stopped vehicle in its lane. The test determines whether the countermeasure's required alert occurs within the expected range.



Source: UMTRI

Figure 15. Illustration. HVT drives behind stopped RVL.

The HVT approaches the stopped remote vehicle at 35 mph on a straight, flat section of track. The actual conditions at the time of the warning are shown in table 5.

The criterion for a successful test was a time-to-collision of 6.5 ± 1.0 s. Five runs were conducted and the system performed as intended on all five. The average time-to-collision at the moment of warning was 5.9 s.

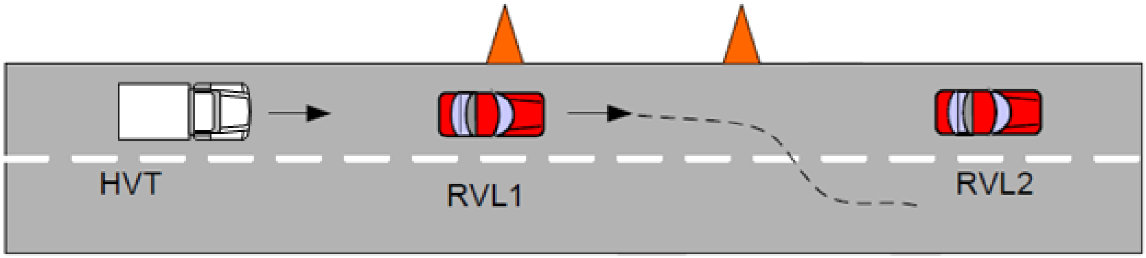
Table 5. FCW-1: HVT conflict with stopped RVL.

	HvSpeed, m/s	**RvSpeed, m/s**	**Range, m**	**Range Rate, m/s**	**TTC, s**	**Pass/Fail**
Design Conditions	**15.7 (35 mph)**	**0.0**	**85.2 ± 8.5**	**--**	**6.5 ± 1.0**	**--**
Case	**Actual Conditions at Warning**				**Test Results**	
Run 1	16.9	0.0	91.5	-17.0	5.4	Pass
Run 2	15.4	0.0	93.6	-15.6	6.0	Pass
Run 3	15.7	0.0	96.2	-15.8	6.1	Pass
Run 4	15.4	0.1	94.1	-15.4	6.1	Pass
Run 5	15.2	0.1	94.8	-15.4	6.1	Pass
Average	15.7	0.0	94.0	-15.8	5.9	--
Stdev	0.7	0.0	1.7	-0.7	0.3	--
Minimum	15.2	0.0	91.5	-17.0	5.4	--
Maximum	16.9	0.1	96.2	-15.4	6.1	--
Requirement: 4 of 5 runs are successful. Result: 5 of 5 were successful.						**Pass**

Source: UMTRI

FCW-2: HVT Drives Behind RVT Which Drives Behind Stopped RVL

This scenario is similar to FCW-1, with the difference that a third vehicle, RVT1 with a trailer, was between HVT and the stopped RVL2. This test verifies that the FCW system will issue a warning to the HVT driver when there is a stopped vehicle in the same lane of travel and there is an obstructing remote vehicle between them. The test determines whether the FCW alert occurs at the correct time even when switching primary targets.



Source: UMTRI

Figure 16. Illustration. HVT drives behind RVT1 which drives behind stopped RVL2.

As illustrated in figure 16, RVT1, changed lanes as it approached RVL2 on a straight section of track. Figure 17 shows two sequential pictures of the scenario. The first picture shows RV1 making a lane change to reveal RV2, while the bottom picture, taken 3 s later, shows RV2 stopped in the path of the HVT.

Source: UMTRI

Figure 17. Photos. FCW-2: picture of RV1 moving left to reveal stopped RV2.

For these runs the HVT was without a trailer, the RVL2 was a light vehicle, and RVT1 a tractor-trailer.

The conditions at the time of the warning are shown in table 6. The actual conditions at alert time were within 10 percent of the desired conditions across all runs. The standard deviation for HVT was less than 1 m/s.

The criteria for a successful test were a time-to-collision of 6.5 ± 1.0 seconds. For this test, eight runs were conducted and the system performed as intended on all eight runs. The average time-to-collision was 6.6 s.

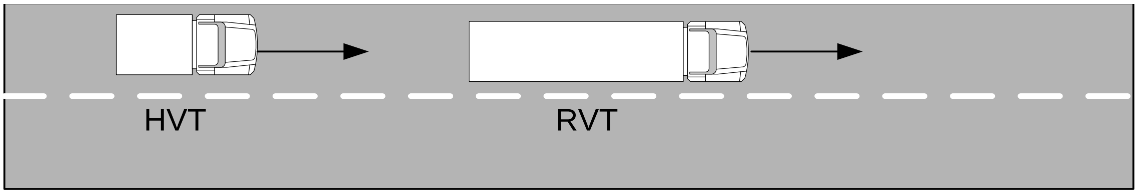
Table 6. FCW-2: HVT conflict with stopped RV2 after cut-out of RV1.

	HvSpeed, m/s	**RvSpeed, m/s**	**Range, m**	**Range Rate, m/s**	**TTC, s**	**Pass/Fail**
Design Conditions	**15.7 (35 mph)**	**15.7 (35 mph)**	**35**	**--**	**6.5 ± 1.0**	**--**
Case	**Actual Conditions at Warning**				**Test Results**	
Run 1	15.7	0.0	97.3	-15.8	6.5	Pass
Run 2	15.7	0.0	97.9	-15.8	6.2	Pass
Run 3	15.7	0.0	96.4	-15.9	6.1	Pass
Run 4	15.7	0.0	96.6	-15.8	6.1	Pass
Run 5	15.7	0.0	98.0	-15.8	6.2	Pass
Average	15.7	0.0	97.2	-15.8	6.2	--
Stdev	0.0	0.0	0.8	0.1	0.1	--
Minimum	15.7	0.0	96.4	-15.9	6.1	--
Maximum	15.7	0.0	98.0	-15.8	6.5	--
Requirement: 4 of 5 runs are successful. Result: 5 of 5 were successful.						**Pass**

Source: UMTRI

FCW-3: HVT Tailgates RVT (False Positive Test)

This test is to verify that the FCW system will not issue a warning when closely following another vehicle in steady state driving. Figure 18 is an illustration of this test procedure.



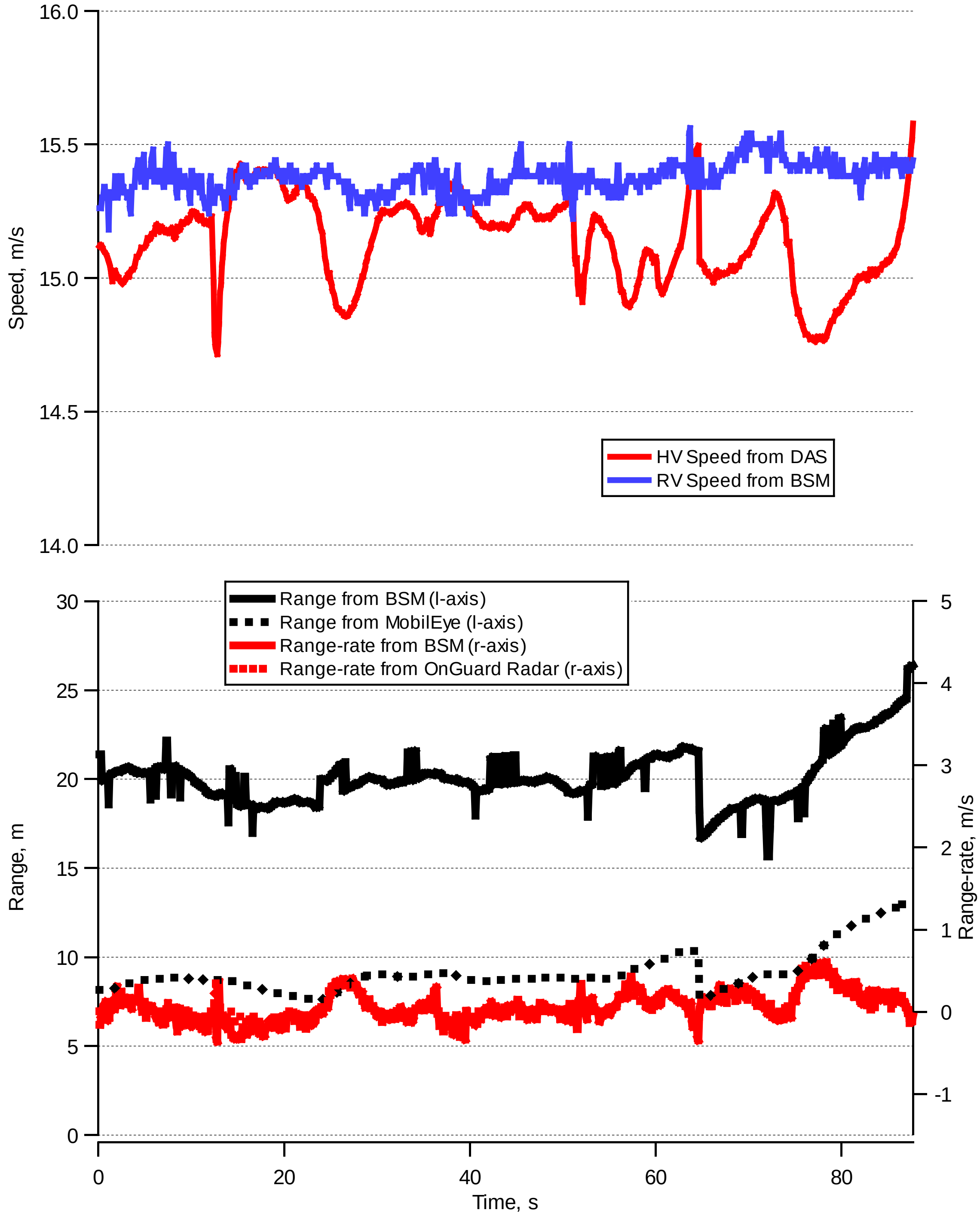
Source: UMTRI

Figure 18. Illustration. HVT tailgates RVT.

The RVT driver was instructed to set the cruise control at 35 mph (15.7 m/s). The HVT then followed the RVT, slowly varying the distance between the HVT and RVT. During the 70-s test, the range between the two vehicles was maintained between 5 and 7 m, and the closing speed in the range ± 0.5 m/s. This method is different than that described in the test plan in that the actual test involved an ongoing tailgating period instead of two discrete events of 2-s duration. By tailgating for an extended time period, the performed test were more rigorous than the original test plan because the system needed to perform as intended for a much longer period of time (70 s instead of 2 s).

