Integrated Vehicle-Based Safety Systems
Heavy Truck Verification Test Plan

Prepared by

The University of Michigan Transportation Research Institute (UMTRI)

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16. Abstract

This test plan documents the procedures that were used to verify that the Integrated Vehicle-Based Safety Systems (IVBSS) heavy truck platform met all its performance requirements. The document was prepared by The University of Michigan Transportation Research Institute (UMTRI) and Eaton Corporation in collaboration with the U.S. Department of Transportation (U.S. DOT) and the National Institute of Standards and Technology (NIST). The test procedures described in this document were used to assess whether the prototype heavy-truck integrated system performed as intended and met its performance requirements. These tests were also used to identify areas for system improvement to ensure system repeatability, robustness and readiness.

The test plan describes each of the test procedures and includes the following details:

1. Test scenarios and conditions (e.g., speeds, closing speeds, road geometry, etc.);
2. Procedures and protocols to run the tests;
3. Pass/Fail criteria for determining repeatability and robustness; and
4. Performance metrics or measurement variables that will be used to evaluate system performance when compared to an independent measurement system.

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Acronyms

ACAS	Automotive Collision Avoidance System
ACC	Adaptive Cruise Control
AMR	Available Maneuvering Room
BOR	Brake Onset Range
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
COTR	Contracting Officer's Technical Representative
CPI/CPOI	Curve Point of Interest (the point in the road with the highest curvature
CSW	Curve Speed Warning
DA	Required deceleration
DAS	Data Acquisition System
DVI	Driver-Vehicle Interface
ET	Engineering Test
FCW	Forward collision warning
FOT	Field Operational Test
HMI	Human Machine Interface
HTM	Headway-time-margin
IMS	Independent Measurement System
ISO	International Standards Organization
IVBSS	Integrated Vehicle Based Safety Systems
LC	Lane Change
LCM	Lane-change merge
LCW	Lane-change warning
LDW	Lateral drift warning
MLP	Most-likely path of the subject vehicle
MT	Multiple Threats
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
NW	No-warn
POV	Principle Other Vehicle (a.k.a. POV1)
POV1	The first Principle Other Vehicle
POV2	The second Principle Other Vehicle
RD	Road Departure
RDCW	Road Departure Crash Warning System
RE	Rear-End
RT	Required Test
Run	Single trial in a verification scenario
SV	Subject Vehicle
TRC	Transportation Research Center
TTC	Time-To-Collision
TTW	Time-To-Warning
U.S. DOT	United States Department of Transportation
UMTRI	University of Michigan Transportation Research Institute

1 Introduction

This test plan documents the test procedures that were used to verify that the Integrated Vehicle-Based Safety Systems (IVBSS) heavy truck platform met all its performance requirements and was ready for the field operational test planned for Phase II of the program. This document was prepared by The University of Michigan Transportation Research Institute (UMTRI) and Eaton Corporation in collaboration with the U.S. Department of Transportation (U.S. DOT) and the National Institute of Standards and Technology (NIST). The test procedures described in this document will be used to assess whether the prototype heavy-truck integrated system performs as intended and meets its performance requirements. These tests will also be used to identify areas for system improvement to ensure system repeatability, robustness and readiness for field operational testing in Phase II.

This test plan describes each of the test procedures and includes the following details:

1. Test scenarios and conditions (e.g., speeds, closing speeds, road geometry, etc.);
2. Procedures and protocols to run the tests;
3. Pass/Fail criteria for determining repeatability and robustness; and
4. Performance metrics or measurement variables that will be used to evaluate system performance when compared to an independent measurement system that was installed on the test vehicle.

1.1 IVBSS System Overview

The primary objective of the IVBSS program is to develop and test a fully integrated collision warning system for light vehicles and commercial heavy trucks (trucks with a gross vehicle weight rating over 10,000 pounds.) IVBSS is a collision countermeasure that will help drivers avoid rear-end, road-departure, and lane-change crashes. A collision warning system that integrates sensors, alert logic, and driver-vehicle interface of different collision countermeasures should maximize system effectiveness, increase driver acceptance, and reduce system cost. Additionally, an integrated system is expected to prevent conflicting warnings, minimize false alarms, and reduce unintended consequences (e.g., cause a road-departure crash while trying to prevent a rear-end crash).

The heavy-truck system consists of three warning functions (Note: detailed description of these functions can be found in the "*IVBSS First Annual Report"*, October 2007, DOT HS 810 842 available on the NHTSA website, http//: www.nhtsa.dot.gov):

- Forward collision warning (FCW) – warns drivers of imminent rear-end crashes.
- Lateral drift warning (LDW) – alerts drivers that they may inadvertently be drifting from the center of their lane to adjacent lane or roadside.
- Lane-change/merge warning (LCM) – provides drivers with situational awareness about the presence of vehicles in their blind spots and warns them of potential collision if lane change maneuver is detected.

Procedures and test conditions presented in this document will be used for verification testing of IVBSS HV platform conducted on closed-course test tracks. Test procedures contained in this document are based on crash scenarios outlined in [5]. Test track results will be compared against the heavy-truck functional requirements and performance guidelines described in [1,2] of Section 1.6 *References.*

1.2 Overview of Tests

Figure 1 illustrates the two major categories of tests that will be carried out:

1. Required Tests: all of the required tests must be passed in order for the IVBSS program to be approved to enter the program's second phase (field operational testing). The pass/fail criteria are outlined in *Criteria for Passing the Required Tests*.

2. Engineering Tests: the objectives of these tests are to characterize system performance and determine system limitations. Engineering Tests will be conducted in the same manner as Required Tests. Test results from engineering tests will identify areas for system improvement, and will not be considered in the program's Phase II Go-No/Go approval decision.

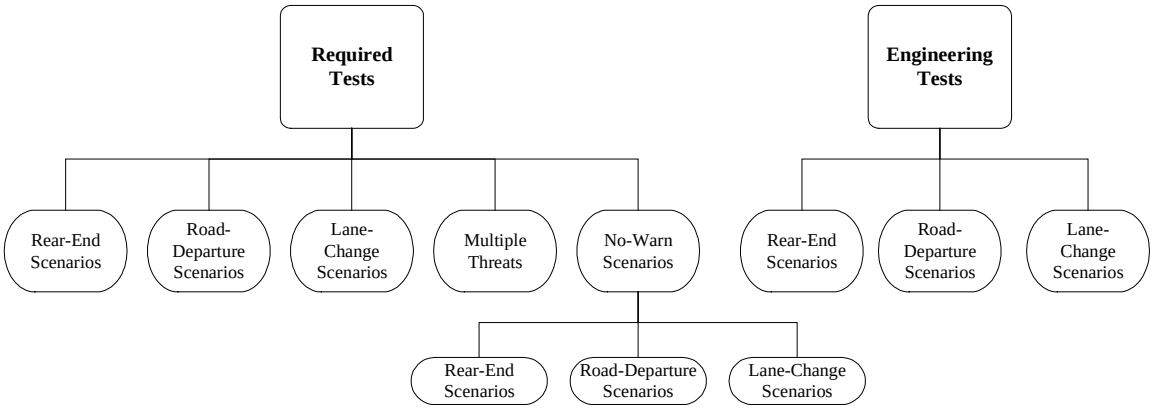


Figure 1. Breakdown of Test Scenarios

Required tests include four sub-categories of crash-imminent test scenarios and one no-warn test scenario sub-category. Rear-end, lane-change, and road-departure test

scenarios are crash-imminent scenarios considered as "baseline tests" since IVBSS is intended to address rear-end, road-departure, and lane-change crashes. In the multiple-threat (MT) crash-imminent scenarios, two or more consecutive warnings are issued to the driver. (Note: an arbitration algorithm manages the timing of a series of warnings to the driver during the multiple-threat scenario). The no-warn (NW) test scenario sub-category will be used to evaluate the capability of the system to suppress false or nuisance alerts under benign driving conditions.

Engineering tests encompass imminent rear-end, lane-change, and road-departure crash scenarios. These tests are devised to challenge the system in dealing with driving situations around its operating envelope so as to characterize its limitations and thus identify adjustments to correct shortcomings.

A list of warning tests and no-warning tests is shown in Table 1.

1.3 Definition of test and pass/fail variables

All the tests described in this document were selected to evaluate the readiness and maturity of the various warning functions working both independently of each other and together in an integrated hierarchical manner that addresses the conflict and is coherent to the driver. In order to objectively make judgments regarding these systems to this effect, the kinematic relationships pertinent to each test procedure must be measured and evaluated. This section defines both the test variables that will be used to judge that the test was run correctly and the pass/fail variables that indicate if the warning was issued according to the performance specification of each subsystem and the system as a whole. Table 2 below lists all the test variables by sub-system and for the multiple threat tests giving an acronym for each measure along with a description and its engineering units. The desired levels for these measures, their tolerances, and the rules used to determine if the run/test conditions were satisfied for these measures will be given in each of the test procedures below.

Table 2 lists the pass/fail and test variables along with their definitions and units also as a function of each sub-system and for the multiple threat tests.

Table 1. Tests for the heavy-truck IVBSS platform

TEST PROCEDURES
FORWARD COLLISION WARNING—Rear-End (RE)
RE-1. Rear-end conflict with a constant speed POV (Required Test)
RE-2. Rear-end conflict with a slowing POV at close range (Required Test)
RE-3. Rear-end conflict with a slowing POV at far range (Required Test)
RE-4. Rear-end conflict with stopped POV (Required Test)
RE-6. Rear-end conflict with slower POV after a lane change by the SV (Required Test)
RE-7. Rear-end conflict with a stopped POV in a curve (Engineering Test)
RE-8. Rear-end conflict with a slower POV in a curve (Engineering Test)
RE-9. Rear-end conflict with constant speed motorcycle behind a truck (Required Test)
RE-10. Rear-end conflict with POV after a cut-in by the POV (Required Test)
RE-11. Rear-end conflict with a slowing POV1 after POV2 cut-out (Engineering Test)
RE-12. Rear-end conflict with a constant speed motorcycle (Required Test)
LANE CHANGE MERGE WARNING TESTS (LC)
LC-1. Lane-change conflict with POV in a blind spot on the right (Required Test)
LC-2. Lane-change conflict with adjacent POV in a blind spot on the left (Required Test)
LC-3. Lane-change into adjacent POV on curve (Engineering Test)
LC-4. Lane-change into adjacent POV on merge (Engineering Test)
LC-5. Lane-change into adjacent POV after passing (Engineering Test)
LC-6. Lane-change into approaching POV (Engineering Test)
ROAD DEPARTURE WARNING TESTS (RD)
RD-1. Road departure toward opposing traffic lane—low lateral speed (Required Test)
RD-2. Road departure toward a clear shoulder—high lateral speed (Required Test)
RD-3. Road departure toward a clear shoulder on a small radius curve (Required Test)
RD-4. Road departure toward a clear shoulder on a large radius curve (Required Test)
RD-5. Road departure toward a barrier (Engineering Test)
MULTIPLE THREAT (MT)
MT-1. Rear-end followed by a lane-change warning (Required Test)
MT-2. Lane-change followed by rear-end warning (Required Test)
NO-WARNING (NW)
NW-1. No FCW when SV closely follows POV (Required Test)
NW-2. No FCW when passing a stopped POV in an adjacent lane on a curve (Required Test)
NW-3. No FCW when a faster POV cuts in front of the SV (Required Test)
NW-4. No FCW when passing between two slower moving POVs in adjacent lanes (Required Test)
NW-5. No LDW with poor lane keeping and a barrier on the left (Required Test)
NW-6. No LCW when SV changes lanes in front of a close POV (Required Test)
NW-7. No LCW when SV changes lanes while a POV is two lanes over (Required Test)

All test detailed in this document shall be driven by professional drivers having no affiliation with the IVBSS program.

Table 2. Test variables for each sub-system and the multiple-threat tests

	RE Test variables
V_{SV}	Subject vehicle forward speed, m/s
Ax_{SV}	Longitudinal acceleration of the subject vehicle[1], m/s[2]
$LatV_{SV}$	Lateral speed of the subject vehicle, m/s
V_{POVN}	N^{th} principal other vehicle forward speed[2], m/s
Ax_{POVN}	Longitudinal acceleration of the N^{th} principal other vehicle[1], m/s[2]
$LatV_{POVN}$	Lateral speed of the Nth principal other vehicle, m/s
R_{POVN}	Range between the subject vehicle and the N^{th} principal other vehicle, m
$Rdot_{POVN}$	Range-rate between subject vehicle and N^{th} principal other vehicle, m/s
	RD Test variables
V_{SV}	Subject vehicle forward speed, m/s
$LOff_{SV}$	Lane offset of the subject vehicle relative to lane center, m
$LatV_{SV}$	Lateral speed of the subject vehicle, m/s
	LC Test variables
V_{SV}	Subject vehicle forward speed, m/s
V_{POVN}	N^{th} principal other vehicle forward speed, m/s
$LOff_{SV}$	Lane offset of the subject vehicle relative to lane center, m
$LOff_{POV}$	Lane offset of the principal other vehicle relative to lane center, m
$LatV_{SV}$	Lateral speed of the subject vehicle, m/s
$LatV_{POV}$	Lateral speed of the principal other vehicle, m/s
	MT Test variables
V_{SV}	Subject vehicle forward speed, m/s
V_{POV}	1^{st} principal other vehicle forward speed, m/s
Ax_{POV}	Longitudinal acceleration of the 1^{st} principal other vehicle[1], m/s[2]
R_{POV}	Range between the subject vehicle and the 1^{st} principal other vehicle, m
$Rdot_{POV}$	Range-rate between subject vehicle and 1^{st} principal other vehicle, m/s
$LOff_{SV}$	Lane offset of the subject vehicle relative to lane center, m
$LOff_{POV}$	Lane offset of the principal other vehicle relative to lane center, m
$LatV_{SV}$	Lateral speed of the subject vehicle, m/s
	NW Test variables
V_{SV}	Subject vehicle forward speed, m/s
V_{POV}	1^{st} principal other vehicle forward speed, m/s
$LatV_{SV}$	Lateral speed of the subject vehicle, m/s
R_{SV}	Range between the principal other vehicle and the subject vehicle, m
$Rdot_{SV}$	Range-rate between the principal other vehicle and the subject vehicle, m/s

[1] Unless measured directly this performance measure is derived by differentiating forward-speed using a phase-neutral 1.1s algorithm derived by calculating the slope of a best-fit line to the forward-speed measure.