Figure 19 is a time history plot of the test. The speed of the RVT and HVT are shown at the top of the figure. Range and range-rate measures are shown in the bottom of the figure. The distance and relative speed measures are from two sources. The first is derived from the BSM messages received by the HVT from the RVT, which shows the distance between the vehicles as derived from their geometric centers. The second sources of range and range-rate values are from a forward-looking radar sensor mounted near the front bumper of the HVT. This sensor shows a measure of the actual distance between the front bumper of the HVT and the rear end of the RVT.

The system did not issue any warning-level FCWs; however, the system did display to the HVT driver inform-level alerts, indicating that the driver was following at an unsafe distance from the RVT. Therefore the test was passed.

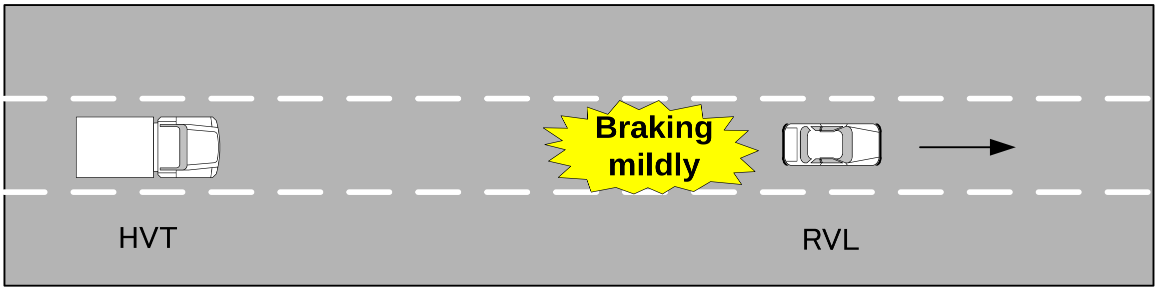


Source: UMTRI

Figure 19. Graph. Speed, range and range-rate for FCW-3: HVT tailgates RVT (false-positive scenario).

FCW-4: HVT Drives Behind Braking RVL

This test is intended to verify the performance of FCW when an RVL ahead begins to decelerate. This test begins with the HVT is following a constant-speed RVL on a straight track at a constant distance (see figure 20). The RVL begins braking and the timing of the FCW is the metric of success.



Source: UMTRI

Figure 20. Illustration. HVT drives behind mildly braking RVL.

The speed of the HVT and RVL was 15.7 m/s (35 mph) before the RVL driver began to slow. The initial following distance was 65 m, corresponding to an interval of 4.1 s. The driver of the RVL was instructed to slow at approximately -2.0 m/s2 (-0.2 g). To achieve a deceleration as steady as possible, the RVL driver monitored the analog accelerometer shown in figure 21. This RVL deceleration is slightly less severe than the test plan, which called for an initial value of -0.2 g ramping up to -0.4 g. The modification was for safety, so that the HVT driver could safely wait for the alert, and then be able to decelerate at a safe level to avoid impacting the RVL. Detecting this lower acceleration may actually be more demanding.

The metric used to evaluate this test was the required deceleration (RqAx). RqAx is an instantaneous measure of the deceleration needed to avoid a crash with the RVL, assuming that the relative kinematic measures of the vehicles do not change. The criterion for a successful run was that the alert be issued at a RqAx of -2.2 ± 0.5 m/s2. This value is conservative. Current production heavy-truck FCW systems have been measured to warn at a required deceleration level of approximately -2.5 m/s2.

The results are in table 7. The average range at warning onset was 61.8 m, with a closing speed of 3.0 m/s when the warning was issued. The most severe of the RqAx at the warning onsets was -2.2 m/s2, which is less demanding than current production systems.

Source: UMTRI

Figure 21. Photo. Analog accelerometer.

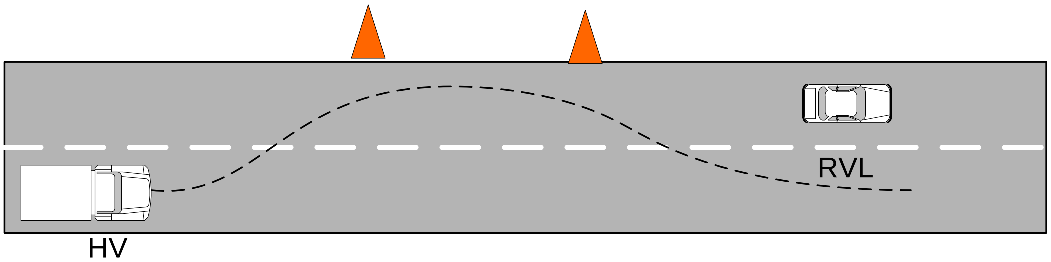
Table 7. FCW-4: HVT conflict with slowing RVL.

	HvSpeed, m/s	**RvSpeed, m/s**	**RvAx, m/s^2**	**Range, m**	**Rdot, m/s**	**RqAx, m/s^2**	**Pass/ Fail**
Design Conditions	**15.7 (35 mph)**	**Slowing from 15.7 (35 mph)**	**-2.0**	**Decreasing from 65**	**--**	**> -2.5**	**--**
Case	**Actual Conditions at Warning**					**Test Results**	
Run 1	16.0	14.1	-1.8	61.1	-2.1	-1.80	Pass
Run 2	15.6	13.7	-1.7	68.7	-2.6	-1.79	Pass
Run 3	16.7	14.2	-1.9	57.9	-3.7	-1.99	Pass
Run 4	16.8	12.9	-2.0	59.6	-3.0	-2.03	Pass
Run 5	17.4	14.8	-2.1	61.9	-3.4	-2.16	Pass
Average	16.5	13.9	-1.9	61.8	-3.0	-2.0	--
Stdev	0.7	0.7	0.1	4.1	0.6	0.2	--
Minimum	15.6	12.9	-2.1	57.9	-3.7	-2.2	--
Maximum	17.4	14.8	-1.7	68.7	-2.1	-1.8	--
Requirement: 4 of 5 runs are successful. Result: 5 of 5 were successful.							**Pass**

Source: UMTRI

FCW-5: HVT Changes Lanes Behind Stopped RVL

This test is to verify that the FCW system will issue a warning when the host vehicle makes a lane change and encounters a stopped vehicle in the new lane, as shown by figure 22. The test determines whether the countermeasure's required collision alert occurs at the expected range and looks at the system's ability to accurately identify stationary in-path targets on a flat, straight section of roadway following a lane change by the HVT.



Source: UMTRI

Figure 22. Illustration. HVT change lanes behind stopped RVT.

The test design initial conditions for the test are shown in table 8. For these runs the HVT was driven on a straight section of track without a trailer and approached a stopped light vehicle. The driver of the HVT was instructed to have completed the lane-change around 100 m from the RVL (the first cone in the figure). The conditions at the time of the warning are also shown in the table. The actual conditions were within 10 percent of the desired conditions across all runs. The standard deviation for HVT speed was less than 1 m/s. The criterion for a successful test was a time-to-collision of 6.5 ± 1.0 s. For this test, four runs were conducted and the system performed as intended on all runs. The average time-to-collision was 6.0 s; this is 0.1 s more than FCW-1.

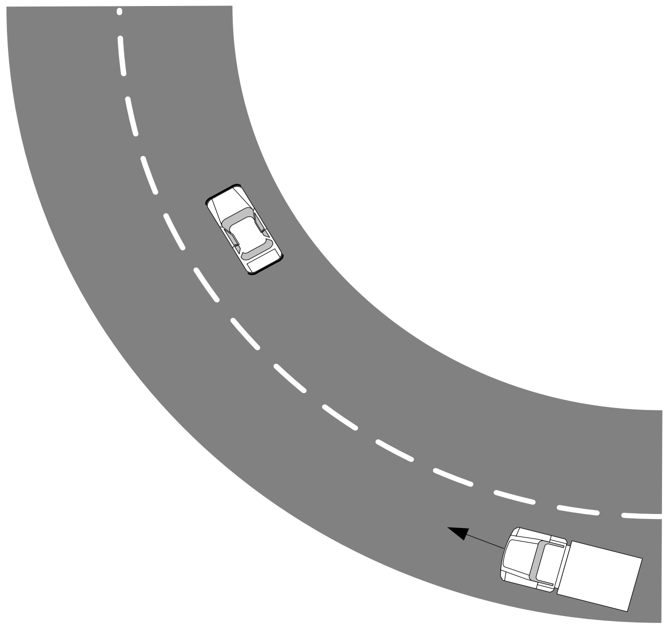
Table 8. FCW-5: HVT makes a lane change behind a stopped RVL.

	HvSpeed, m/s	**Range, m**	**Range Rate, m/s**	**TTC, s**	**Pass/Fail**
Design Conditions	**15.7 (35 mph)**	**300**	**-15.7**	**6.5 ± 1.0**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1	16.1	96.9	-16.2	6.0	Pass
Run 2	16.2	96.7	-16.3	5.9	Pass
Run 3	15.9	96.6	-16.0	6.0	Pass
Run 4	15.7	97.8	-16.0	6.1	Pass
Average	16.0	97.0	-16.1	6.0	--
Stdev	0.2	0.6	0.2	0.1	--
Minimum	15.7	96.6	-16.3	5.9	--
Maximum	16.2	97.8	-16.0	6.1	--
Requirement: 4 of 5 runs are successful. Result: 4 of 4 were successful.					**Pass**

Source: UMTRI

FCW-6: HVT Passes a Stopped RVL on a Curve
(False Positive Test)

This false-positive test shows whether the system can determine that a stopped RVL is not in the lane of travel of the HVT in a curve. No collision alert should be given when there are no FCW threats in the HVT path, so a successful test run is one in which the countermeasure does not warn. An illustration of this test procedure is shown in figure 23.