[2] Unless otherwise specified this performance measure is derived by adding $Rdot_{PN}$ and $V_{SV.}$

Table 3. Instantaneous test variables for each sub-system and the multiple-threat tests

	RE variables
R_{FCW}	Range between the subject vehicle and the principal other vehicle at the time of the rear-end warning.
$Rdot_{FCW}$	Range-rate between the subject vehicle and the principal other vehicle at the time of the rear-end warning.
Time-to-$Warn_{FCW}$	Elapsed time, during a POV cut-in, between when half of the POV is in the SV lane and the onset of the FCW.
	RD variables
$LatDist_{RDW}$	The lateral distance from the nearest edge of the lane-boundary of interest and the corresponding out-side edge of the front wheel of the subject vehicle at the time of the RD warning (a negative number means the front wheel passed over the nearest edge of the boundary of interest i.e., it is on or outside of the lane).
$LatVel_{RDW}$	The lateral speed of the subject vehicle relative to the lane boundary lines
	LC variables
$LatDist_{LCW}$	The lateral distance from the nearest edge of the lane-boundary of interest and the corresponding out-side edge of the front wheel of the subject vehicle at the time of the LC warning (a negative number means the front wheel passed over the nearest edge of the boundary of interest i.e., it is on or outside of the lane).
$LatDist2_{LCW}$	When there is no boundary line between the subject vehicle and the principal other vehicle: $LatDist2_{LCW}$ is the lateral distance between the subject vehicle and the principal other vehicle as determined by the geometry of the scenario and assumes the POV and SV driver are able to position their vehicles using temporary pavement marks for reference.
$LatVel_{LCW}$	The lateral speed of the subject vehicle relative to the lane boundary lines
	*MT variables**

*Same as above at the time of each sub-system warning, respectively.

1.4 Criteria for passing the required tests

All tests described in this document (Required, Engineering, No-Warn, Multiple Threat, etc) shall be run and evaluated by applying the respective run validity and pass/fail criteria for the given test. Ten valid runs shall be conducted for each test and a test shall be considered "passed" if 8 out of 10 valid runs meet the pass/fail criteria. A run is considered valid if it meets the run validity requirement for the given run. Pass/fail criteria shall only be applied to valid runs. No more than 15 consecutive runs can be used to obtain 10 valid runs. All Engineering tests shall also be run and evaluated according to the "8 of 10" valid run pass/fail criteria. However, the pass/fail results of the Engineering tests shall not be used to determine to the overall pass/fail acceptance of the system under test.

For the Required No-Warn tests the pass/fail criteria are the same as other Required tests. For No-Warn tests the experimenter will choose reasonable times before and after the run to define the testing period in which no warning from the test subsystem shall be

given. No-Warn test are to run as separate stand-alone events/runs and not combined with other tests.

The measures for evaluation for the tests have been included in this document. However, the values have been removed and should be determined by the user, based on the performance requirements of their system.

1.5 Definitions and Standard Test Conditions

This section of the plan outlines a standard set of conditions that are assumed for each of the Required, Engineering, and No-Warn tests given below. If a characteristic of a specific test deviates from this standard set of conditions, the details of the change are given in the procedure itself (e.g., the Principal other Vehicle (POV) is motorcycle, not a passenger car). In the case where more details and explicit descriptions (e.g., vehicle performance criteria, road geometry details, lane boundary reflectivity characteristics, etc.) are needed they are detailed in Appendix A.

1.5.1.1. Environment and ambient conditions

Unless a particular test specifies otherwise, the tests shall be conducted with:

1. Daytime illumination—defined as a natural outdoor illumination that occurs when the angle between vertical and the sun (Solar Zenith Angle) is less than 90 degrees. See Appendix A for a more complete discussion of Solar Zenith Angle
2. Reasonable atmospheric visibility—defined as an absence of fog and the ability to see clearly for more than 1000 meters.
3. Moderate wind conditions—defined a having sustained wind speeds of less than 5.4 m/s (12 mph) and gusts less than 10.7 m/s (24 mph).
4. Dry conditions—defined as no visible evidence of water including discoloration of the pavement due to wetness.
5. Non-extreme temperature—defined as an ambient temperature between 18 C (34 F) and 38 C (100 F).

1.5.1.2. Pavement quality and type

The test surface shall be constructed from asphalt or concrete and should be smooth and in good condition.

1.5.1.3. Subject vehicle

The Subject Vehicle (SV) for these tests is defined as a Class 8 tractor. In addition to the specific technology being evaluated, the vehicle should be equipped with

conventional cruise control, anti-lock brakes and relatively new tires and brakes. It is assumed that the tests for FCW and LDW are done without a semi-trailer i.e., bobtail. Test for LCW are performed with a tractor and single semi-trailer combination where the semi-trailer is a typical dry-freight van between 45 and 53 feet with a box width of 102 inches and is unloaded in terms of additional cargo or dummy weights.

Trailer requirements for the multiple-threat scenarios are detailed within the test scenarios themselves for each of the multiple-threat tests.

1.5.1.4. Subject vehicle driver selected IVBSS settings

Not applicable to the Heavy Truck IVBSS system. Other than warning volume the subject vehicle driver cannot adjust the sensitivity of the system either on a component level or the system as a whole. Each subsystem's false alarm database shall be disabled during all track-based and on-road verification tests.

1.5.1.5. Subject vehicle instrumentation

The subject vehicle shall be equipped with an instrumentation system that allows the primary and secondary evaluation measures to be recorded and analyzed. For some tests, this may require additional equipment to verify that the initial conditions for the test were correctly established and that the conditions at the time of the subsequent alert were within the tolerances given in each procedure.

1.5.1.6. Principal other vehicle

In the test outlined below, the principal other vehicle (POV) is a small to mid-range passenger car. The vehicle should be relatively new with good brakes and tires and be equipped with conventional cruise control for consistent speed control.

Additionally, the principal other vehicle should be equipped with an additional monitoring instrumentation to verify that the initial conditions for the test were correctly established. The additional instrumentation is test specific with the requirements specified for each test scenario given in each of the procedures below.

1.5.1.7. Secondary other vehicle

When a secondary other vehicle is needed (POV2), it shall be a small to mid-range passenger car. The vehicle should be relatively new with good brakes and tires and be equipped with conventional cruise control for consistent speed control.

1.5.1.8. Road geometry

Unless otherwise stipulated in the test itself, the road geometry for each test should be straight and flat, where straight is having a horizontal curvature of less than 1 km^{-1} and flat is a grade of less than 0.1 percent (Kiefer et al., 1999).

1.5.1.9. Lane geometry and boundary types

Unless specified specifically in a test, the tests will be conducted on a test track with two or more adjacent lanes. If possible, the standard 12 ft (3.66m) lane width is recommended for each test, however, many test-tracks have wider lane widths ranging from 14 to 15 ft. Wider lanes are acceptable provided the lane-tracking system (LDW) is capable of tracking both the right and left boundaries of the subject vehicle lane. Boundary lines between lanes shall be separated with a conventional dashed or solid white or yellow line while the outer boundaries (between the lane and adjacent shoulders), shall be marked with solid white or yellow lane boundary markers. For tests involving an adjacent shoulder, the width of the shoulder shall be at least 10 ft and the shoulder should be made from asphalt or concrete and should be smooth and in good condition.

1.5.1.10. Inter-vehicle communication

Communication between the experimenter in the SV and driver(s) of the principal other vehicles is required for staging many of the test procedures given below. It is recommended that the communication be either through cell phones or high-quality portable radios. With either technology, having a hands-free interface is recommended.

1.6 References

1. Functional Requirements for the Integrated Vehicle-Based Safety System (IVBSS) – Heavy Truck Platform, March 17, 2008, Prepared by UMTRI, Visteon, and Cognex for U.S. DOT, Rpt. No. UMTRI-2008-17
2. System Performance Guidelines for a Prototype Integrated Vehicle-Based Safety System (IVBSS) – Heavy Truck Platform, March 17, 2008, Prepared by UMTRI, Visteon, and Cognex for U.S. DOT, Rpt. No. UMTRI-2008-19
3. Kiefer, R., LeBlanc, D. Palmer, M., Salinger, J., Deering, R., and Shulman, M., “Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems” DOT HS 808 964, NHTSA Technical Report produced by Crash Avoidance Metrics Partnership (CAMP), August 1999.

4. Ference, J. (2006). The Integrated Vehicle-Based Safety Systems Initiative, National Highway Traffic Safety Administration, Washington DC.
5. W. Najm, J. Smith, "Development of Crash Imminent Test Scenarios for Integrated Vehicle-Based Safety Systems (IVBSS)", Research and Innovation Technology Administration and Volpe National Transportation Systems Center, December 2006.

2 Forward Collision Warning (Rear-end) Tests

The tests detailed in this section are longitudinal and involve the SV approaching from behind a slower or slowing POV. In some cases the conflict does not begin from long range due to either the SV or POV changing lanes to initiate a same-lane conflict.

2.1 RE-1. Rear-end conflict with a constant speed POV (Required Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches, from behind, a slower moving POV in the center of the same lane. In this test the SV and POV are traveling at a constant speed with a speed differential between the SV and POV of at least 8.9 m/s (20 mph).

2.1.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 2 shows the initial, transitional and final conditions for the rear-end conflict with a constant speed POV. The initial conditions are in the top third of the figure and show a constant speed SV approaching from long range a slower-moving constant-speed POV at a closing rate that exceeds 8.9 m/s (20 mph). The center of the figure shows that a warning should occur when the SV reaches the R_{FCW} as specified by the designers of the FCW system. Finally, the bottom of the figure shows that the conflict is resolved when the SV slows and moves laterally to the right while the POV accelerates and moves to the left to avoid a crash. If an FCW is not issued at the specified R_{FCW} then the conflict is aborted with the SV driver senses a crash is imminent.

2.1.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 4. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

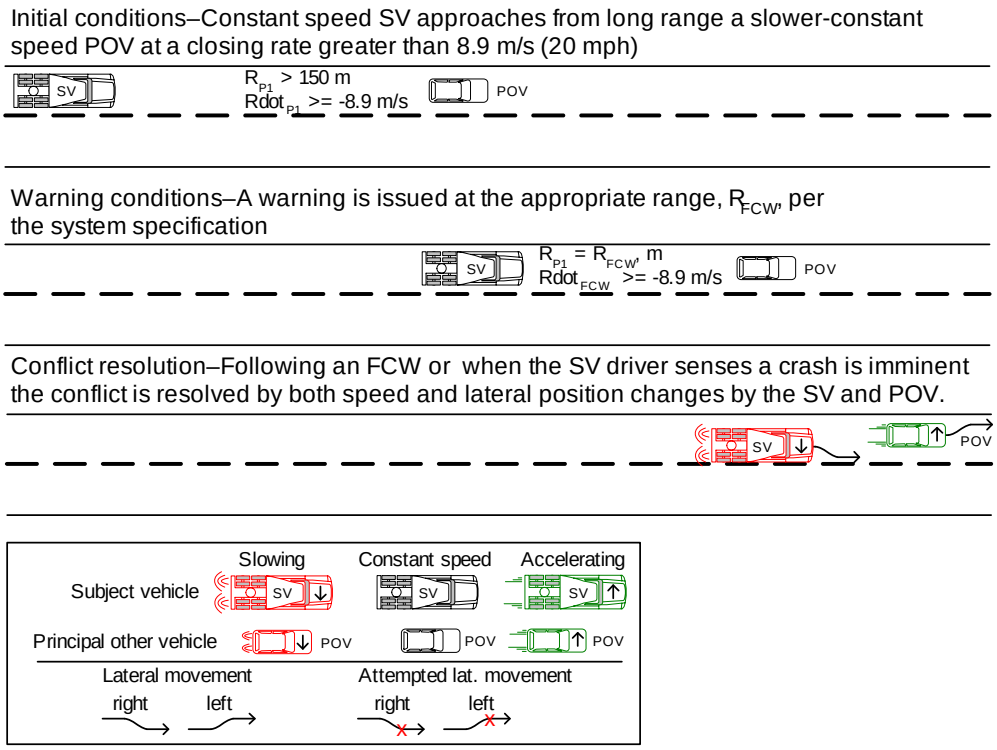


Figure 2. Test concept for rear-end conflict with a constant speed POV.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

Table 4. Run validity criteria for rear-end conflict with a constant speed POV.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	24.6 (55 mph)	1.0
V_{POV1}, m/s	13.4 (30 mph)	1.0
$Rdot_{POV1}$, m/s	-11.2	1.5
Initial R_{POV1}, m	150	10.0

- Steady-state: The minimum and maximum values of V_{SV}, V_{POV} and $Rdot_{POV}$ over a 2 second window ending at the time of the FCW cannot exceed the target values and their associated tolerances given above.
- Steady-state: The initial sensing range is greater than 140 m
- The SV and POV drivers do not touch the brake pedal before the FCW is issued.
- Both the SV and POV remain in the center of the designated lane until a FCW is issued.

- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 5 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 5. Pass/fail criteria for rear-end with a constant speed POV

Run pass/fail criteria	*Target value*[3]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

- The value of R_{POV} and $Rdot_{POV}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.1.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

2.1.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, straight-path test requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 35, this test will be conducted at the Dana test track using Set-up S1. The initial conditions for the test will be staged using a set of cones. See section 7 for a more explicit explanation including detailed figures of how these tests will be staged. Section 7 also includes tables for estimating the time and distance needed to stage the test given the constraints of the facility chosen. The placement of the cones, relative to the start of the straight section of track given in S1, for this particular test is shown below in Table 6 (a negative distance means the cone is placed before the straight section of track). The cones are labeled to indicate their purpose. The general scenario for executing the test is:

[3] The values are dependent of the actual system design and should be determined by the user.

- SV travels around the track at the desired test speed in the center of the designated lane.
- The POV is stopped at cone 2.
- When the SV passes cone 1 the driver or experimenter instructs the POV to start.
- The POV driver accelerates at the nominally constant rate of 1.5 m/s^2 (the POV driver is assisted by a windshield mounted accelerometer) for 9 seconds to reach the desired speed in the space between cones 2 and 3 while staying in the center of the designated lane.
- If staged correctly the POV will reach cone 3 simultaneously with the SV entering the straight section of the track with the desired initial conditions.

Table 6. Cone location for rear-end with a constant speed POV

Cone	*Distance, m*	*Label/Purpose*
1	-250	SV commands POV to start
2	90	From a stop the POV accelerates at 1.5 m/s^2
3	150	POV at specified speed in 9 seconds

2.1.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates, in the center of the selected lane, to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.
2. At the specified speed, and upon passing cone 1, the driver (or accompanied experimenter) commands the POV driver to start driving.
3. The SV driver then continues along the center of the selected lane at the commanded speed closing on the POV in a straight section of the test track.
4. Upon a warning by the FCW system or if the SV driver senses a crash is imminent the test is aborted.
5. The SV driver then brakes appropriately while steering to the left to avoid the POV.

Principal other vehicle driver:

1. From a stopped position located at cone 2 (either in or adjacent to selected lane) the driver waits for the experimenter in the SV to give the start command.
2. The POV driver then accelerates steadily to the desired speed using cone 3, a window mounted accelerometer, and an estimated time window.

3. At the desired speed the POV engages the cruise control and makes small adjustments to speed if necessary while staying in the center of the designated lane.

4. Upon the *abort* command from the SV experimenter, the POV driver accelerates while steering to the right and to clear a path for the SV.

2.2 RE-2. Rear-end conflict with a slowing POV at close range (Required Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches, from behind, a modestly slowing POV.

2.2.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 3 shows the initial, transitional and final conditions for the rear-end conflict with a modestly slowing POV. The initial conditions are in the top of the figure and show a constant speed SV following a same-speed POV at a predetermined range. Next, the figure shows the POV slowing at a steady-state rate of less than 2.0 m/s^2 prompting a warning when the SV reaches the R_{FCW} as specified by the designers of the FCW system. Finally, the bottom of the figure shows that upon a warning of if the SV driver senses a crash is imminent, the conflict is resolved by both speed and lateral position changes by the SV and POV.

2.2.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 7. The table is separated into two sections; the top section shows the target steady-state initial conditions for the test, while the bottom sections shows transitional kinematics that induce a conflict. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

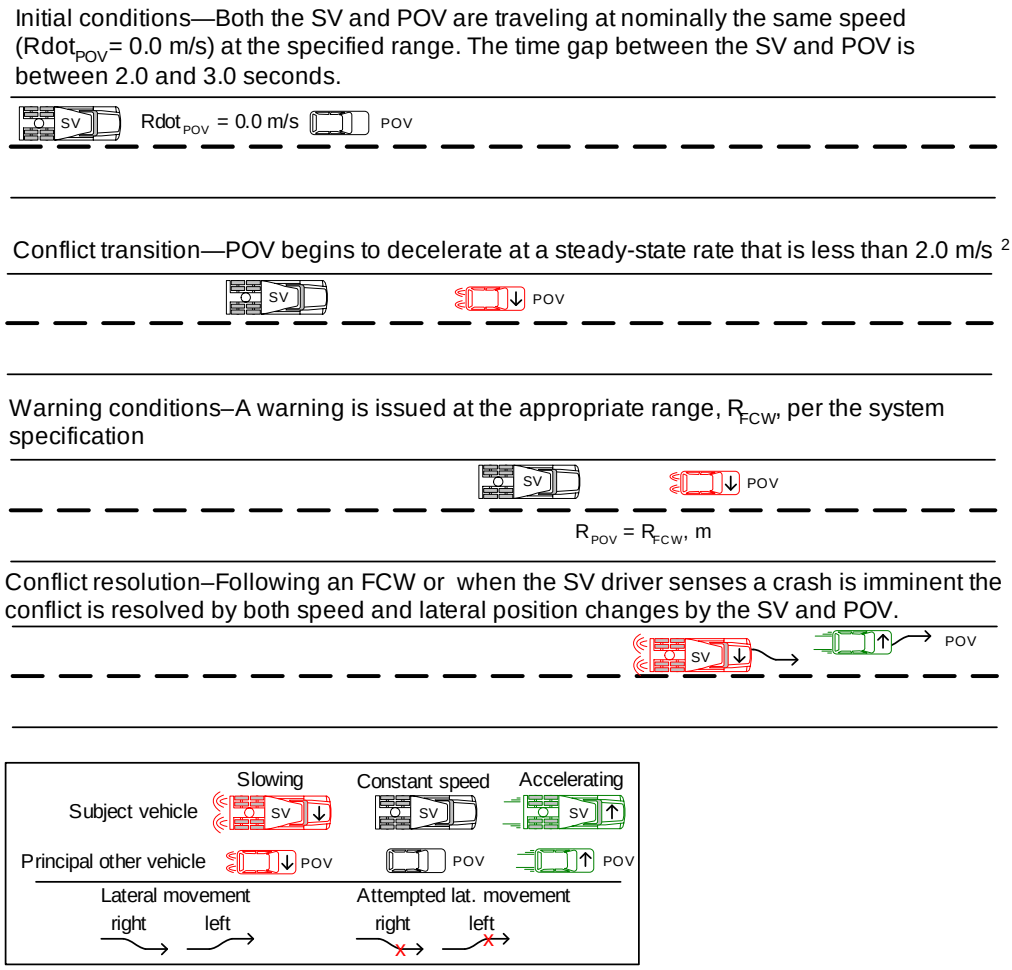


Figure 3. Test concept for rear-end conflict with a modestly slowing POV and a short time gap.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition. Note: there may be more than one transitional event in procedures that involve multiple threats and multiple POVs.

Table 7. Run validity criteria for rear-end conflict with a modestly slowing POV and a short time gap.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	17.9 (40 mph)	1.5
R_{POV1}, m	40	4.0
Transitional test variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
$Ax_{POV1,}$ m/s^2	-1.5	.5

- Steady-state: The minimum and maximum values of V_{SV}, V_{POV1}, R_{POV1} and $Rdot_{POV1}$ do not exceed the target values and their associated tolerances over a 2 second window ending at the start of the transition event by the POV.
- Transitional: The average acceleration of the POV is within the desired range from the start of braking by the POV and the time of the FCW.
- Transitional: The minimum and maximum values of V_{SV} are within the desired range from the start of braking by the POV and the time of the FCW.
- The SV driver does not touch the brake pedal before the FCW is issued.
- Both the SV and POV remain in the center of the designated lane until a FCW is issued.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 8 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 8. Pass/fail criteria for rear-end conflict with a modestly slowing POV and a short time gap.

Run pass/fail criteria	*Target value*[4]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

[4] The values are dependent of the actual system design and should be determined by the user.

- The value of R_{POV} and $Rdot_{FCW}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.2.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

2.2.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, straight-path test requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 39, this test will be conducted at the Dana test track using Set-up S1. The initial conditions for the test will be staged using range and range-rate measurements from the SV radar. The SV driver engages the cruise control at the desired initial speed while the POV driver slowly modulates speed to maintain a constant distance at the desired range. When the initial test conditions have been established and maintained for at least 2 seconds on a straight section of track, then the experimenter instructs the POV driver to decelerate at the desired rate. The test ends when an FCW is issued.

2.2.5 Driving instructions

Subject vehicle driver:

1. Accelerate in the center of the selected lane to the desired speed and engages the cruise control. If necessary use the cruise-control speed-adjustment buttons to attain the desired speed.
2. Upon a warning by the FCW system or if a crash is imminent abort the test by braking appropriately while steering to the left to avoid the POV.

Principal other vehicle driver:

1. Accelerate in the center of the desired lane to the desired speed in front of the SV to the initial range of the test, approximately.
2. Based range values given by the experimenter in the SV make small adjustments in speed to establish the desired initial distance condition for the test. The small adjustments can be done manually using the throttle or by engaging the cruise control and using the accel/decel buttons. Whichever method, the speed changes must be very gradual when near the initial test

range since both the range and range-rate conditions must be satisfied for at least 2 seconds prior to the start of the braking event.

3. Upon the command by the experimenter apply the brake and decelerate steadily using the window-mounted accelerometer as a guide to control the deceleration rate.

4. Upon the *abort* command from the SV experimenter or an alert by the FCW system, the POV driver accelerates while steering to the right and to clear a path for the SV.

2.3 RE-3. Rear-end conflict with a slowing POV at far range (Required Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches, from behind, an aggressively slowing POV. The test is strictly longitudinal with both the SV and the POV in the center of the designated lane on a straight segment of roadway.

2.3.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 4 shows the initial, transitional and final conditions for the rear-end conflict with an aggressively slowing POV. The initial conditions are in the top of the figure and show a constant speed SV following at a same-speed POV at predetermined range. The next element of the figure shows the POV slowing at a steady-state rate of more than 3.0 m/s^2. Next, the figure illustrates that a warning should occur when the SV reaches the R_{FCW} as specified by the designers of the FCW system. Finally, the bottom of the figure shows that upon a warning of if the SV driver senses a crash is imminent, the conflict is resolved by both speed and lateral position changes by the SV and POV.

2.3.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in

Table 9. The table is separated into two sections; the top section shows the target steady-state initial conditions for the test, while the bottom sections shows transitional kinematics that induce a conflict. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

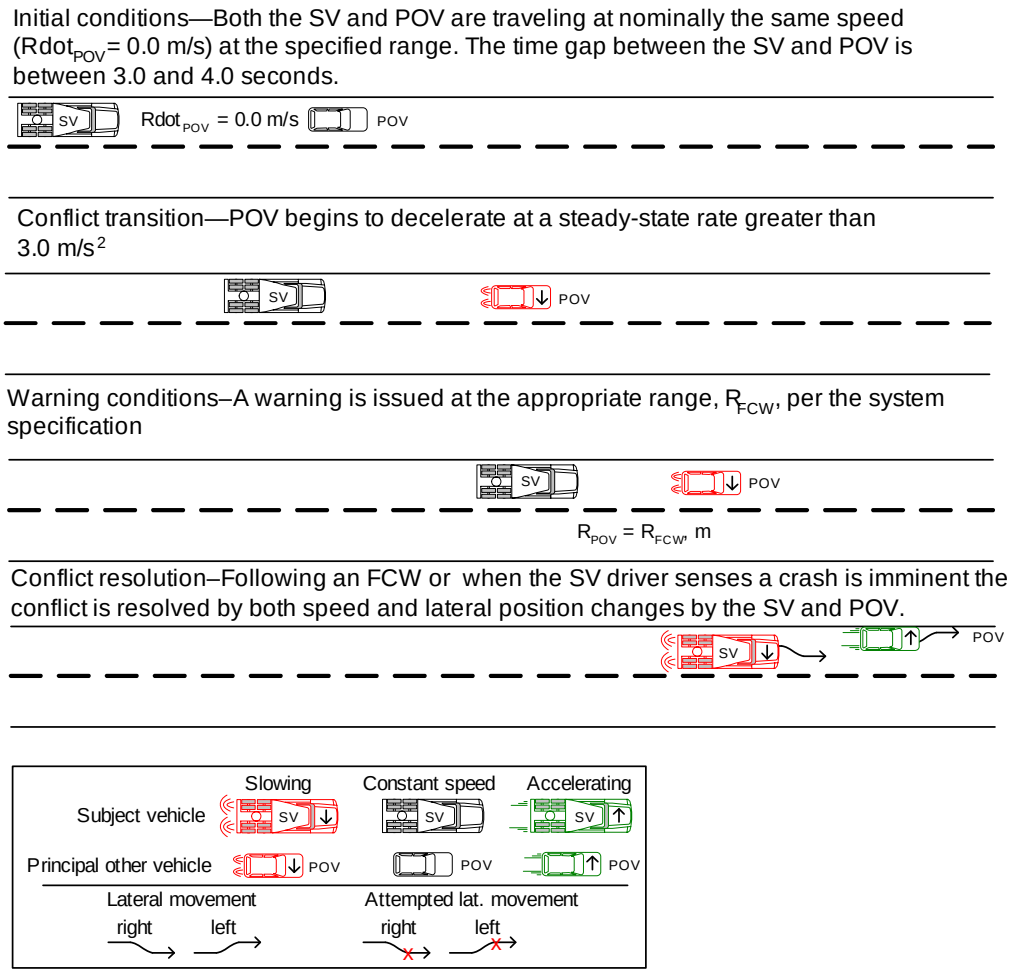


Figure 4. Test concept for rear-end conflict with an aggressively slowing POV and a long time gap.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition. Note: there may be more than one transitional event in procedures that involve multiple threats and multiple POVs.