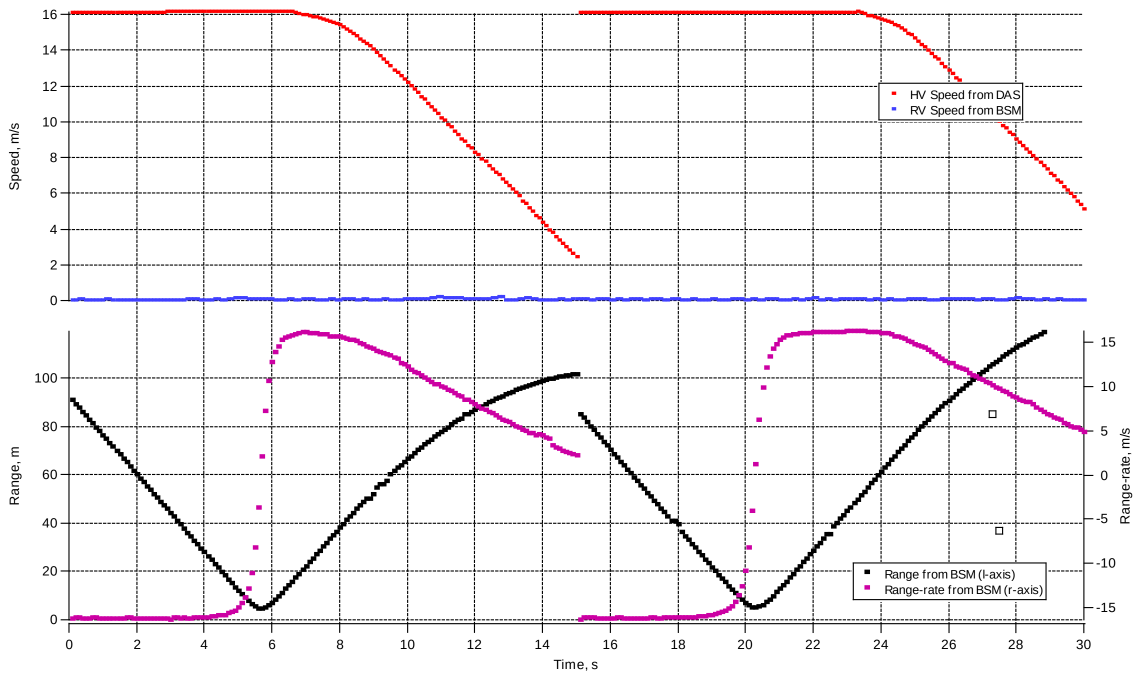


Source: UMTRI

Figure 23. Illustration. HVT drives behind a stopped RVT in a curve.

Figure 24 shows a time-history plot of the two runs done for the FCW-6 scenario. In these tests the RVL was stopped in the inner lane on the curve while the HVT passed in the center lane at 35 mph. A picture of the RVL during one of the runs is shown in figure 25. The system passed this test and no FCW alerts (at either the warn or inform level) during the four runs of this scenario.

The top of figure 24 shows the HVT speed during the each run. The bottom plot in the figure shows the range and range-rate measures derived from the BSM from the RVL. The range values (black) show the vehicles closing until a small value near zero before increasing. This minimum value corresponds to the instant in time when the HVT passes the RVL on the track. The figure also shows the range-rate, which goes from a closing value (negative) to a separating value (positive).



Source: UMTRI

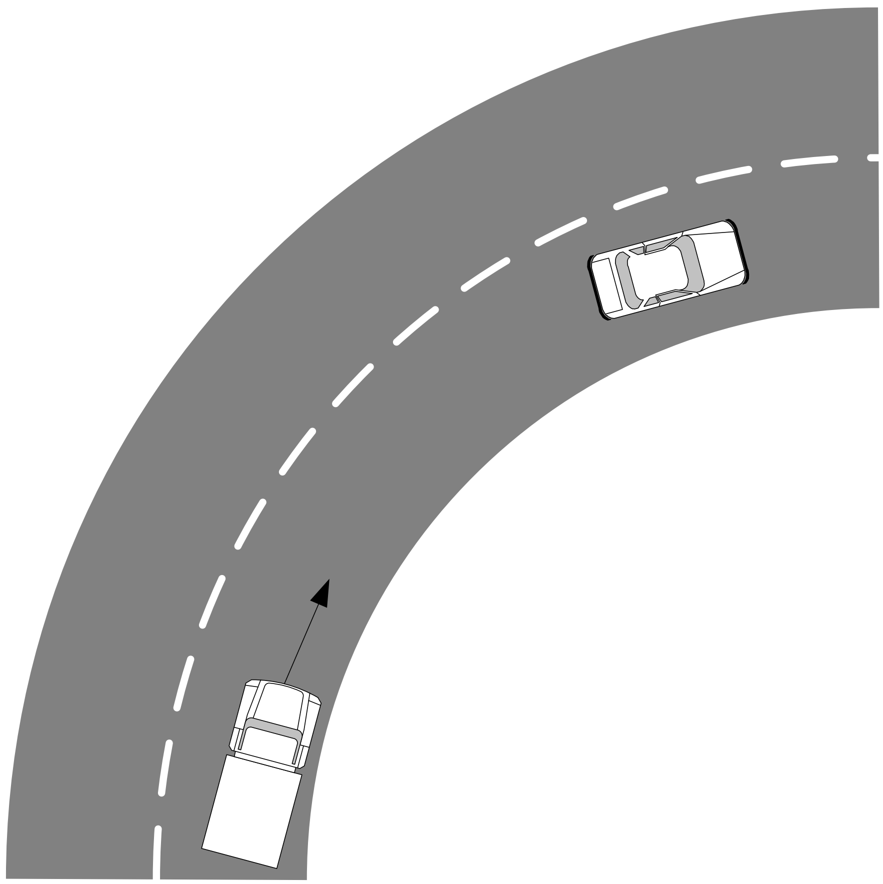
Figure 24. Graph. Speed, range, and range-rate for FCW-6 (false-positive scenario).

Source: UMTRI

Figure 25. Photo. Picture of RVL during FCW-6: passing a stopped RVL in a curve (false-positive scenario).

FCW-7: HVT Drives on a Curve Behind RVT Stopped in a Curve

This test is similar to FCW-1. The primary difference is that both vehicles are in a curve, as illustrated in figure 26, to demonstrate the system's ability to accurately identify stationary in-path targets on a flat, curved section of roadway. The HVT approached the stopped RVL at 36 mph (16.1 m/s) in this test, or about 0.9 mph (0.4 m/s) faster than in FCW-1.



Source: UMTRI

Figure 26. Illustration. HVT drives on a curve behind RVT stopped in the curve.

The results of this test are in table 9. The criterion for a successful test was a time-to-collision of 6.5 ± 1.0 s. For this test, five runs were conducted and the system performed as intended on all five. The average time-to-collision was 6.0 s, or 0.1 s greater than in FCW-1.

Table 9. FCW-7: HVT conflict with stopped RVL in a curve.

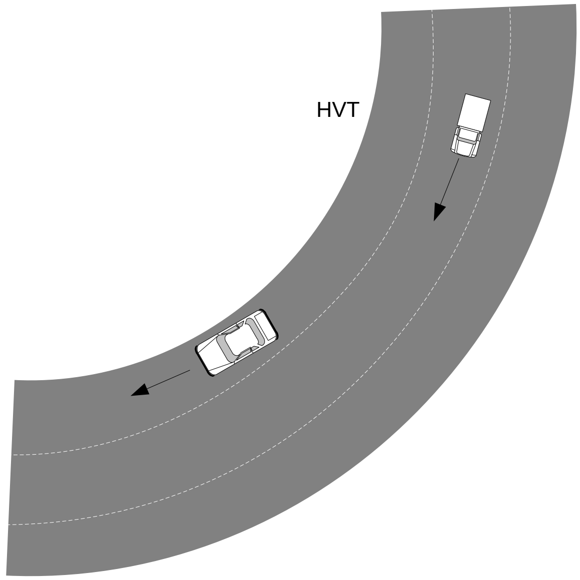
	HvSpeed, m/s	Range, m	Range Rate, m/s	TTC, s	Pass/Fail
Design Conditions	**15.7 (35 mph)**	**300**	**-15.7**	**6.5 ± 1.0**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1	16.1	94.8	-16.0	5.9	Pass
Run 2	16.0	95.9	-15.9	6.0	Pass
Run 3	16.1	95.6	-16.0	6.0	Pass
Run 4	16.1	94.6	-16.2	5.9	Pass
Run 5	16.1	95.2	-15.9	6.0	Pass
Average	16.1	95.2	-16.0	6.0	--
Stdev	0.1	0.5	0.1	0.1	--
Minimum	16.0	94.6	-16.2	5.9	--
Maximum	16.1	95.9	-15.9	6.1	--
Requirement: 4 of 5 runs are successful. Result: 5 of 5 were successful.					**Pass**

Source: UMTRI

FCW-8: HVT Passes Moving RVT on Left Side in a Curve (False Positive Test)

This test shows whether the system can determine that the RVL is not in the lane of travel of the HVT even though the articulated vehicles take up more of the lane width in a curve than in a straight section of road. Figure 27 shows the host vehicle about to pass a remote vehicle in a curve. Figure 28 shows a scene of the RVT taken from the HVT during the testing.

Figure 36 shows traces of the three test runs done to verify that the system does not issue FCWs when the HVT passes the RVL in the curve. Therefore the system passed this false-positive test. For this test the HVT passed the RVL on both the left and the right. HVT and RVL speed are shown in the top of the figure. For this scenario the RVL test speed was 30 mph, the HVT was 35 mph. The bottom of the figure shows the range and range-rate measures as derived from the RVL BSM messages received by the HVT. The passing event occurs when the range plot reaches a minimum.

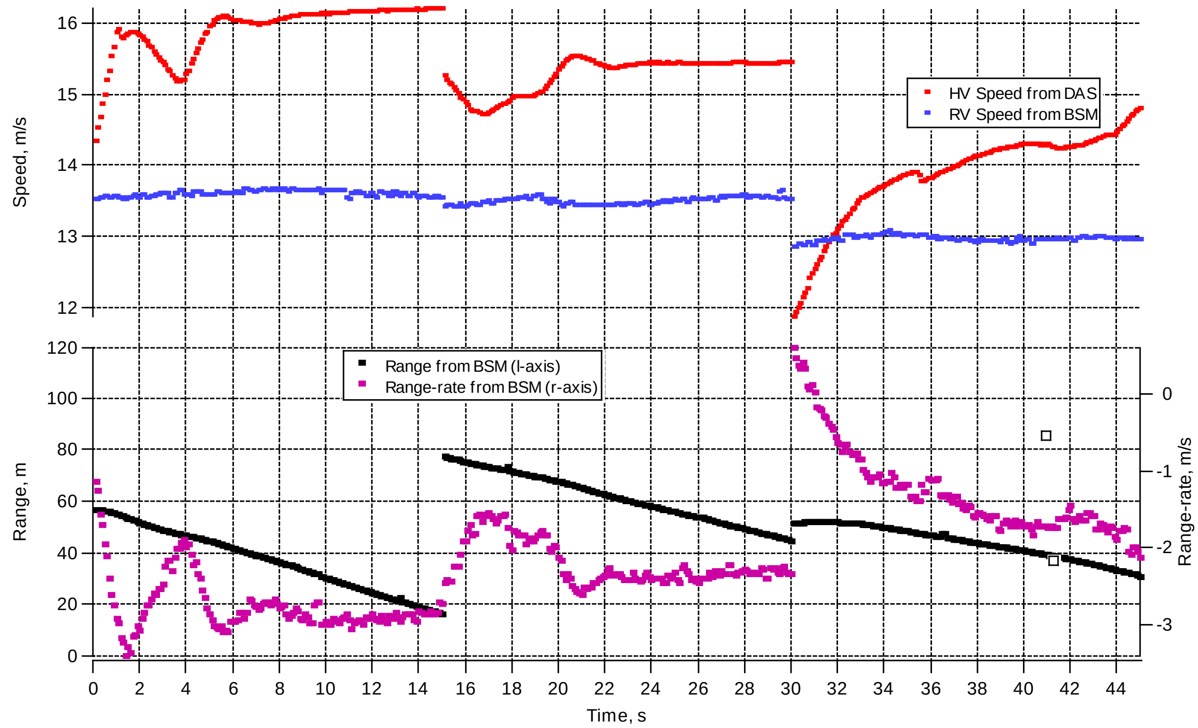


Source: UMTRI

Figure 27. Illustration. HVT drives behind moving RVT in adjacent lane and passes it in a curve.