Table 9. Run validity criteria for rear-end conflict with an aggressively slowing POV and a long time gap.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	17.9 (40 mph)	1.0
Initial R_{POV1}, m	60	4.0
Transitional test variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
$Ax_{POV1,}$ m/s^2	-3.0	1.0

- Steady-state: The minimum and maximum values of V_{SV}, V_{POV1}, R_{POV1} and $Rdot_{POV1}$ do not exceed the target values and their associated tolerances over a 2 second window ending at the start of the transition event by the POV.
- Transitional: The average acceleration of the POV is within the desired range from the start of braking by the POV and the time of the FCW.
- Transitional: The minimum and maximum values of V_{SV} are within the desired range from the start of braking by the POV and the time of the FCW.
- The SV driver does not touch the brake pedal before the FCW is issued.
- Both the SV and POV remain in the center of the designated lane until a FCW is issued.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 10 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 10. Pass/fail criteria for rear-end conflict with an aggressively slowing POV and a long time gap.

Run pass/fail criteria	*Target value*[5]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

- The value of R_{POV} and $Rdot_{POV}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.3.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

2.3.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, straight-path test requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 39, this test will be conducted at the Dana test track using Set-up S1. The initial conditions for the test will be staged using range and range-rate measurements from the SV radar. The SV driver engages the cruise control at the desired initial speed while the POV driver slowly modulates speed to maintain a constant distance at the desired range. When the initial test conditions have been established and maintained for at least 2 seconds on a straight section of track, then the experimenter instructs the POV driver to decelerate at the desired rate. The test ends when an FCW is issued.

2.3.5 Driving instructions

Subject vehicle driver:

1. Accelerate in the center of the selected lane to the desired speed and engages the cruise control. If necessary use the cruise-control speed-adjustment buttons to attain the desired speed.
2. Upon a warning by the FCW system or if a crash is imminent abort the test by braking appropriately while steering to the left to avoid the POV.

Principal other vehicle driver:

[5] The values are dependent of the actual system design and should be determined by the user.

- Accelerate in the center of the desired lane to the desired speed in front of the SV to the initial range of the test, approximately.
- Based range values given by the experimenter in the SV make small adjustments in speed to establish the desired initial distance condition for the test. The small adjustments can be done manually using the throttle or by engaging the cruise control and using the accel/decel buttons. Whichever method, the speed changes must be very gradual when near the initial test range since both the range and range-rate conditions must be satisfied for at least 2 seconds prior to the start of the braking event.
- Upon the command by the experimenter apply the brake and decelerate steadily using the window-mounted accelerometer as a guide to control the deceleration rate.
- Upon the *abort* command from the SV experimenter or an alert by the FCW system, the POV driver accelerates while steering to the right and to clear a path for the SV.

2.4 RE-4. Rear-end conflict with stopped POV (Required Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches, from behind and at a moderate speed, a stopped POV from long range in the same lane on a straight segment of roadway with both the SV and POV in the center of the designated lane.

2.4.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 5 shows the initial, transitional and final conditions for the rear-end conflict with a stopped POV. The initial conditions are in the top of the figure and show a constant speed SV approaching from long range a stopped POV. Next, the figure illustrates that a warning should occur when the SV reaches the R_{FCW} as specified by the designers of the FCW system. Finally, the bottom of the figure shows that upon a warning or if the SV driver senses a crash is imminent the conflict is resolved by the SV slowing and moving laterally to the right.

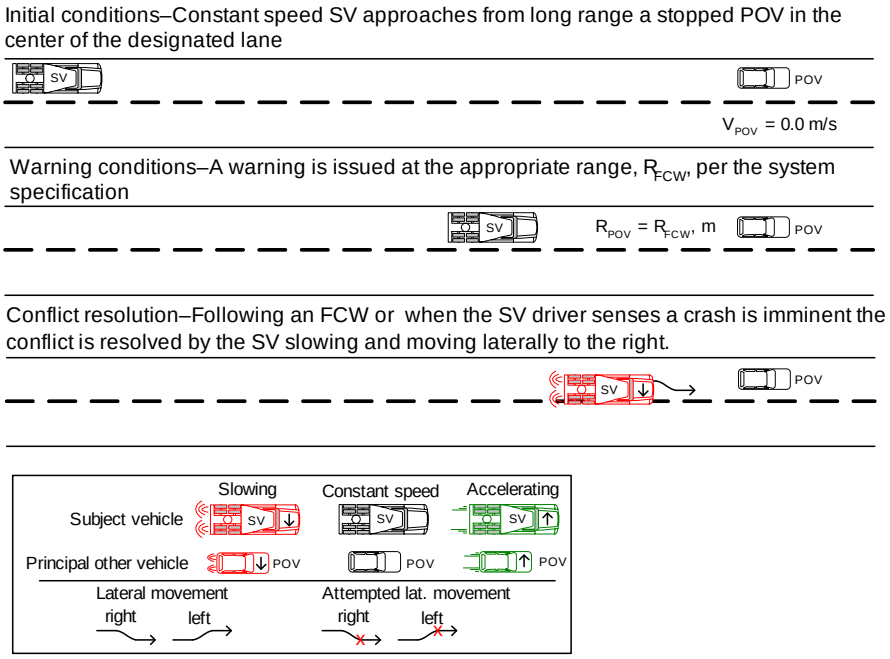


Figure 5. Test concept for rear-end conflict with stopped POV.

2.4.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 11. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

Table 11. Run validity criteria for rear-end conflict with stopped POV.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	1.0
$Rdot_{POV1}$, m/s	-15.7	1.0

- Steady-state: The minimum and maximum values of V_{SV} and $Rdot_{POV1}$ over a 2 second window ending at the time of the FCW cannot exceed the target values and their associated tolerances given above.
- Steady-state: The initial sensing range is greater than 50 m
- The SV driver does not touch the brake pedal before the FCW is issued.
- Both the SV remains in the center of the designated lane until a FCW is issued.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 12 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 12. Pass/fail criteria for rear-end conflict with stopped POV.

Run pass/fail criteria	*Target value*[6]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

- The value of R_{POV} and $Rdot_{POV}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.4.3 Exceptions to the standard test conditions

The one exception to the default conditions as detailed in the section Definitions and Standard Test Conditions is that the POV is parked and unattended during this test.

2.4.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, straight-path test requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. For this test the POV should be parked in the center of the designated lane with at least 200 m of straight track available for the SV approach.

[6] The values are dependent of the actual system design and should be determined by the user.

2.4.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates, in the center of the selected lane, to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.
2. The SV driver then continues along the center of the selected lane at the commanded speed closing on the POV in a straight section of the test track.
3. Upon a warning by the FCW system or if the SV driver senses a crash is imminent the test is aborted.
4. The SV driver then brakes appropriately while steering laterally to avoid the POV.

2.5 RE-6. Rear-end conflict with slower POV after a lane change by SV (Deleted)

2.6 RE-6. Rear-end conflict with slower POV after a lane change by the SV (Required Test)

This test is intended to verify the timeliness detecting a new in-path vehicle and the appropriateness of an FCW when the SV changes lanes while approaching from behind a moderately slower moving POV. The lane change by the SV should occur simultaneously with the newly acquired POV entering the forward-conflict region of the FCW system.

2.6.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 6 shows the initial, transitional and final conditions for the rear-end conflict with a slower POV after a lane change by the SV. The initial conditions are in the top of the figure and show a constant speed SV approaching a slower constant-speed POV that is traveling in an adjacent lane to the left of the SV. Then, at a predetermined range, the driver of the SV changes lanes to the left to be behind the POV. Next, the figure illustrates that a warning should occur when the SV reaches the R_{FCW} as specified by the designers of the FCW system. Finally, the bottom of the figure shows that upon a warning or if the SV driver senses a crash is imminent the conflict is resolved by both speed and lateral position changes by the SV and POV.

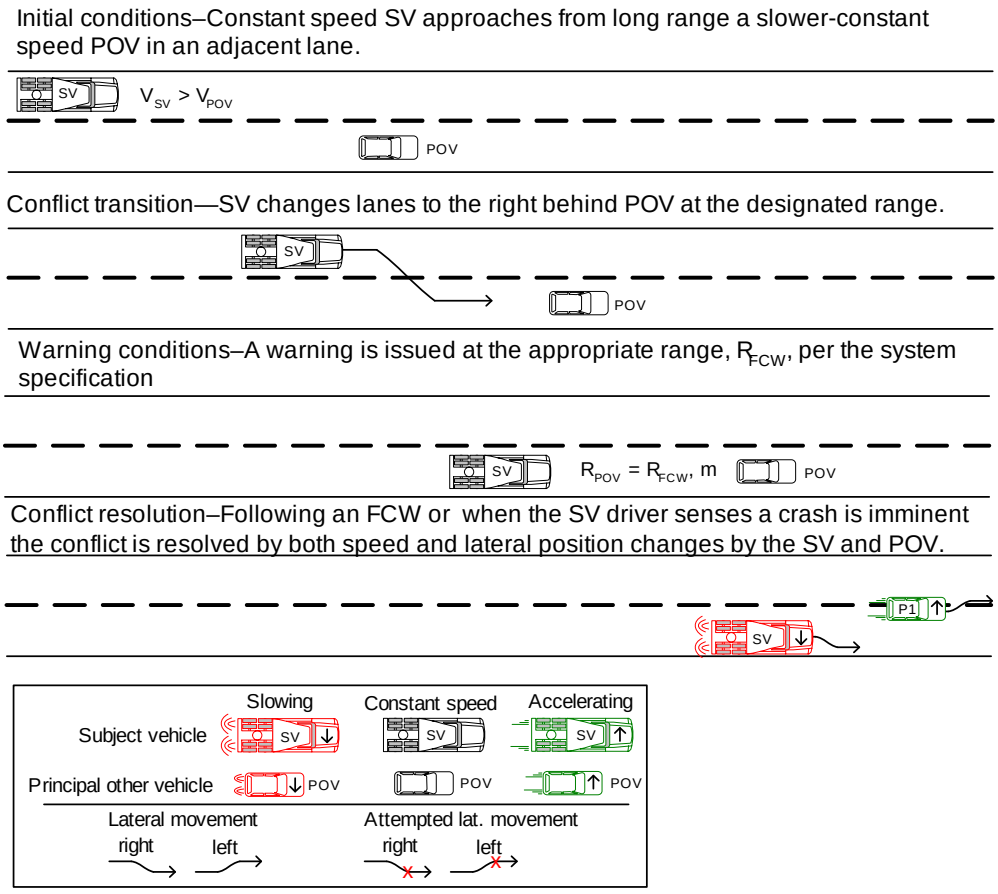


Figure 6. Test concept for rear-end conflict with slower POV after a lane change.

2.6.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 13. The table is separated into two sections; the top section shows the target steady-state initial conditions for the test, while the bottom sections shows transitional kinematics that induce a conflict. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as

applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition. Note: there may be more than one transitional event in procedures that involve multiple threats and multiple POVs.

Table 13. Run validity criteria for rear-end conflict with slower POV after a lane change.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
V_{POV1}, m/s	15.7 (35 mph)	1.0
$Rdot_{POV1}$, m/s	-4.47	1.5
Transitional test variables	*Target Value*	*± Tolerance*
R_{POV1}, m	45	5.0
V_{SV}, m/s	20.1 (45 mph)	1.0
V_{POV1}, m/s	15.7 (35 mph)	1.0

- Steady-state: The minimum and maximum values of V_{SV}, V_{POV1}, R_{POV1} and $Rdot_{POV1}$ do not exceed the target values and their associated tolerances over a 2 second window ending at the start of the transition event by the SV.
- Transitional: The driver of the SV does a moderate, non-aggressive lane change lasting 10 to 15 seconds into the POV lane.
- Transitional: The minimum and maximum values of V_{SV} and V_{POV1} remain within the desired range from the start of the lane change to the time of the FCW.
- The SV driver does not touch the brake pedal before the FCW is issued.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 14 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 14. Pass/fail criteria for rear-end conflict with slower POV after a lane change.

Run pass/fail criteria	*Target value*[7]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

- The value of R_{POV} and $Rdot_{POV}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.6.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

2.6.4 Test site preparation and special equipment

This is longitudinal conflict, straight-path test involving a lane-change maneuver by the SV and requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 36, this test will be conducted at the Dana test track using Set-up S2. The initial conditions for the test will be staged using range measurements by the IVBSS. Initially, both the SV and POV will travel at the test speed of the SV with the POV at least 150 m in front of the SV in the center of the adjacent lane. Then, when both vehicles are in a straight section of track the POV driver decelerates quickly to the desired speed while the experimenter reads the range between the two vehicles. At the desired range, nominally 45 m, the experimenter instructs the SV driver to make a non-aggressive lane-change lasting about 12 seconds into the POV lane to create the longitudinal conflict and an FCW.

2.6.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates in the center of the center lane at Dana to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.
2. The SV driver then continues along the middle of the center lane at the commanded speed closing on the POV, which is in the center of the adjacent lane to the left.

[7] The values are dependent of the actual system design and should be determined by the user.

3. When asked by the experimenter, complete a non-aggressive lane change lasting about 12 seconds to the left behind the POV.
4. Upon a warning by the FCW system or if the SV driver senses a crash is imminent the test is aborted.
5. The SV driver then brakes appropriately while steering to the left to avoid the POV.

Principal other vehicle driver:

1. Using range estimates by the experimenter stay approximately 100 m in front of the SV in center of the center lane traveling at the same speed as the SV.
2. Then upon instruction by the experiment, decrease from the SV speed to the specified test speed while staying in the center of the center lane. Engage the cruise control at the desired speed to reduce variability in speed.
3. Upon the *abort* command from the SV experimenter, the POV driver accelerates while steering to the right and to clear a path for the SV.

2.7 RE-7. Rear-end conflict with a stopped POV in a curve (Engineering Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches a stopped vehicle while both the SV and POV are in a constant radius curve.

2.7.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 7 shows the initial, warning and conflict resolution conditions for a rear-end conflict in a curve. The test begins when a constant speed SV approaches a stopped POV in the center of the designated lane. The test ends when an FCW is issued at the appropriate range, R_{FCW}, or when the SV driver senses a crash is imminent. The conflict is resolved by braking and a lateral position change by SV.

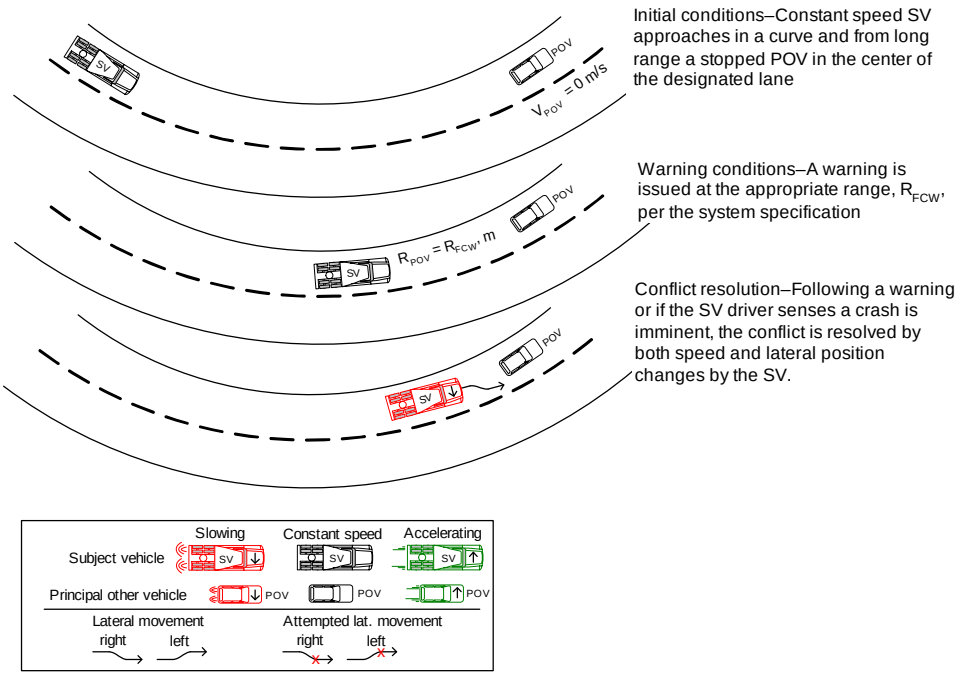


Figure 7. Test concept for rear-end conflict with stopped POV in a curve.

2.7.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 15. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

Table 15. Run validity criteria for rear-end conflict with stopped POV on a curve.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	13.4 (30 mph)	1.0
$Rdot_{POV1}$, m/s	-13.4	1.0
Curve Radius	500 m	25
Initial R_{POV1}, m	50	5.0

- Steady-state: The minimum and maximum values of V_{SV} and $Rdot_{POV1}$ over a 2 second window ending at the time of the FCW cannot exceed the target values and their associated tolerances given above.
- Steady-state: The initial sensing range is greater than 45 m
- The SV driver does not touch the brake pedal before the FCW is issued.
- Both the SV remains in the center of the designated lane until a FCW is issued.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 16 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 16. Pass/fail criteria for rear-end conflict with stopped POV in a curve.

Run pass/fail criteria	*Target value*[8]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

- The value of R_{POV} and $Rdot_{POV}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.7.3 Exceptions to the standard test conditions

The one exception to the default conditions as detailed in the section Definitions and Standard Test Conditions is that the POV is parked and unattended during this test.

2.7.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, curved-path test requiring a site large enough for the establishment of steady-state initial conditions, including a steady-state yaw-rate by the SV, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 39, this test will be conducted at the Dana test track using Set-up C1. For this test the POV should be parked

[8] The values are dependent of the actual system design and should be determined by the user.

in the center of the designated lane with at least 100 m of constant-radius track available for the SV approach.

2.7.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates, in the center of the selected lane, to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.
2. The SV driver then continues along the center of the selected lane at the commanded speed closing on the POV in the curved section of the test track.
3. Upon a warning by the FCW system or if the SV driver senses a crash is imminent the test is aborted.
4. The SV driver then brakes appropriately while steering laterally to avoid the POV.

2.8 RE-8. Rear-end conflict with a slower POV in a curve (Engineering Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches a slower moving POV while both vehicles are in a constant radius curve.

2.8.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 8 shows the initial, warning and conflict resolution conditions for a rear-end conflict in a curve. The test begins when a constant speed SV approaches a slower moving POV in the center of the designated lane. The test ends when an FCW is issued at the appropriate range, RFCW, or when the SV driver senses a crash is imminent. The conflict is resolved by braking and a lateral position change by SV and by the POV accelerating

2.8.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 17. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

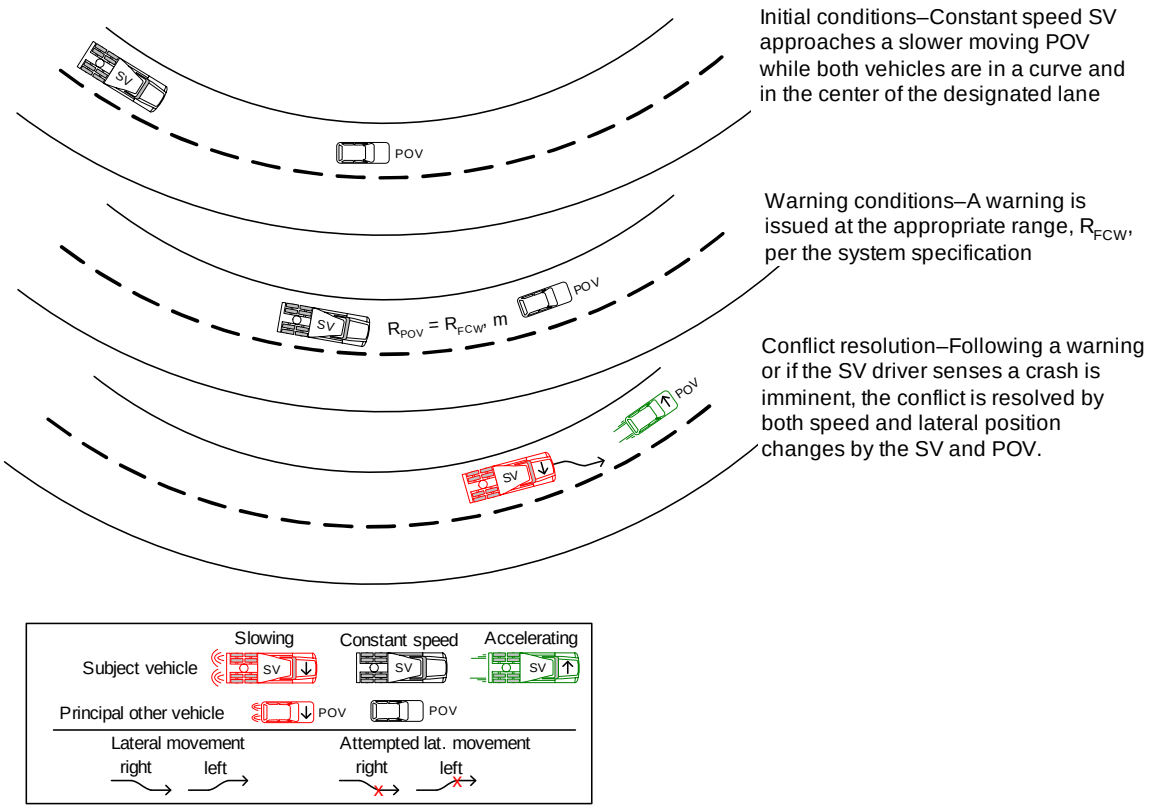


Figure 8. Test concept for rear-end conflict for a slower POV in a curve.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

Table 17. Run validity criteria for rear-end conflict with slower moving POV in a curve.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	24.6 (55 mph)	1.0
V_{POV1}, m/s	17.9 (40 mph)	1.0
$Rdot_{POV1}$, m/s	-6.7	1.5
Initial R_{POV1}, m	55	10.0
Curve Radius	280 m	30

- Steady-state: The minimum and maximum values of V_{SV}, V_{POV} and $Rdot_{POV}$ over a 2 second window ending at the time of the FCW cannot exceed the target values and their associated tolerances given above.

- Steady-state: The initial sensing range is greater than 45 m
- The SV and POV drivers do not touch the brake pedal before the FCW is issued.
- Both the SV and POV remain in the center of the designated lane until a FCW is issued.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 18 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 18. Pass/fail criteria for rear-end conflict with slower moving POV in a curve.

Run pass/fail criteria	*Target value*[9]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

- The value of R_{POV} and $Rdot_{POV}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.8.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

2.8.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, curved-path test requiring a site large enough for the establishment of steady-state initial conditions, including a steady-state yaw-rate by the SV and POV, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 39, this test will be conducted at the Dana test track using Set-up C1. The initial conditions for the test will be staged using a set of cones. See section 7 for a more explicit explanation including detailed figures of how these tests will be staged. Section 7 also includes tables for estimating the time and distance needed to stage the test given the constraints of the

[9] The values are dependent of the actual system design and should be determined by the user.

facility chosen. The placement of the cones, relative to the start of the curved section of track given in C1, for this particular test is shown below in Table 19 (a negative distance means the cone is placed before the designated start of the initial conditions). The cones are labeled to indicate their purpose. The general scenario for executing the test is:

- SV travels around the track at the desired test speed in the center of the designated lane.
- The POV is stopped at cone 2.
- When the SV passes cone 1 the driver or experimenter instructs the POV to start.
- The POV driver accelerates at the nominally constant rate of 1.5 m/s^2 (the POV driver is assisted by a windshield mounted accelerometer) for 10.4 seconds to reach the desired speed in the space between cones 2 and 3 while staying in the center of the designated lane.
- If staged correctly the POV will reach cone 3 simultaneously with the SV being at the desired initial range with both vehicles in a steady-state yaw-rate condition.

Table 19. Cone location for rear-end with a constant speed POV in a curve

Cone	*Distance, m*	*Label/Purpose*
1	-210	SV commands POV to start
2	-48	From a stop the POV accelerates at 1.5 m/s^2
3	40	POV at specified speed in 10.4 seconds

Note: For this test the reference start point should be at least 50 m into the curve.

2.8.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates, in the center of the selected lane, to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.

2. At the specified speed, and upon passing cone 1, the driver (or accompanied experimenter) commands the POV driver to start driving.

3. The SV driver then continues along the center of the selected lane at the commanded speed closing on the POV in a curved section of the test track.