Source: UMTRI

Figure 28. Photo. Picture showing the RVL in FCW-8 curve (false-positive scenario).



Source: UMTRI

Figure 29. Graph. Results of FCW-8: HVT in an adjacent lane passes a moving RVL in a curve.

BLIND SPOT WARNING (BSW) TESTS

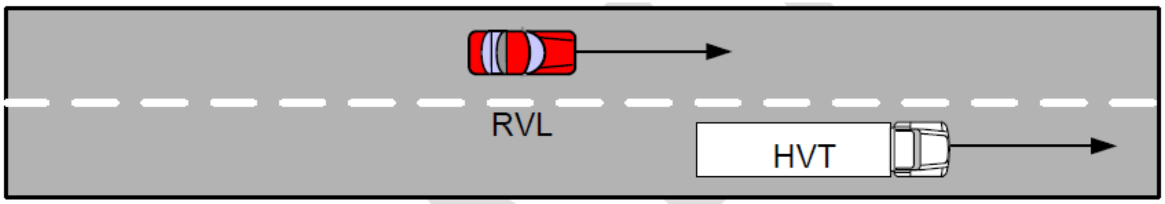
The Blind Spot Warning+Lane Change Warning (BSW+LCW) application provides information the driver when an RV occupies or soon will occupy the HVT blind spot. The inform level is a visual icon with no sound; it is displayed when an equipped vehicle is in the lane adjacent to the HVT. Because the RSD kit does not have access to the tractor's turn signal, it does not have a more urgent Warning level when the driver activates the turn signal.

In all BSW scenarios, the HVT was a tractor-trailer combination and the RVL was a passenger vehicle. When an additional RV is needed, a heavy truck was used. For the safety of the tests, none of the vehicles changed lanes during these tests.

The criterion for a successful run was that the HVT DVI inform the driver that an RV is in the left blind zone when the RVL enters the blind zone, and the message disappears after the RVL has moved ahead of the HVT. The requirement to pass each test was that four of five runs were successful. Test personnel subjectively noted whether the message appeared and disappeared at the proper moments. The tables list the result as the Duration, which is defined as the amount of time the inform icon was shown to the driver.

BSW-1: RVL Passes HVT on the Left

This scenario tests the correct functioning of the BSW+LCW with two vehicles in adjacent lanes on a straight two or more lane road. An illustration of this test procedure is shown in figure 30.



Source: UMTRI

Figure 30. Illustration. RVL passes HVT on the left.

Figure 31 is a series of pictures from the HVT cameras as the RVL passes through the inform zone. The top two are from a rearward-looking camera mounted on the side mirror of HVT's cab. The bottom image is from a forward-looking camera on the HVT.

The HVT and RVL are traveling at 30 mph (13.4 m/s), and each run begins with the RVL at least 30 m behind the rear of the HVT trailer in the adjacent lane. As the two vehicles enter a straight section of track, the test conductor instructs the RVL driver to increase speed to 35 mph (15.7 m/s). Both the HVT and RVL drivers stay in the center of their respective lanes. As the RVL passes the HVT on the left, the RVL driver informs the test conductor when the front of the RVL passes the rear of the trailer. Simultaneously, the HVT driver confirms that the inform icon is shown on the DVI. When the RVL reaches the longitudinal center of the trailer, the HVT driver initiates the turn indicator to the left, which then should change the inform-level message to a warning.

The results of this test are shown in table 10. The data was recorded at the instant when the DVI issued the warning. In all runs, an inform-level alert was issued when the RVL was in position. Six runs were conducted and all passed.

Table 10. BSW-1: RVL passes HVT on the left.

	HvSpeed, m/s	RvSpeed, m/s	Rdot, m/s	Duration, s	Pass/Fail
Design Conditions	**13.4 (30 mph)**	**15.7 (35 mph)**	**2.3**	**--**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1	14.0	16.0	2.1	11.6	Pass
Run 2	13.9	16.1	2.1	11.0	Pass
Run 3	13.1	16.1	3.0	8.3	Pass
Run 4	13.1	16.1	3.0	8.1	Pass
Run 5	13.0	16.3	3.3	9.6	Pass
Run 6	13.4	15.7	2.3	14.3	Pass
Average	13.4	16.1	2.6	10.48	--
Stdev	0.4	0.2	0.5	2.34	--
Minimum	13.0	15.7	2.1	8.10	--
Maximum	14.0	16.3	3.3	14.30	--
Requirement: 4 of 5 runs are successful. Result: 6 of 6 were successful.					**Pass**

Source: UMTRI

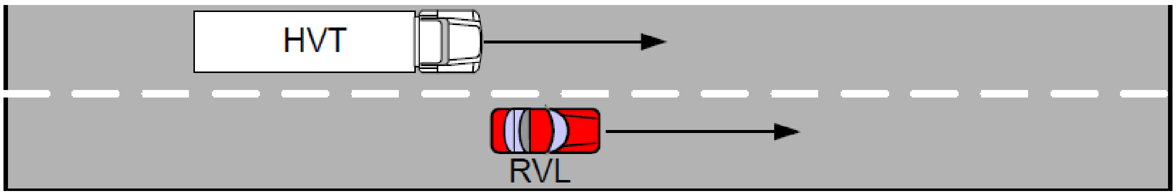
Figure 31 contains pictures from the HVT side and forward cameras of the RVL as it enters (top) and exits (bottom) the inform zone of the HVT.

Source: UMTRI

Figure 31. Photos. Picture of RVL at the start and end of the HVT BSW inform zone on the HVT left.

BSW-2: RVL Passes HVT on the Right

This scenario (illustrated in figure 32) is identical to BSW-1 with the exception that the RVL is on the right side of the HVT. Figure 33 shows pictures from the HVT side and forward cameras of the RVL as it enters (top) and exits (bottom) the inform zone of the HVT.



Source: UMTRI

Figure 32. Illustration. RVL passes HVT on the right.

The results of the test are in table 11. The warning measures are captured at the instant when the DVI issued the warning. Six runs were conducted and all passed.

Table 11. BSW-2: RVL passes HVT on the right.

	HvSpeed, m/s	RvSpeed, m/s	Rdot, m/s	Duration, s	Pass/ Fail
Design Conditions	**13.4 (30 mph)**	**15.7 (35 mph)**	**2.3**	**--**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1	13.2	15.4	2.1	9.3	Pass
Run 2	13.5	15.5	2.0	11.2	Pass
Run 3	13.4	15.8	2.4	8.9	Pass
Run 4	13.5	15.9	2.4	9.9	Pass
Run 5	13.4	15.6	2.3	10.5	Pass
Run 6	12.9	15.6	2.7	8.8	Pass
Average	13.2	15.6	2.3	9.77	--
Stdev	0.2	0.2	0.2	0.95	--
Minimum	12.9	15.4	2.0	8.8	--
Maximum	13.5	15.9	2.7	11.2	--
Requirement: 4 of 5 runs are successful. Result: 6 of 6 were successful.					**Pass**

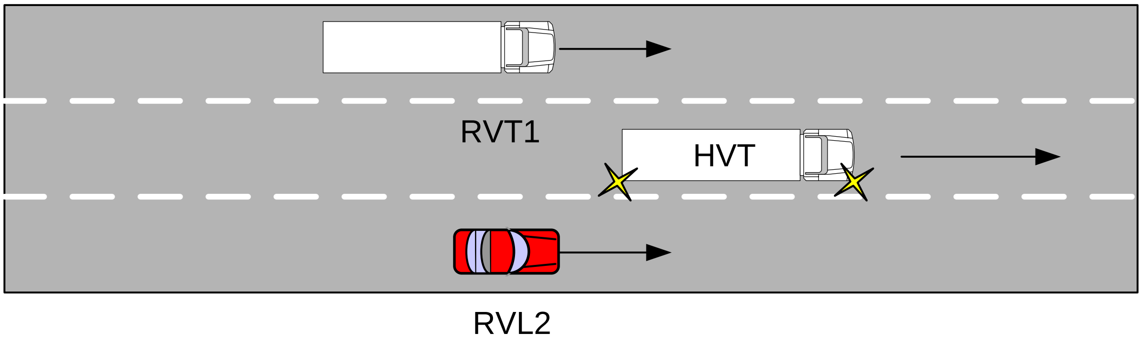
Source: UMTRI

Source: UMTRI

Figure 33. Photos. Sequence of pictures of the RVL as it passes the HVT on the right.

BSW-3: Two RVs Pass HVT on the Left and the Right

In this test, the HVT is passed in adjacent lanes on both sides by a remote vehicle. An illustration of this test procedure is shown in figure 34. The purpose of the test is to ensure that the system issues appropriate inform displays and full alerts.



Source: UMTRI

Figure 34. Illustration. Two RVLs pass HVT on left and right.

The test is conducted by having two remote vehicles simultaneously pass the host vehicle, with monitoring of the DVI to verify that the inform-level alerts are presented when the remote vehicles are adjacent. These tests were conducted with the HVT using the trailer, one RV being the light vehicle described earlier, and the second RV being another RSD tractor.

The DVI displayed a vehicle present on either the left or the right. Because there was no icon for a vehicle present on both the right and left, it would switch back and forth. This was judged to be passing.

Although the two RVs approached the HVT essentially simultaneously, the DAS separately recorded the durations that the two RVs were sensed. These are the durations reported in table 12.

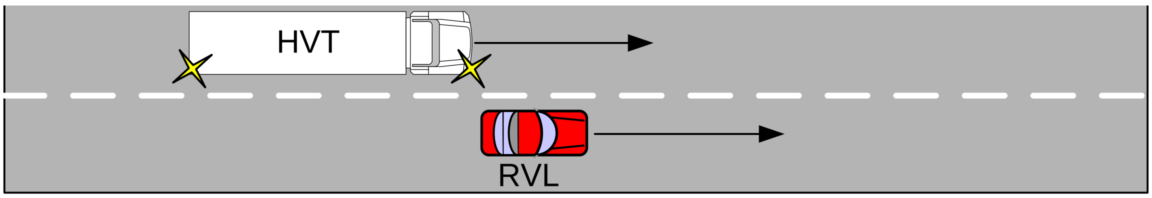
Table 12. BSW-3: Two RVs pass HVT on the left and the right.