4. Upon a warning by the FCW system or if the SV driver senses a crash is imminent the test is aborted.

5. The SV driver then brakes appropriately while steering to the left to avoid the POV.

Principal other vehicle driver:

1. From a stopped position located at cone 2 (either in or adjacent to selected lane) the driver waits for the experimenter in the SV to give the start command.
2. The POV driver then accelerates steadily to the desired speed using cone 3, a window mounted accelerometer, and an estimated time window.
3. At the desired speed the POV engages the cruise control and makes small adjustments to speed if necessary while staying in the center of the designated lane.
4. Upon the *abort* command from the SV experimenter, the POV driver accelerates while steering to the right and to clear a path for the SV.

2.9 RE-9. Rear-end conflict with constant speed motorcycle behind a truck (Required Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches a slower moving motorcycle that is traveling behind a same-speed truck.

2.9.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 9 shows the initial, transitional and final conditions for the rear-end conflict when a constant speed SV approaches from long range a slower moving, constant speed POV1 and POV2. The warning condition occurs when either an FCW is issued at the appropriate range as specified by the FCW system specification. Following the FCW or when the SV driver senses a crash is imminent the conflict is resolved by both speed and lateral changes by the SV driver.

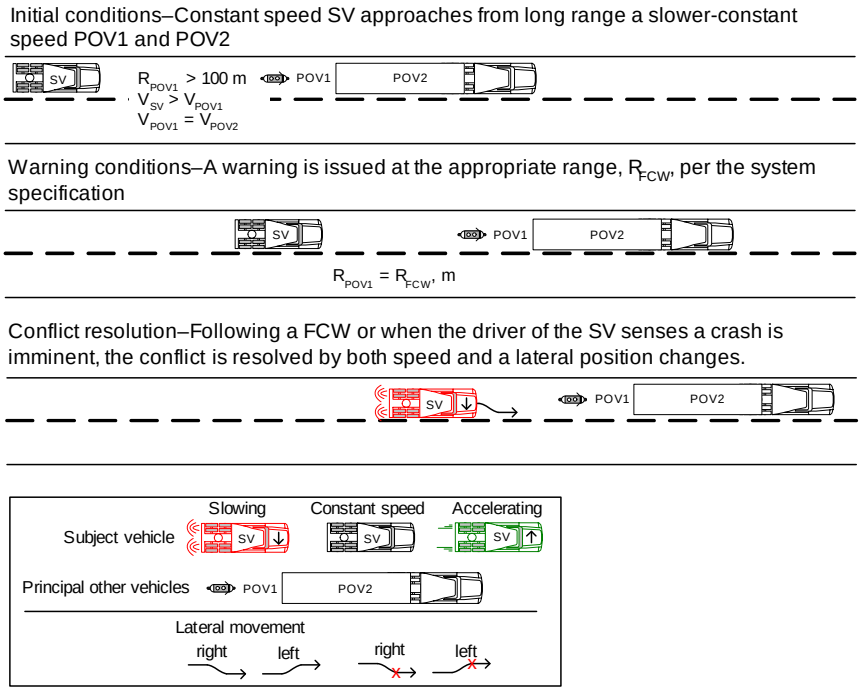


Figure 9. Test concept for rear-end conflict with constant speed motorcycle (POV1) behind a truck (POV2).

2.9.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in

Table 20. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

Table 20. Run validity criteria for rear-end conflict with constant speed motorcycle (POV1) behind a truck (POV2).

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	22.4 (50 mph)	1.0
V_{POV1}, m/s	15.7 (35 mph)	1.0
V_{POV2}, m/s	15.7 (35 mph)	1.0
$Rdot_{POV1}$, m/s	-6.7	1.5
Initial R_{POV1}, m	100	10.0
R_{POV2}	R_{POV1} + 23.5 m	3.0
$Rdot_{POV2}$	-6.7	1.5

- Steady-state: The minimum and maximum values of V_{SV}, $V_{POV1,}$ V_{POV2}, $Rdot_{POV1}$, $Rdot_{POV2}$ over a 2 second window ending at the time of the FCW can not exceed the target values and their associated tolerances given above.
- Steady-state: The initial sensing range is greater than 90 m
- The SV, POV1 and POV2 drivers do not touch the brake pedal before the FCW is issued.
- Both the SV, POV1 and POV2 remain in the center of the designated lane until a FCW is issued.
- The time gap between POV1 and POV2 is between 1.3 and 1.7 s
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 21 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 21. Pass/fail criteria for rear-end conflict with constant speed motorcycle (POV1) behind a truck (POV2).

Run pass/fail criteria	*Target value*[10]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

[10] The values are dependent of the actual system design and should be determined by the user.

- The values of R_{POV} and $Rdot_{FCW}$ are both measured relative to POV1 and at the time of the warning they are within the target value and associated tolerance for each measure shown in the table above.

2.9.3 Exceptions to the standard test conditions

The two exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions are the POV1 is a motorcycle and POV2 is a conventional tractor-semi-trailer with a dry-van trailer.

2.9.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, straight-path test requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 35, this test will be conducted at the Dana test track using Set-up S1. The initial conditions for the test will be staged using a set of cones. See section 7 for a more explicit explanation including detailed figures of how these tests will be staged. Section 7 also includes tables for estimating the time and distance needed to stage the test given the constraints of the facility chosen. The placement of the cones, relative to the start of the straight section of track given in S1, for this particular test is shown below in Table 6 (a negative distance means the cone is placed before the straight section of track). The cones are labeled to indicate their purpose. The general scenario for executing the test is:

- SV travels around the track at the desired test speed in the center of the designated lane.
- The POV1 and POV2 are stopped at cone 2.
- When the SV passes cone 1 the driver or experimenter instructs the POV1 and POV2 to start.
- The POV2 driver accelerates at the nominally constant rate of 1.5 m/s^2 (the POV2 driver is assisted by a windshield mounted accelerometer) for 10.4 seconds to reach the desired speed in the space between cones 2 and 3 while staying in the center of the designated lane.
- POV1 follows POV2 at the desired range using telltales of a predetermined length as a guide to the specified following range for the test
- If staged correctly the POV1 and POV2 will reach cone 3 simultaneously with the SV entering the straight section of the track with the desired initial conditions.

Table 22. Cone location for rear-end with a constant speed POV

Cone	*Distance, m*	*Label/Purpose*
1	-233	SV commands POV to start
2	69	From a stop the POV accelerates at 1.5 m/s^2
3	150	POV2 at specified speed in 10.4 seconds

2.9.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates, in the center of the selected lane, to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.
2. At the specified speed, and upon passing cone 1, the driver (or accompanied experimenter) commands the POV1 and POV2 drivers to start driving.
3. The SV driver then continues along the center of the selected lane at the commanded speed closing on the POV1 in a straight section of the test track.
4. Upon a warning by the FCW system or if the SV driver senses a crash is imminent the test is aborted.
5. The SV driver then brakes appropriately while steering to the left to avoid the POV1 and POV2.

Principal other vehicle 2 driver:

1. From a stopped position located at cone 2 (either in or adjacent to selected lane) the driver waits for the experimenter in the SV to give the start command.
2. The POV2 driver then accelerates steadily to the desired speed using cone 3, a window mounted accelerometer, and an estimated time window.
3. At the desired speed the POV2 engages the cruise control and makes small adjustments to speed if necessary while staying in the center of the designated lane.
4. Upon the *abort* command from the SV experimenter, the POV2 driver accelerates while steering to the right and to clear a path for the SV.

Principal other vehicle 1 driver:

1. From a stopped position located at cone 2 (either in or adjacent to selected lane) the POV1 driver waits for the experimenter in the SV to give the start command.
2. The POV1 driver then accelerates steadily behind POV2 using telltales to keep a constant distance from POV2.
3. At the desired speed the POV1 continues to follow POV2 make small adjustments in speed to control the distance behind POV2 while staying in the center of the designated lane.
4. Upon the *abort* command from the SV experimenter, the POV1 driver accelerates while steering to the right and to clear a path for the SV.

2.10 RE-10. Rear-end conflict with POV after a cut-in by the POV (Required Test)

This test is intended to verify the timeliness detecting a new in-path vehicle and the appropriateness of an FCW when a slower moving POV changes lanes in front of the SV. The lane-change/cut-in by the POV should occur within the forward-conflict region of the FCW system on the SV.

2.10.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 10 shows the initial, transitional and final conditions for the rear-end conflict with a slower POV after a lane change by the POV. The initial conditions are in the top of the figure and show a constant speed SV approaching a slower constant-speed POV that is traveling in an adjacent lane to the right of the SV. Then, at a predetermined range, the driver of the POV changes lanes to the left in front of the SV. Next, the figure illustrates that a warning should occur when the SV reaches the R_{FCW} as specified by the designers of the FCW system. Finally, the bottom of the figure shows that upon a warning or when the SV driver senses a crash is imminent with the POV, the conflict is resolved by the SV slowing and moving laterally to the right while the POV accelerates and moves to the left to avoid a crash.

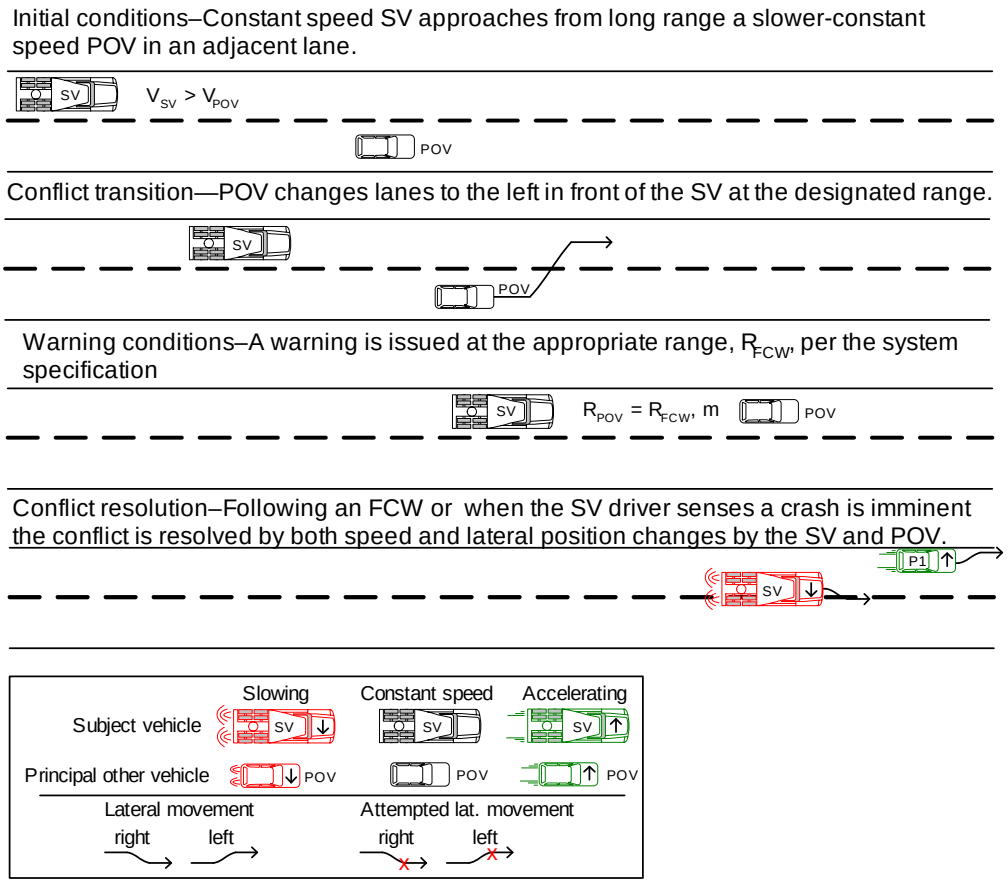


Figure 10. Test concept for rear-end conflict with POV after a cut-in by the POV.

2.10.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 23. The table is separated into two sections; the top section shows the target steady-state initial conditions for the test, while the bottom sections shows transitional kinematics that induce a conflict. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as

applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition. Note: there may be more than one transitional event in procedures that involve multiple threats and multiple POVs.

Table 23. Run validity criteria for rear-end conflict with POV after a cut-in by the POV.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0

Transitional test variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
V_{POV1}, m/s	15.7 (35 mph)	1.0
Initial Range[11], m	30.0	8.0
Initial Range-rate, m/s	-4.4	1.5

- Steady-state: The minimum and maximum values of V_{SV} do not exceed the target value and associated tolerances over a 2 second window ending at the start of the transition event by the POV.
- Transitional: The minimum and maximum value of V_{SV} and V_{POV1} do not exceed the target and associated tolerances between the start of the transitional time (POV is identified as the primary FCW target) and the time of the FCW.
- The SV driver does not touch the brake pedal before the FCW is issued.
- The SV remains in the center of the designated lane during the entire test.
- The POV driver does a modestly aggressive lane-change lasting from 3 to 6 seconds.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a Required test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 24 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

[11] This is the range at which the lateral centerline of the POV crosses the boundary line between the SV and POV.

Table 24. Pass/fail criteria for rear-end conflict with POV after a cut-in by the POV.