	HvSpeed, m/s	RvSpeed, m/s	Rdot, m/s	Duration, s	Pass/Fail
Design Conditions	**13.4 (30 mph)**	**15.7 (35 mph)**	**2.3**	**--**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1-RV2	13.0	15.6	2.5	8.8	Pass
Run 1-RV1	13.0	15.9	2.9	8.8	Pass
Run 2-RV2	13.0	15.6	2.6	8.3	Pass
Run 2-RV1	13.0	15.7	2.7	8.3	Pass
Run 3-RV2	13.0	11.8	-1.2	9.0	Pass
Run 3-RV1	13.0	11.4	-1.6	9.0	Pass
Run 4-RV2	13.0	15.0	2.0	11.3	Pass
Run 4-RV1	13.0	14.9	1.9	11.3	Pass
Run 5-RV2	13.7	16.2	2.5	9.5	Pass
Run 5-RV1	13.7	16.8	3.1	9.5	Pass
Run 6-RV2	13.8	16.0	2.3	9.6	Pass
Run 6-RV1	13.8	16.3	2.6	9.6	Pass
Average	13.3	15.1	1.9	9.4	--
Stdev	0.4	1.7	1.6	1.0	--
Minimum	13.0	11.4	-1.6	8.3	--
Maximum	13.8	16.8	3.1	11.3	--
Requirement: 4 of 5 runs are successful. Result: 6 of 6 were successful.					**Pass**

Source: UMTRI

BSW-4: HVT with RVL in Right Side Blind Spot

This test verifies the proper operation of BSW+LCW in the case that the remote vehicle is in the forward, right side portion of the blind spot. In this scenario, the RVL is positioned in the adjacent lane to the HVT with the front bumper of the RVL aligned longitudinally with the front bumper of the HVT making it exceptionally difficult for the HVT driver to see without the aid of hood-mounted mirrors. An illustration of this test procedure is shown in figure 35.



Source: UMTRI

Figure 35. Illustration. HVT passes RVL on the left and pauses.

This test is conducted with a light vehicle RVL. Initially, in the right adjacent lane, the RVL follows the HVT outside of the BSW inform zone behind the trailer. Upon entering a straight section of roadway, the test conductor instructs the RVL driver to increase speed by 5 mph and move into position adjacent to the HVT. As the RVL does this, the RVL driver reports when it enters the BSW zone at the rear of the trailer. At this point, the HVT driver and test conductor confirm that the DVI indicates that the RVL is adjacent to the HVT with the inform icon.

The results for this scenario are in table 13. Six runs were conducted and all six passed.

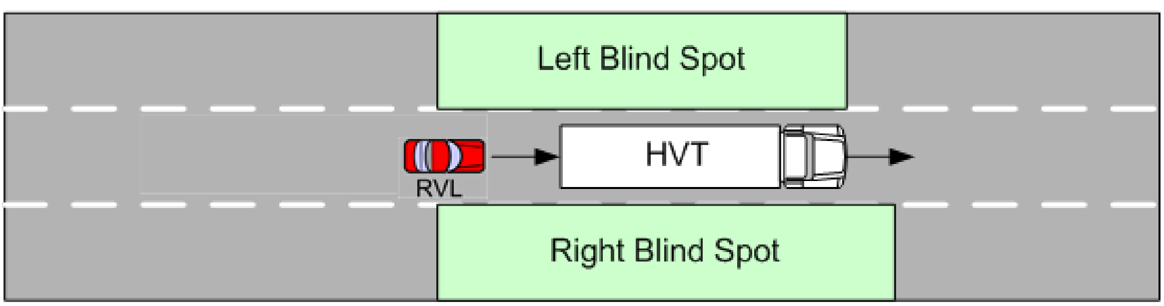
Table 13. BSW-4: RVL in HVT blind spot on right (bumper to bumper).

	HvSpeed, m/s	RvSpeed, m/s	Rdot, m/s	Duration, s	Pass/Fail
Design Conditions	**15.7 (35 mph)**	**15.7 (35 mph)**	**0.0**	**--**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1	15.7	15.7	0.0	14.1	Pass
Run 2	15.8	15.8	0.0	40.1	Pass
Run 3	16.0	15.7	-0.3	15.7	Pass
Run 4	15.8	15.8	0.0	44.1	Pass
Run 5	15.9	15.7	-0.1	38.8	Pass
Run 6	15.8	15.8	0.0	65.9	Pass
Average	15.8	15.8	-0.1	36.5	--
Stdev	0.1	0.1	0.1	19.4	--
Minimum	15.7	15.7	-0.3	14.1	--
Maximum	16.0	15.8	0.0	65.9	--
Requirement: 4 of 5 runs are successful. Result: 6 of 6 were successful.					**Pass**

Source: UMTRI

BSW-5: RVT Tailgates HVT (False Positive Test)

This false positive test verifies the system can distinguish that a vehicle tailgating the HVT is not in an adjacent lane. No alert or warning should be displayed when a RVL is following directly behind the HVT. The test procedure is illustrated in figure 36. The RVL is barely visible behind the HVT in figure 37, a picture taken from the right side mirror of HVT.



Source: UMTRI

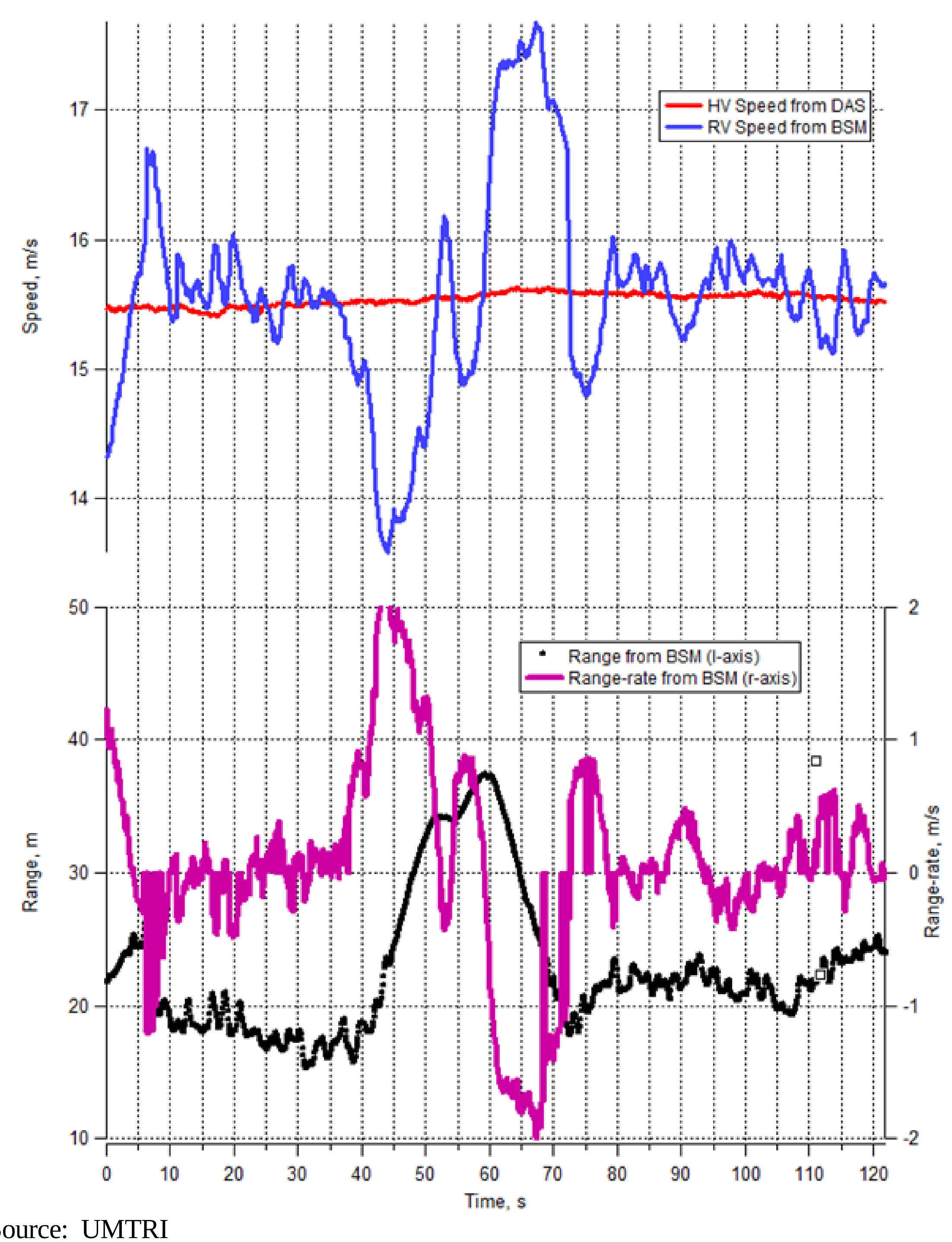
Figure 36. Illustration. RVL tailgates HVT.

For this scenario, the RVL driver was instructed to follow the HVT as close as safely possible, to verify that the BSW system did not issue any inform displays or warnings. This scenario was tested over an extended period of time with the RVL being repositioned in the area just behind the HVT trailer.

Figure 37 shows a picture of the RVL following the HVT. Figure 38 shows a time-history of the test. As shown in the time-history plot, the HVT maintained a constant speed for the test while the RVL modulated speed to both close and separate behind the HVT trailer. The range and range-rate values are shown in the lower part of figure 38. The range between the geometric centers reached a minimum of about 15 m and a maximum of 33 m. The center-to-center offset for these vehicles is about 12 m which when accounted for, indicates that the bumper-to-bumper distance between the front of the RVL and rear of the HVT trailer varied between 3 and 21 m. During this time no BSW indicators were issued by the HVT, so the system passes this test.

Source: UMTRI

Figure 37. Photo. Picture of RVL tailgating HVT during BSW-6 scenario (false-positive scenario).

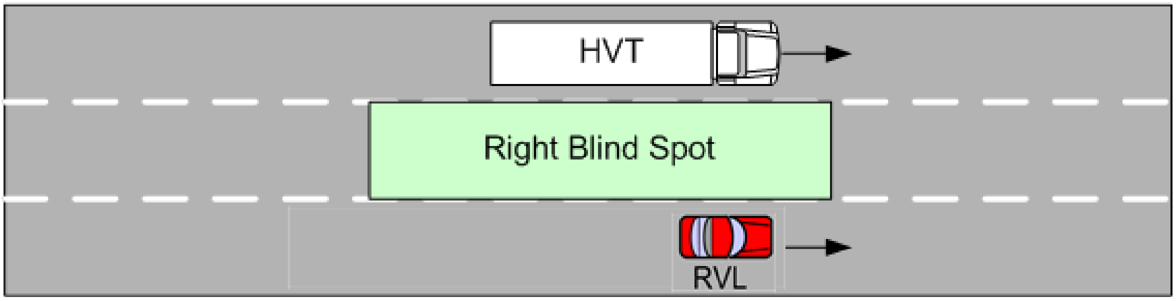


Source: UMTRI

Figure 38. Graph. Time history of BSW-5: RV tailgates HVT (false-positive scenario).

BSW-6: RVL and HVT Separated by One Lane (False Positive Test)

This false positive test verifies that the system can accurately determine that the RVL is two lanes away, not one. No information or warning should be displayed when a RVL is not in a lane adjacent to the HVT. An illustration of this test procedure is in figure 39.



Source: UMTRI

Figure 39. Illustration. HVT and RVL separated by one lane.

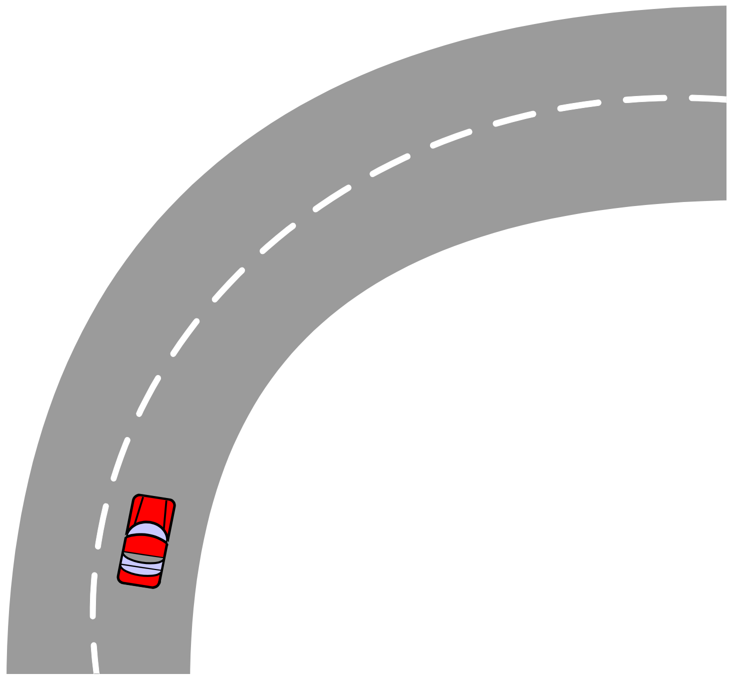
The HVT speed was 35 mph and was held constant using the HVT cruise control. The RVL driver was instructed to move longitudinally, relative to the HVT, in the third lane (with an empty lane between vehicles) to verify that the BSW did not indicate that the RVL was in the space adjacent to the HVT. This maneuver by the RVL was done numerous times with the RVL on both the left and the right of the HVT, and no alerts were issued by the HVT DVI. Thus the system passed this test.

Source: UMTRI

Figure 40. Photos. Photographs of the RVL two lanes away from the HVT.

BSW-7: RVT Passes HVT in a Curve

This scenario tests the correct functioning of the BSW+LCW on a curved road with two or more same-direction travel lanes. The speeds and procedure of this test are identical to BSW-2; the only difference is the curvature of the road. An illustration of this test procedure is shown in figure 41, and camera views from one test run are in figure 42.



Source: UMTRI

Figure 41. Illustration. RVT passes HVT in a curve.

The criterion for success is that the inform-level icon appears in the HVT when the RVL enters the blind zone. The results of the test runs are shown in table 14. The warning measures are captured at the instant when the warning occurs.

Table 14. BSW-7: RVL passes HVT on the right on a curve.

	HvSpeed, m/s	**RvSpeed, m/s**	**Rdot, m/s**	**Duration, s**	**Pass/Fail**
Design Conditions	**13.4 (35 mph)**	**15.7 (35 mph)**	**0.0**	**--**	**--**
Case	**Actual Conditions at Warning**			**Test Results**	
Run 1	13.9	16.2	2.3	10.2	Pass
Run 2	13.8	16.2	2.3	9.1	Pass
Run 3	13.9	16.2	2.3	10.2	Pass
Run 4	13.8	15.4	1.5	13.1	Pass
Run 5	13.9	15.7	1.8	13.1	Pass
Average	13.9	15.9	2.0	11.1	--
Stdev	0.1	0.4	0.4	1.8	--
Minimum	13.8	15.4	1.5	9.1	--
Maximum	13.9	16.2	2.3	13.1	--
Requirement: 4 of 5 runs are successful. Result: 5 of 5 were successful.					Pass

Source: UMTRI

Source: UMTRI

Figure 42. Photos. Picture of RVL at the start and end of the HVT BSW inform zone in a curve.

INTERSECTION MOVEMENT ASSIST (IMA) TESTS

The Intersection Movement Assist (IMA) is a V2V communication safety application that aims to prevent crashes at uncontrolled and stop sign controlled intersections for straight through traffic with intersecting paths. IMA does this by issuing a warning to the driver of the HVT in case a conflict is detected. The IMA presents two levels of alert. An inform display is presented to the driver if other vehicles are approaching and a potential conflict has been detected. A warning is presented to the driver if a potential conflict has been detected and a crash is likely to occur if corrective action is not taken. Only warnings will be tested.

The objective tests fall into two general scenarios. Scenarios IMA-1A to -1D involved a moving RVL and HVT, and Scenarios IMA-2A to -2B involved a stopped HVT with a moving RVL. The test plan called for a blocking vehicle in the case where the HVT was initially stopped, but none was used because the driver's view was not part of the test.

The distances for inform and warn are calculated in reference to the conflict point. The conflict point is the location, in the intersection where the projected trajectories of the HVT and the RVL intersect.

Table 15. Summary of conditions for the scenarios to evaluate the IMA application.

Scenario	Name	HVT Design Speed, mph	RVL Design Speed, mph
IMA-1A	HVT at 15 mph and RVL at 15 mph	15	15
IMA-1B	HVT at 15 mph and RVL at 30 mph	15	30
IMA-1C	HVT at 30 mph and RVL at 15 mph	30	15
IMA-1D	HVT at 30 mph and RVL at 30 mph	30	30
IMA-2A	HVT Stopped and RVL at 20 mph	0	20
IMA-2B	HVT Stopped and RVL at 40 mph	0	40

Source: UMTRI

The tests were conducted at the MITRP testing facility using the intersection of the straight section of the oval track and the driveway into the staging area shown in figure 43. For all IMA scenarios, the HVT was operated without a trailer and the RVL was a passenger car.

IMA-1A: 15 mph HVT and 15 mph RVL Approach at 90 Degree rel. Heading

The purpose of the moving HVT scenarios in the IMA tests is to verify that the system provides warnings and that the timing is consistent with the intended timing.

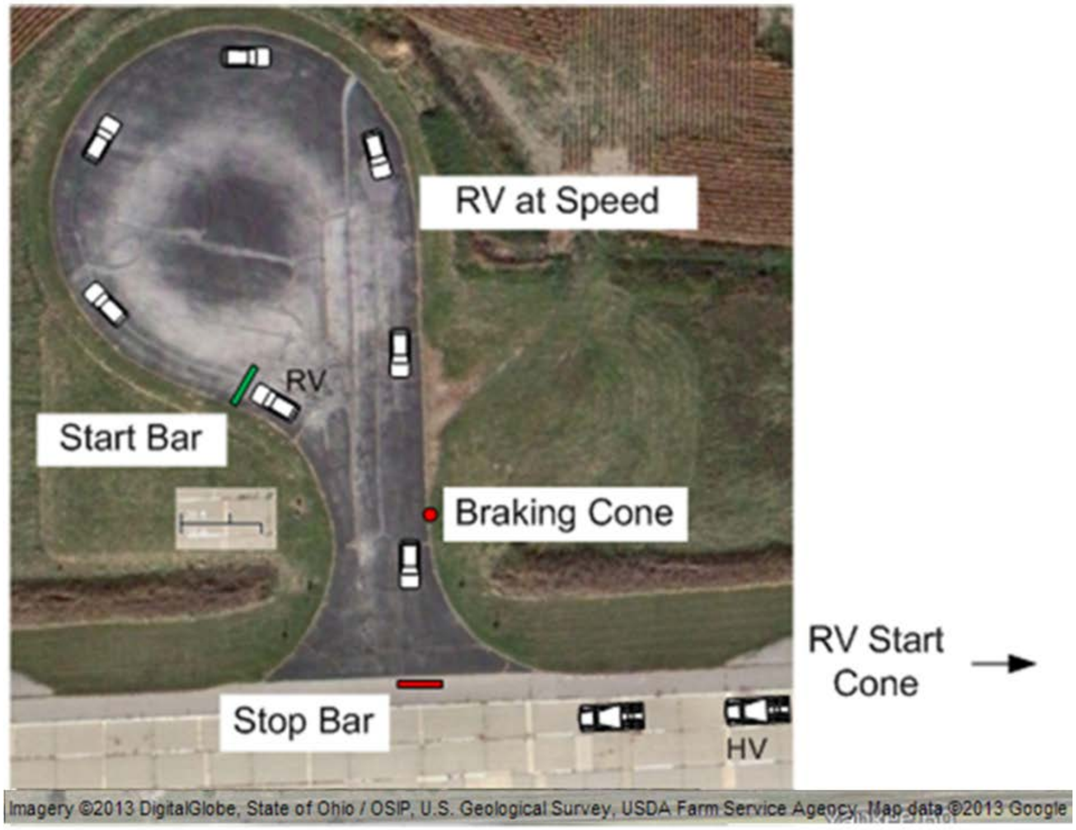
For the scenarios in which the HVT is moving, the execution is directed by the HVT driver (test conductor), who performs these steps:

1. The HVT is positioned about a half-mile from the intersection of the oval and staging area.
2. The HVT accelerates in the inner lane to the desired test speed.
3. When the HVT reaches the RVL start cone, the HVT driver instructs the RVL to go.
4. When an IMA warning is presented the HVT driver brakes and maneuvers to the left away from the RVL.

Instructions for the RVL driver in the moving HVT scenarios are:

1. RVL is stopped and waiting at the Start bar as shown in figure 43.
2. When told to go by the HVT driver, the RVL driver accelerates to the desired test speed while negotiating around the perimeter of the staging area.
3. At the Braking Cone, the RVL driver begins to brake and brings the RVL to a stop before reaching the Stop Bar at the intersection of the oval and staging area.

The position of the Braking Cone and RVL start cone are changed depending on speed of both the HVT and RVL. Practice runs at the different test speeds were conducted to measure the time it takes for the RVL driver to reach the braking cone.



Source: UMTRI

Figure 43. Illustration. IMA test set-up for a moving RVL and HVT.