Run pass/fail criteria	*Target value*[12]	*± Tolerance*
Time-to-Warn$_{FCW,}$, s		
Rdot$_{FCW}$, m/s		
FCW Alert Type		

- The value of Time-to-Warn$_{Fcw}$ and Rdot$_{POV}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.10.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

2.10.4 Test site preparation and special equipment

The test will be conducted on the Skid Pad facility of TRC. This facility is shown in Figure 41. The test will be conduced in lanes 4 and 5 of the TRC Skid pad in the northern direction only with the SV is in lane 4 while the POV is in lane 5 and changes to the left to lane 4.

The initial conditions for the test will be staged using range measurements by the IVBSS. Initially, both the SV and POV will travel at the test speed of the SV with the POV at least 110 m in front of the SV and in the center of the adjacent lane. When both vehicles are in a straight section of track the POV driver decelerates quickly to the desired speed while the experimenter reads the range between the two vehicles. At the desired range, nominally 45 m, the experimenter instructs the POV driver to make a moderately aggressive lane-change lasting 3 to 6 seconds into the SV lane to create the longitudinal conflict and an FCW.

2.10.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates in the center of the lane 4 on the Skid Pad to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.

2. The SV driver then continues along the center of the center lane at the commanded speed closing on the POV, which is in the center of the adjacent lane to the right (lane 5).

[12] The values are dependent of the actual system design and should be determined by the user.

3. Upon a warning by the FCW system or if the SV driver senses a crash is imminent the test is aborted.

4. The SV driver then brakes appropriately while steering to the left to avoid the POV.

Principal other vehicle driver:

1. Using range estimates by the experimenter stay approximately 120 m in front of the SV in center of the center lane traveling at the same speed as the SV.

2. Then upon instruction by the experimenter, decrease from the SV speed to the specified test speed while staying in the center of the lane. Engage the cruise control at the desired speed to reduce variability in speed.

3. When instructed by the experimenter, make a modest lane-change lasting 3 to 6 seconds into the SV lane to create a longitudinal conflict.

4. Upon the *abort* command from the SV experimenter, the POV driver accelerates while steering to the right and to clear a path for the SV.

2.11 RE-11. Rear-end conflict with a slowing POV1 after POV2 cut-out (Engineering Test)

This test is intended to verify the appropriateness of an FCW when the SV encounters a slowing vehicle after the cut-out of an intermediate vehicle.

2.11.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 11 shows the initial, transitional and final conditions for the rear-end conflict with a constant speed POV. The initial conditions are in the top view of the figure and show the SV, POV1 and POV2 traveling at nominally the same speed at a specified initial range in the center of the same lane. The conflict is initiated when POV1 slows at a constant rate. Shortly after POV1 begins to slow, POV2 makes a moderate lane-change maneuver to the left exposing POV1 to the SV. The warning condition occurs when either an FCW is issued or the SV driver senses a crash is imminent with POV1. The conflict is resolved by both speed and lateral position changes by the SV and POV1.

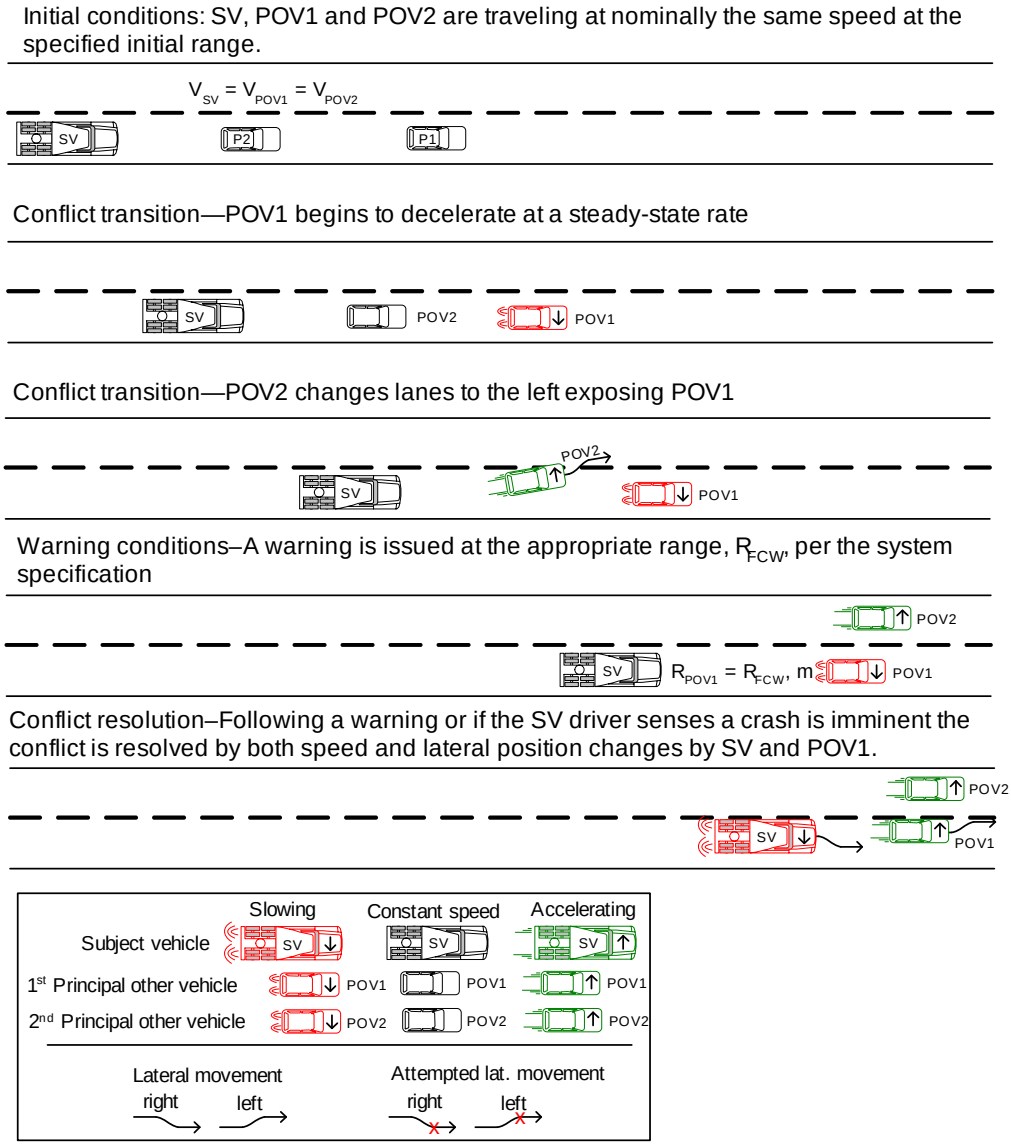


Figure 11. Test concept for rear-end with POV1 after a cut-out by POV2

2.11.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 25. The table is separated into two sections; the top section shows the target steady-state initial conditions for the test, while the bottom sections shows transitional kinematics that induce a conflict. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and

transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition. Note: there may be more than one transitional event in procedures that involve multiple threats and multiple POVs.

Table 25. Run validity criteria for rear-end conflict with a slowing POV1 after POV2 cut-out.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	17.9 (40 mph)	1.0
V_{POV2}, m/s	17.9 (40 mph)	1.0
R_{POV2}, m	50	5.0
R_{POV1}, m	R_{POV2} + 18 m	20
1st Transition test variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV2}, m/s	17.9 (40 mph)	1.0
$Ax_{POV1,}$ m/s^2	-1.5	0.5

- Steady-state: The minimum and maximum values of V_{SV}, V_{POV2}, and R_{POV2} do not exceed the target values and their associated tolerances over a 2 second window ending at the start of the transition event by the POV1.
- Transitional: The average acceleration of the POV1 ($\Delta V/\Delta t$--measured while the brake switch is high) is within the desired range given above for Ax_{POV1}.
- Transitional: The lane change by POV2 begins 1 second after POV1 begins to slow
- Transitional: The minimum and maximum value of V_{SV} remains within the desired range from the start of the braking event by POV1 to the time of the FCW.
- POV2 make a quick lane-change lasting 4 to 5 seconds exposing POV1.
- The SV driver does not touch the brake pedal before the FCW is issued.
- The SV remains in the center of the designated lane during the entire test.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a Required test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 26 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 26. Pass/fail criteria for rear-end conflict with a slowing POV1 after POV2 cut-out.

Run pass/fail criteria	*Target value*[13]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

- The value of R_{POV} and $Rdot_{POV}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.11.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

2.11.4 Test site preparation and special equipment

This is longitudinal conflict, straight-path test involving a braking event by POV1 and a lane-change maneuver by the POV2. To conduct this test requires a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 36, this test will be conducted at the Dana test track using Set-up S2. The initial conditions for the test will be staged using a set of cones. See section 7 for a more explicit explanation including detailed figures of how these tests will be staged. Section 7 also includes tables for estimating the time and distance needed to stage the test given the constraints of the facility chosen. The placement of the cones, relative to the start of the straight section of track given in S2, for this particular test is shown below in Table 27 (a negative distance means the cone is placed before the straight section of track). The cones are labeled to indicate their purpose. The general scenario for executing the test is:

[13] The values are dependent of the actual system design and should be determined by the user.

- SV travels around the track at the desired test speed in the center of the designated lane. For this test the designated lane is the right-most of the two adjacent lanes.
- The POV2 is stopped at cone 2 and POV1 is stopped at cone 3. Both vehicles are in the same lane as the SV
- When the SV passes cone 1 the driver or experimenter instructs the POV1 and POV2 to start.
- The POV2 driver accelerates at the nominally constant rate of 1.5 m/s^2 (the POV2 driver is assisted by a windshield mounted accelerometer) for 12.0 seconds to reach the desired speed in the space between cones 2 and 4 while staying in the center of the designated lane. The POV1 driver accelerates at the nominally constant rate of 1.5 m/s^2 for 12.0 seconds to reach the desired speed in the space between cones 3 and 5 while staying in the center of the designated lane.
- Upon reaching cone 6, POV1 begins a constant deceleration at the desired level using cone 7 as a guide to finishing the event.
- Upon the start of braking by POV1, the driver of POV2 waits 1 second and begins a modest lane-change to the left revealing POV1 to the SV.

Table 27. Cone location for rear-end conflict after a lane change by a slower moving POV

Cone	*Distance, m*	*Label/Purpose*
1	-213	SV commands POV1 and POV2 to start
2	-46.7	From a stop the POV2 accelerates at 1.5 m/s^2
3	-26.7	From a stop the POV1 accelerates at 1.5 m/s^2
4	40	POV2 reaches speed in 12 seconds
5	60	POV1 reaches speed in 12 seconds
6	80	POV1 begins to decelerate at 1.5 m/s^2
7	160	POV1 reaches target transition speed

2.11.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates, in the center of the selected lane, to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.
2. At the specified speed, and upon passing cone 1, the driver (or accompanied experimenter) commands the POV1 and POV2 drivers to start.
3. At cone 6 prepare for the POV1 to begin a transition event.
4. Upon a warning by the FCW system or if the SV driver senses a crash is imminent abort the test.
5. The SV driver then brakes appropriately while steering to the left to avoid the POV1.

Principal other vehicle driver (POV1):

1. From a stopped position located at cone 3 and in the center lane of the track, the driver waits for the experimenter in the SV to give the start command.
2. The driver then accelerates steadily to the desired speed using cone 5, a window mounted accelerometer, and an estimated time window.
3. At cone 6, decelerate steadily to the desired speed using cone 7 as a guide along with a window mounted accelerometer, and an estimated time window.
4. Upon the *abort* command from the SV experimenter, the POV driver accelerates while steering to the right and to clear a path for the SV.

Principal other vehicle driver (POV2):

1. From a stopped position located at cone 2 and in the center lane of the track, the driver waits for the experimenter in the SV to give the start command.
2. The driver then accelerates steadily to the desired speed using cone 4, a window mounted accelerometer, and an estimated time window.
3. One second after POV1 begins to brake make a modest lane change to the left toward the inner lane and expose POV1 to the SV.
4. One out of the center lane, accelerate to clear the area and allow POV1 and the SV room to maneuver and avoid a conflict.

2.12 RE-12. Rear-end conflict with a constant speed motorcycle (Required Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches, from behind and from long range, a slower moving motorcycle in the center of the same lane.

2.12.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 12 shows the initial, transitional and final conditions for the rear-end conflict with a constant speed POV. The initial conditions are in the top third of the figure and show a constant speed SV approaching from long range a slower-moving constant-speed POV at a closing rate at the desired closing rate. The center of the figure shows that a warning should occur when the SV reaches the R_{FCW} as specified by the designers of the FCW system. Finally, the bottom of the figure shows that the conflict is resolved when the SV slows and moves laterally to the right while the POV accelerates and moves to the

left to avoid a crash. If the driver of the SV senses a crash is imminent at any time during the test the test is aborted.