In this particular test (IMA-1A), both the HVT and the RVL are traveling at 15 mph on perpendicular paths, such that a crash would occur if no driver action is taken. As described earlier, the drivers wait until either a warning is issued, or until they pass safety cones, and then the RVL brakes hard and the HVT changes lanes away from the RVL.

This test scenario was executed only once since it was the last of the moving HVT scenarios performed, and all other IMA-1 runs had been run with successful results for the system. Table 16 shows the conditions at the onset of the IMA warning, as well as the resulting time to collision (time to the virtual crash point). For this test, the criterion for a successful test was a time-to-collision of 5.0 ± 1.0 s, and the system issued its warning within the pass/fail band. So this test was passed with the caveat that fewer runs were conducted than originally proposed.

Table 16. IMA-1A 15 mph HVT and 15 mph RVL 90 deg. approach to an uncontrolled intersection.

	HvSpeed, m/s	HvHdg, °	RvSpeed, m/s	RvHdg, °	Range, m	Range Rate, m/s	TTC, s	Pass/ Fail
Design Conditions	**6.7 (15 mph)**	**west**	**6.7 (15 mph)**	**south**	**(40.25)**	**(-6.7)**	**5.0 ± 1.0**	**--**
Case	**Actual Conditions at Warning**						**Test Results**	
Run 1	6.5	267.2	7.2	178	31.4	-6.5	4.2	Pass

Source: UMTRI

IMA-1B: 15 mph HVT and 30 mph RVL Approach at 90 Degree rel. Heading

In this version of the scenario, the HVT is traveling at 15 mph while the RVL is at 30 mph. Table 17 shows the results from the four runs that were conducted. For all runs, the HVT was heading west while the RVL was heading south. The target speed for the RVL was 30 mph, but the speed achieved by the RVL at the time of warning was less than that. The average distance between the HVT and RVL at the time of the warning was 43.8 m. The average time-to-collision was 5.9 s at the time of the warning. The criteria for a successful test were a time-to-collision of 6.0 ± 1.0 seconds.

Table 17. IMA-1B 15 mph HVT and 30 mph RVL 90 deg. approach to an uncontrolled intersection.

	HvSpeed, m/s	HvHdg, °	RvSpeed, m/s	RvHdg, °	Range, m	Range Rate, m/s	TTC, s	Pass/ Fail
Design Conditions	**6.7 (15 mph)**	**west**	**13.4 (30 mph)**	**south**	**(40.25)**	**(-6.7)**	**6.0 ± 1.0**	**--**
Case	**Actual Conditions at Warning**						**Test Results**	
Run 1	6.8	268	11.9	176	41.3	-6.8	5.4	Pass
Run 2	6.7	267	13.3	177	45.7	-6.7	6.1	Pass
Run 3	6.6	268	11.6	177	46.7	-6.6	6.3	Pass
Run 4	6.7	267	11.9	177	41.6	-6.7	5.6	Pass
Average	6.7	267	12.2	177	43.8	-6.7	5.9	--
Stdev	0.0	0.2	0.8	0.5	2.8	0.1	0.4	--
Minimum	6.6	267	11.6	176	41.3	-6.8	5.4	--
Maximum	6.8	268	13.3	177	46.7	-6.6	6.3	--
Requirement: 2 of 2 runs are successful. Result: 4 of 4 were successful.								**Pass**

Source: UMTRI

IMA-1C: 30 mph HVT and 15 mph RVL Approach at 90 Degree rel. Heading

Similar to IMA-1B the purpose of this test is to determine if a warning will be given to the HVT when both the HVT and RVL are moving toward each other at a relative heading of 90 degrees and are projected to crash at a conflict point if either vehicle fails to significantly change speed. In this version of the scenario the HVT is traveling at 30 mph while the RVL is at 15 mph. Figure 43 illustrates how the scenario is conducted and table 18 shows the results from the four runs conducted. For all runs, the HVT heading was west while the RVL heading was south. The target speed for the RVL was 15 mph and this speed was achievable at the time of the warning in HVT. The average distance between the HVT and RVL at the time of the warning was 79 m. The average time-to-collision was 6.1 s at the time of the warning. The criteria for a successful test were a time-to-collision of 6.0 ± 1.0 seconds. In this test, 4 of 4 runs met the TTC criteria.

Table 18. IMA-1C 30 mph HVT and 15 mph RVL 90 deg. approach to an uncontrolled intersection

	HvSpeed, m/s	**HvHdg, °**	**RvSpeed, m/s**	**RvHdg, °**	**Range, m**	**Range Rate, m/s**	**TTC, s**	**Pass/ Fail**
Design Conditions	**13.4 (30 mph)**	**west**	**6.7 (15 mph)**	**south**	**(80.4)**	**(-15.0)**	**6.0 ± 1.0**	**--**
Case	**Actual Conditions at Warning**						**Test Results**	
Run 1	13.0	268	7.0	177	41.2	-13.0	5.7	Pass
Run 2	12.9	267	6.8	176	45.6	-12.9	6.3	Pass
Run 3	12.5	268	6.7	176	46.6	-12.5	6.6	Pass
Run 4	12.7	269	6.8	177	41.5	-12.7	5.9	Pass
Average	12.8	268	6.8	177	43.7	-12.8	6.1	--
Stdev	0.2	0.8	0.1	0.6	2.8	0.2	0.4	--
Minimum	12.5	267	6.7	176	41.2	-12.5	5.7	--
Maximum	13.0	269	7.0	177	46.6	-13.0	6.6	--
Requirement: 2 of 2 runs are successful. Result: 3 of 4 were successful.								**Pass**

Source: UMTRI

IMA-1D: 30 mph HVT and 30 mph RVL Approach at 90 Degree rel. Heading

Similar to IMA-1B the purpose of this test is to determine if a warning will be given to the HVT when both the HVT and RVL are moving toward each other at a relative heading of 90 degrees and are projected to crash at a conflict point if either vehicle fails to significantly change speed. In this version of the scenario the HVT is traveling at 30 mph while the RVL is at 30 mph. Figure 43 illustrates how the scenario is conducted and table 19 shows the results from the four runs conducted. For all runs, the HVT heading was west while the RVL heading was south. As with IMA-1B, the speed of the RVL was slightly less than the target. The average distance between the HVT and RVL at the time of the warning was 74 m. The average time-to-collision was 7.6 s at the time of the warning. The criteria for a successful test were a time-to-collision of 7.0 ± 1.0 seconds. In this test, all runs met these criteria.

Table 19. IMA-1D 30 mph HVT and 30 mph RVL 90 deg. approach to an uncontrolled inter.

	HvSpeed, m/s	**HvHdg, °**	**RvSpeed, m/s**	**RvHdg, °**	**Range, m**	**Range Rate, m/s**	**TTC, s**	**Pass/ Fail**
Design Conditions	**13.4 (30 mph)**	**west**	**13.4 (30 mph)**	**south**	**(80.4)**	**(-13.4)**	**7.0 ± 1.0**	**--**
Case	**Actual Conditions at Warning**						**Test Results**	
Run 1	14.0	268	10.2	177	73.7	-14.0	7.4	Pass
Run 2	14.0	267	11.7	178	74.5	-14.0	7.5	Pass
Run 3	13.6	267	10.9	177	73.2	-13.6	7.6	Pass
Run 4	13.6	268	9.6	178	74.5	-13.6	7.7	Pass
Average	13.8	268	10.6	178	74.0	-13.8	7.6	--
Stdev	0.2	0.6	0.9	0.6	0.6	0.2	0.1	--
Minimum	13.6	267	9.6	177	73.2	-14.0	7.4	--
Maximum	14.0	268	11.7	178	74.5	-13.6	7.7	--
Requirement: 2 of 2 runs are successful. Result: 4 of 4 were successful.								**Pass**

Source: UMTRI

IMA-2A: HVT Stopped; 20 mph RVL Approaches at 90 Degree rel. Heading

The purpose of the IMA-2A scenario is to determine if a warning will be given to the HVT when the HVT is stopped and waiting, while the RVL is moving toward HVT at a heading of 90 degrees. For this test, a warning is expected when the HVT driver releases the brake pedal, which may indicate a risk of the HVT moving into the path of the RVL.

This and the following test scenarios involve a stopped HVT and a moving RVL. The general set-up and procedure for this scenario is shown in figure 44. A general description of how to run the procedure for the HVT driver is as follows:

1. HVT stopped at the Start Bar. When ready, the HVT driver accelerates to a speed above 15 mph (the threshold speed for IMA) while negotiating around the perimeter of the staging area as shown in figure 44.

2. The HVT driver then does a moderate braking maneuver to a stop at the Stop Bar, keeping the brake pedal depressed after the vehicle comes to a stop

3. When the HVT driver sees the RVL has reached the HVT brake release cone, the brake pedal is released and an IMA warning is presented to the HVT driver

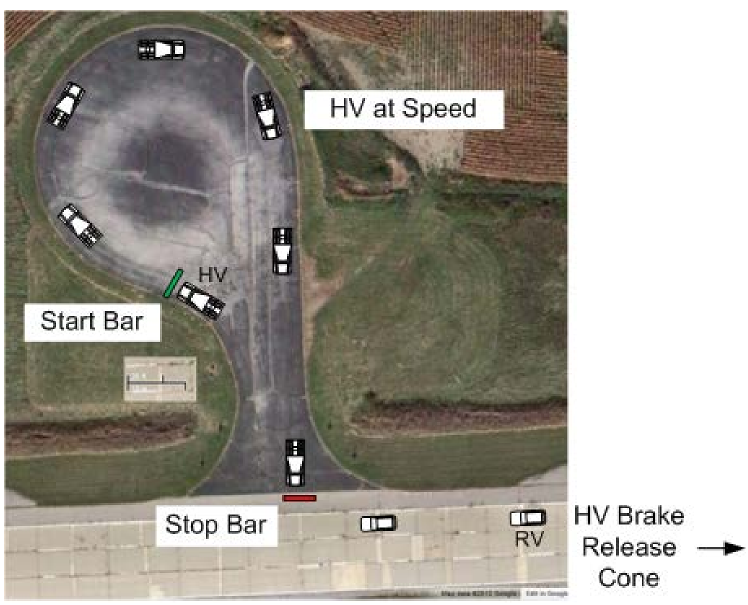
Instructions for the RVL driver are:

1. From the starting position, and in the appropriate lane (inner-lane when heading West, center-lane when heading East), when the HVT driver begins to move from the Start Bar, accelerate moderately to the desired test speed

2. Continue at that speed, without applying the brake, through the intersection of the staging area and oval or until the test conductor instructs otherwise.

Figure 44 illustrates how the scenario is conducted. The starting position of the RVL was a function of the RVL test speed and the position was selected to allow the HVT to be stopped for 3 to 5 seconds at the stop bar before the RVL reached the HVT Brake Release cone. For the 40 mph tests of IMA-2B, the HVT driver was instructed to ignore the HVT Brake Release cone and simply release the brake when the approaching RVL was in a position that would require very aggressive braking to avoid a crash with the HVT.

This scenario was run with the RVL approaching from both directions relative to the HVT. Table 20 has the results for IMA-2A, those with the RVL at 20 mph. The criterion for a successful run was a latency of less than 0.5 s between the HVT brake release and the warning being issued by the DVI. The measured latency was well within the threshold on all four runs, so the system passed the test IMA-2A.



Source: UMTRI

Figure 44. Illustration. IMA test set-up for a moving RVL and a stopped HVT.

Table 20. IMA-2A HVT stops at intersection; 20 mph RVL passes through intersection from left.

	HvHdg, °	RvSpeed, m/s	RvHdg, °	Range, m	Range Rate, m/s	TTC, s	Latency, s	Pass/ Fail
Design Conditions	**south**	**8.9 (20 mph)**	**west**	**--**	**--**	**--**	**< 0.5 s**	**--**
Case	**Actual Conditions at Warning**						**Test Results**	
Run 1	178	9.5	267	32.8	-8.3	3.9	0.27	Pass
Run 2	176	9.9	268	30.2	-8.4	3.6	0.20	Pass
Run 3	179	9.3	268	35.7	-8.1	4.4	0.27	Pass
Run 4	179	9.7	268	32.6	-8.1	4.0	0.19	Pass
Average	178	9.6	268	32.8	-8.2	4.0	0.23	--
Stdev	1.4	0.3	0.5	2.3	0.1	0.3	0.04	--
Minimum	176	9.3	267	30.2	-8.4	3.6	0.19	--
Maximum	179	9.9	268	35.7	-8.1	4.4	0.27	--
Requirement: 4 of 5 runs are successful. Result: 4 of 4 were successful.								**Pass**

Source: UMTRI

IMA-2B: HVT Stopped; 40 mph RVL Approaches at 90 Degree rel. Heading

Similar to IMA-2A, the purpose of the IMA-2B scenario is to determine if a warning will be given to the HVT when the HVT is stopped and waiting while the RVL is moving toward HVT at a heading of 90 degrees and 40 mph. For this test, a warning is triggered when the HVT driver releases the brake pedal which indicates the intention of pulling into the path of the RVL. This scenario was run with the RVL approaching from both directions relative to the HVT.

The criterion for a successful test was a latency of less than 0.5 s between the HVT brake release and the warning being issued by the DVI. Results are in table 21. The test plan required success in at least four runs. All four runs were successful, so the system passed the test IMA-2B.

Table 21. IMA-2B HVT stops at inter; 40 mph RVL passes through inter. from left.

	HvHdg, °	RvSpeed, m/s	RvHdg, °	Range, m	Range Rate, m/s	TTC, s	Latency, s	Pass/ Fail
Design Conditions	**south**	**17.9 (40 mph)**	**west**	**--**	**--**	**--**	**< 0.5 s**	**--**
Case	**Actual Conditions at Warning**						**Test Results**	
Run 1	176	17.5	267	41.6	-15.7	2.7	0.24	Pass
Run 2	176	17.2	267	42.8	-15.7	2.7	0.24	Pass
Run 3	176	17.1	267	40.6	-15.5	2.6	0.19	Pass
Run 4	177	17.3	267	47.0	-16.2	2.9	0.22	Pass
Average	176	17.3	267	43.0	-15.8	2.7	0.22	--
Stdev	0.4	0.2	0.2	2.8	0.3	0.1	0.02	--
Minimum	176	17.1	267	40.6	-16.2	2.6	0.19	--
Maximum	177	17.5	267	47.0	-15.5	2.9	0.24	--
Requirement: 4 of 5 runs are successful. Result: 4 of 4 were successful.								**Pass**

Source: UMTRI

IMA-3: HVT Stopped; 40 mph RVL Approaches at 90 Degree rel. Heading (False Positive Test)

This test was not run.

CHAPTER 4. SUMMARY AND CONCLUSIONS

This report presents the results from objective testing of the Connected Commercial Vehicle RSD safety applications including Emergency Electronic Brake Light (EEBL), Forward Collision Warning (FCW), Blind Spot Warning + Lane Change Warning (BSW+LCW), and Intersection Movement Assist (IMA). Twenty-five test scenarios, including five false-positive tests, were conducted on a test track with most scenarios conducted over multiple runs. For the true-positive tests, the metric of success was the timing of the presentation of driver warnings. For false-positive tests, the metric of success was whether the system did not present a warning.

Results from a total of 111 valid runs made in testing warnings were presented in chapter 3. The intent of these tests was to verify that the system issues warnings in a consistent, reliable manner. In general, the results substantiate the repeatability of the timing and appropriateness of the warning in these more complex scenarios.

Table 22 summarizes the scenarios, the number of valid runs associated with warnings, and the resulting Pass/Fail evaluation for each scenario. The system passed all 25 of the test scenarios that were run. The one test scenario that needs improvement was BSW+LCW-3. In this case the system was able to locate and monitor the two remote vehicles, but the DVI did not have a corresponding icon to show a vehicle in the adjacent space on both sides of the HVT. However, because the DVI did switch between showing a vehicle on the left and right of the HVT multiple times during each run, the test was classified as passed.

The EEBL, FCW, BSW+LCW, and IMA safety applications onboard the RSD tractors demonstrated repeatable performance in a wide variety of challenging situations.

Table 22. Master summary of results.

Scenario Code	Name	Criterion for a Successful Run	Number of Successful Runs		Test Outcome
			Requirement to Pass the Test	Result	
EEBL-1	HVT Drives Behind Braking RVL	Latency < 0.6 s	4 of 5	5 of 5	Pass
EEBL-2	HVT Drives Behind RVL Which Drives Behind Braking RVL	Latency < 0.6 s	4 of 5	6 of 6	Pass
EEBL-3	HVT Drives Behind Mildly Braking RVL	No message when RV brakes	2 of 2	2 of 2	Pass
EEBL-4	HVT Drives Behind Braking RVL in Left Adjacent Lane	Latency < 0.6 s	4 of 5	6 of 6	Pass
FCW-1	HVT Drives Behind Stopped RVL	Warn at TTC 6.5 ± 1.0 s	4 of 5	5 of 5	Pass
FCW-2	HVT Drives Behind RVL Which Drives Behind Stopped RVL	Warn at TTC 6.5 ± 1.0 s	4 of 5	5 of 5	Pass
FCW-3	HVT Tailgates RVT (false positive)	No message	2 s	> 80 s	Pass
FCW-4	HVT Drives Behind Mildly Braking RVL	Warn when RqAx = -2.2 ± 0.2 m/s^2	4 of 5	5 of 5	Pass
FCW-5	HVT Changes Lanes Behind Stopped RVL	Warn at TTC 6.5 ± 1.0 s	4 of 5	4 of 4	Pass
FCW-6	HVT Passes a Stopped RVL on a Curve (false positive)	No message	2 of 2	2 of 2	Pass
FCW-7	HVT Drives on a Curve Behind RVL Stopped in the Curve	Warn at TTC 6.5 ± 1.0 s	4 of 5	4 of 5	Pass
FCW-8	HVT Drives Behind Moving RVL in Left Adjacent Lane and Passes it in a Curve (false positive)	No message	2 of 2	3 of 3	Pass
BSW+LCW-1	RVL Passes HVT on the Left	Message appears	4 of 5	6 of 6	Pass

Scenario Code	Name	Criterion for a Successful Run	Number of Successful Runs		Test Outcome
			Requirement to Pass the Test	Result	
BSW+LCW-2	RVL Passes HVT on the Right	Message appears	4 of 5	6 of 6	Pass
BSW+LCW-3	Two RVs Pass HVT on the Left and Right	Message appears	4 of 5	6 of 6	Pass
BSW+LCW-4	HVT with RVL in Right Side Blind Spot	Message appears	4 of 5	6 of 6	Pass
BSW+LCW-5	RVL Tailgates HVT (false positive)	No message	2 of 2, for 3 s each	> 120 s	Pass
BSW+LCW-6	RVL and HVT Separated by One Lane (false positive)	No message	2 of 2, for 5 s each	more than 2	Pass
BSW+LCW-7	RVL Passes HVT in a Curve	Message appears	4 of 5	5 of 5	Pass
IMA-1A	HVT at 15 mph and RVL at 15 mph	Warn at TTC 5.0 ± 1.0 s	6 of 8, of the pooled conditions	1 of 1	Pass
IMA-1B	HVT at 15 mph and RVL at 30 mph	Warn at TTC 6.0 ± 1.0 s		4 of 4	
IMA-1C	HVT at 30 mph and RVL at 15 mph	Warn at TTC 6.0 ± 1.0 s		3 of 4	
IMA-1D	HVT at 30 mph and RVL at 30 mph	Warn at TTC 7.0 ± 1.0 s		4 of 4	
IMA-2A	HVT Stopped and RVL at 20 mph from the left	Latency < 0.5 s	4 of 5	4 of 4	Pass
IMA-2B	HVT Stopped and RVL at 40 mph from the left	Latency < 0.5 s	4 of 5	4 of 4	Pass

Source: UMTRI

ACKNOWLEDGEMENTS

This work was conducted primarily by UMTRI, with support from Denso as part of the Connected Commercial Vehicles—Retrofit Safety Device Kit Project. The Connected Commercial Vehicles Team is led and managed by Battelle. The team includes Mercedes-Benz Research and Development North America, Inc. (MBRDNA), DENSO International North America Research Laboratory (NARL), UMTRI, Daimler Trucks North America (DTNA), and Meritor WABCO.

Oversight from the United States Department of Transportation was provided by Kate Hartman of the Research and Innovative Technology Administration Intelligent Transportation Systems Joint Program Office, Alrik Svenson of the National Highway Traffic Safety Administration, and Cem Hatipoglu of the Federal Motor Carrier Safety Administration.

REFERENCES

1. Wells, B., and Berg, R. (2014) *Connected Commercial Vehicles—Retrofit Safety Device Kit Project: Safety Applications and Development Plan*, FHWA-JPO-14-106, Federal Highway Administration, Washington, DC.

2. Wells, B., and Berg, R. (2014) *Connected Commercial Vehicles—Retrofit Safety Device Project: Safety Applications Performance and Functional Test Plan and Procedure*, FHWA-JPO-14-107, Federal Highway Administration, Washington, DC.

3. SAE standard J2735 (November 19, 2009) "Dedicated Short Range Communications (DSRC) Message Set Dictionary."

U.S. Department of Transportation
Federal Highway Administration
Office of Freight Management and Operations
1200 New Jersey Avenue, SE
Washington, DC 20590
http://ops.fhwa.dot.gov/FREIGHT/
March 2014
Publication No. FHWA-JPO-14-108