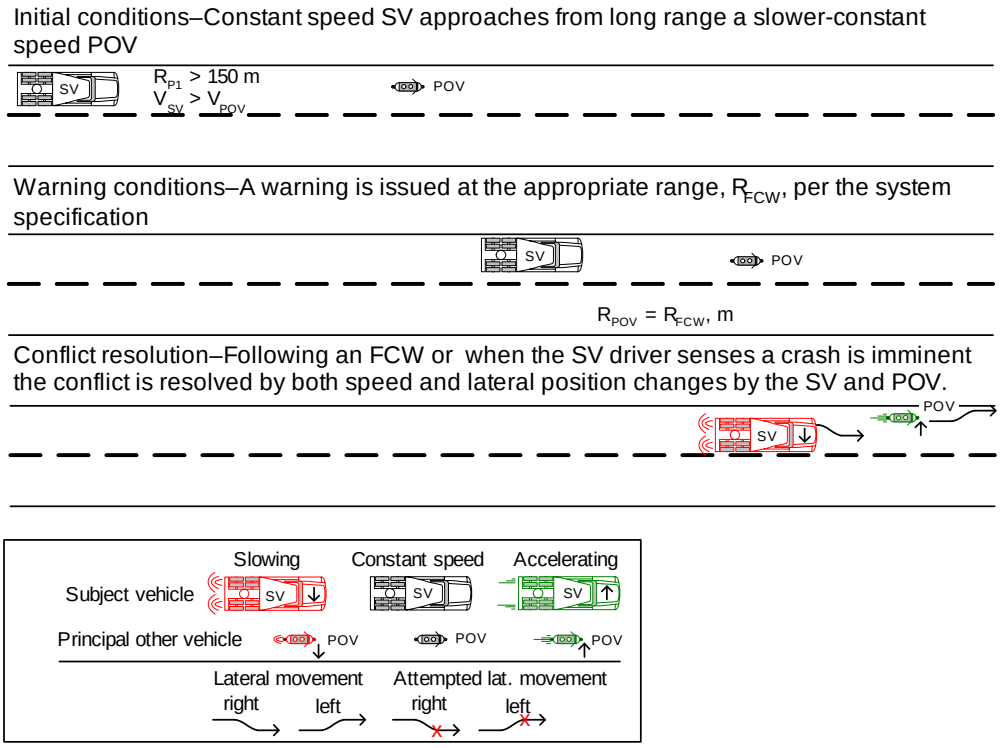


Figure 12. Test concept for rear-end conflict with a constant speed POV (motorcycle).

2.12.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 28. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

Table 28. Run validity criteria for rear-end conflict with a constant speed POV (motorcycle).

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	22.4 (50 mph)	1.0
V_{POV1}, m/s	13.4 (30 mph)	1.0
$Rdot_{POV1}$, m/s	-9.0	1.5
Initial R_{POV1}, m	120	10.0

- Steady-state: The minimum and maximum values of V_{SV}, V_{POV} and $Rdot_{POV}$ over a 2 second window ending at the time of the FCW cannot exceed the target values and their associated tolerances given above.
- Steady-state: The initial sensing range is greater than 110 m
- The SV and POV drivers do not touch the brake pedal before the FCW is issued.
- Both the SV and POV remain in the center of the designated lane until a FCW is issued.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 29 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 29. Pass/fail criteria for rear-end conflict with a constant speed POV (motorcycle).

Run pass/fail criteria	*Target value*[14]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
FCW Alert Type		

- The value of R_{POV} and $Rdot_{POV}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

2.12.3 Exceptions to the standard test conditions

Other than the POV is a motorcycle, there are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

[14] The values are dependent of the actual system design and should be determined by the user.

2.12.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, straight-path test requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 35, this test will be conducted at the Dana test track using Set-up S1. The initial conditions for the test will be staged using a set of cones. See section 7 for a more explicit explanation including detailed figures of how these tests will be staged. Section 7 also includes tables for estimating the time and distance needed to stage the test given the constraints of the facility chosen. The placement of the cones, relative to the start of the straight section of track given in S1, for this particular test is shown below in Table 30 (a negative distance means the cone is placed before the straight section of track). The cones are labeled to indicate their purpose. The general scenario for executing the test is:

- SV travels around the track at the desired test speed in the center of the designated lane.
- The POV is stopped at cone 2.
- When the SV passes cone 1 the driver or experimenter instructs the POV to start.
- The POV driver accelerates at the nominally constant rate of 1.5 m/s^2 (the POV driver is assisted by a windshield mounted accelerometer) for 9 seconds to reach the desired speed in the space between cones 2 and 3 while staying in the center of the designated lane.
- If staged correctly the POV will reach cone 3 simultaneously with the SV entering the straight section of the track with the desired initial conditions.

Table 30. Cone location for rear-end with a constant speed POV (motorcycle)

Cone	*Distance, m*	*Label/Purpose*
1	-220	SV commands POV to start
2	90	From a stop the POV accelerates at 1.5 m/s^2
3	150	POV at specified speed in 9 seconds

2.12.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates, in the center of the selected lane, to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.

2. At the specified speed, and upon passing cone 1, the driver (or accompanied experimenter) commands the POV driver to start driving.

3. The SV driver then continues along the center of the selected lane at the commanded speed closing on the POV in a straight section of the test track.
4. Upon a warning by the FCW system or if the SV driver senses a crash is imminent the test is aborted.
5. The SV driver then brakes appropriately while steering to the left to avoid the POV.

Principal other vehicle driver:

1. From a stopped position located at cone 2 (either in or adjacent to selected lane) the driver waits for the experimenter in the SV to give the start command.
2. The POV driver then accelerates steadily to the desired speed using cone 3 and an estimated time window.
3. At the desired speed the POV engages the cruise control and makes small adjustments to speed if necessary while staying in the center of the designated lane.
4. Upon the *abort* command from the SV experimenter, the POV driver accelerates while steering to the right and to clear a path for the SV.

3 Lane Change/Merge Warning Tests

The procedures described in this section are designed to thoroughly test the LCM sub-system for repeatability and pertinence. Each of the tests involve both longitudinal and lateral position changes and although the LCM system is primarily concerned with the presence of vehicles in adjacent lanes, it also has a predictive element that alerts the SV driver if a vehicle is entering the region adjacent to the subject vehicle.

3.1 LC-1. Lane-change conflict with adjacent POV in a blind spot on the right (Required Test)

This test is intended to verify the appropriateness of an LCW when the SV signals and begins to change lanes to the right while the adjacent lane is occupied by another vehicle that is located in the foremost blind-spot with the front bumper of the POV aligned with the front bumper of the SV. The test is intended to use information provided by the laterally oriented proximity sensors of the LCM system. In this test both vehicles are traveling at the same forward speed.

3.1.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 13 shows the initial, transitional, warning and conflict resolution conditions for a lane-change conflict. The test begins with both the SV and POV are traveling nominally at the same speed in the center of their designated lanes with the front bumper of the POV aligned with the front bumper of the SV. The conflict initiates when the SV driver uses the right-side turn indicator and moves to the right with a lateral velocity, $LatV_{SV}$, between 0.1 and 0.4 m/s. The test ends when an LCW is issued or the SV driver senses a crash is imminent. The conflict is resolved by a lateral position change to the left by the SV driver.

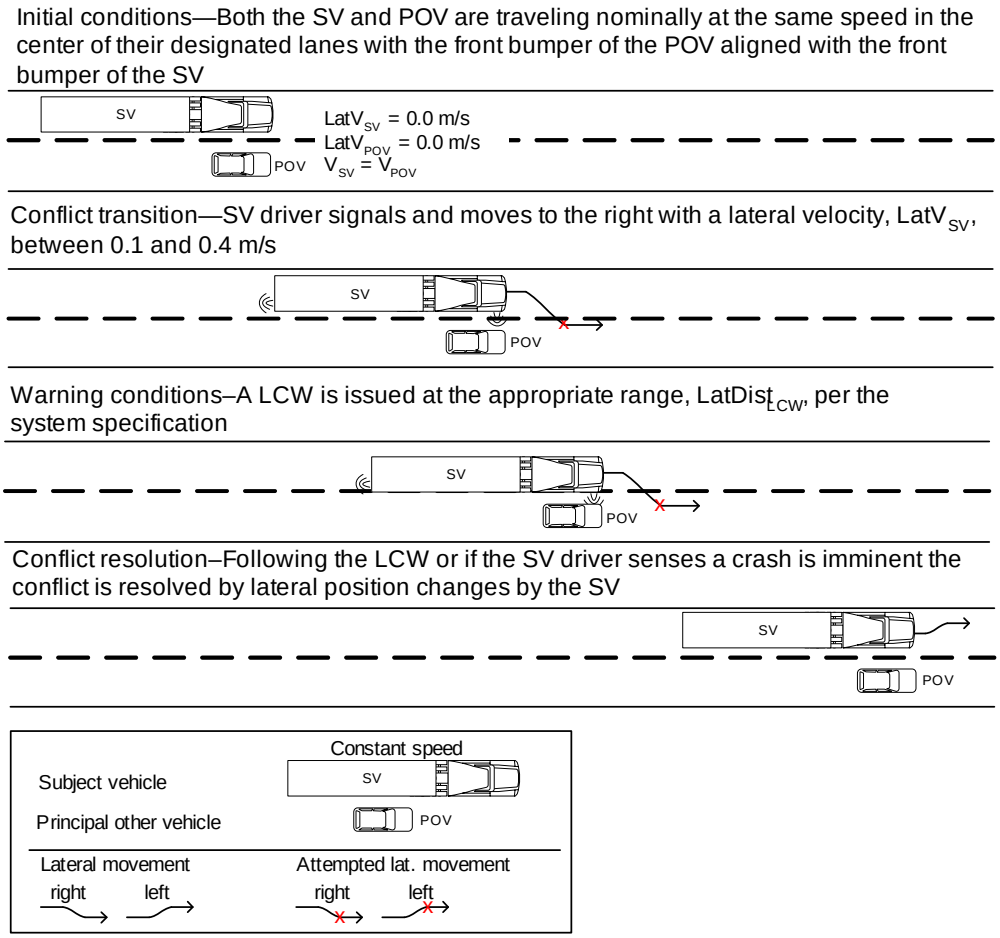


Figure 13. Test concept for lane-change conflict with POV in blind-spot (front bumper) on right.

3.1.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 31. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions

are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

Table 31. Run validity criteria for lane-change conflict with POV in blind-spot (front bumper) on right.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	17.9 (40 mph)	1.0
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.25	0.15

- Steady-state: The minimum and maximum values of V_{SV} and V_{POV1} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the LCW.
- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the LCW.
- The right-side turn indicator is on at least 1 second prior to the LCW.
- The SV driver does not touch the brake pedal before the LCW is issued.
- The SV starts the lateral movement to the right from the center of the designated lane.
- The POV remains in the center of the adjacent lane at the appropriate longitudinal position as specified for the test.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 32 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 32. Pass/fail criteria for lane-change conflict with POV in blind-spot (front bumper) on right.

Run pass/fail criteria	*Target value*[15]	*± Tolerance*
$LatDist_{LCW}$, m		

- The value of $LatDist_{LCW}$ at the time of the warning must be within the target value and associated tolerance as shown in the table above.

3.1.3 Exceptions to the standard test conditions

In addition to the default conditions as detailed in the section Definitions and Standard Test Conditions, the following exceptions are necessary for this procedure:

The test is to be run with a tractor and single semi-trailer combination where the semi-trailer is a typical dry-freight van between 45 and 53 feet with a box width of 102 inches and is unloaded in terms of additional cargo or dummy weights.

3.1.4 Test site preparation and special equipment

The test will be conducted on the Skid Pad facility of TRC. This facility is shown in Figure 41. The test will be conduced in lanes 4 and 5 of the TRC Skid pad traveling in the northern direction only. For the test, the SV is in lane 4, and the POV is in lane 5. The SV driver will signal to the right and attempt a lane change to the right causing the lateral conflict and the LCW. No changes to the existing boundary markers are required for this test.

3.1.5 Driving instructions

Subject vehicle driver:

1. Drive in the center of the designated lane at the desired test speed using either cruise control or manual control of the throttle.

[15] The values are dependent of the actual system design and should be determined by the user.

2. On an adequate straight section of track with the POV in position, use the turn indicator to signal to the right. Wait one second and begin a slow lane change maneuver toward the POV.
3. Abort or end the test upon a warning by the LCM system or if a crash is imminent.
4. Return to the center of the designated lane.

Principal other vehicle driver:

1. Drive in the center of the designated lane with the front bumper of your vehicle aligned with the front bumper of the SV. Maintain the desired test speed using either cruise control or manual control of the throttle.

3.2 LC-2. Lane-change conflict with adjacent POV in a blind spot on the left (Required Test)

This test is intended to verify the appropriateness of an LCW when the SV signals and begins to change lanes to the left while the adjacent lane is occupied by another vehicle that is located alongside the SV trailer. The test is intended to use information provided by the rear-facing long-range LCW sensors. In this test both vehicles are traveling at the same forward speed.

3.2.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 14 shows the initial, transitional, warning and conflict resolution conditions for a lane-change conflict. The test begins with the SV and POV traveling nominally at the same speed in the center of their designated lanes with the front bumper of the POV aligned laterally with the longitudinal center of the SV trailer. The conflict is initiated when SV driver signals and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.1 and 0.4 m/s. The test ends when an LCW is issued or the SV driver senses a crash is imminent. The conflict is resolved by a lateral position change to the right by the SV.

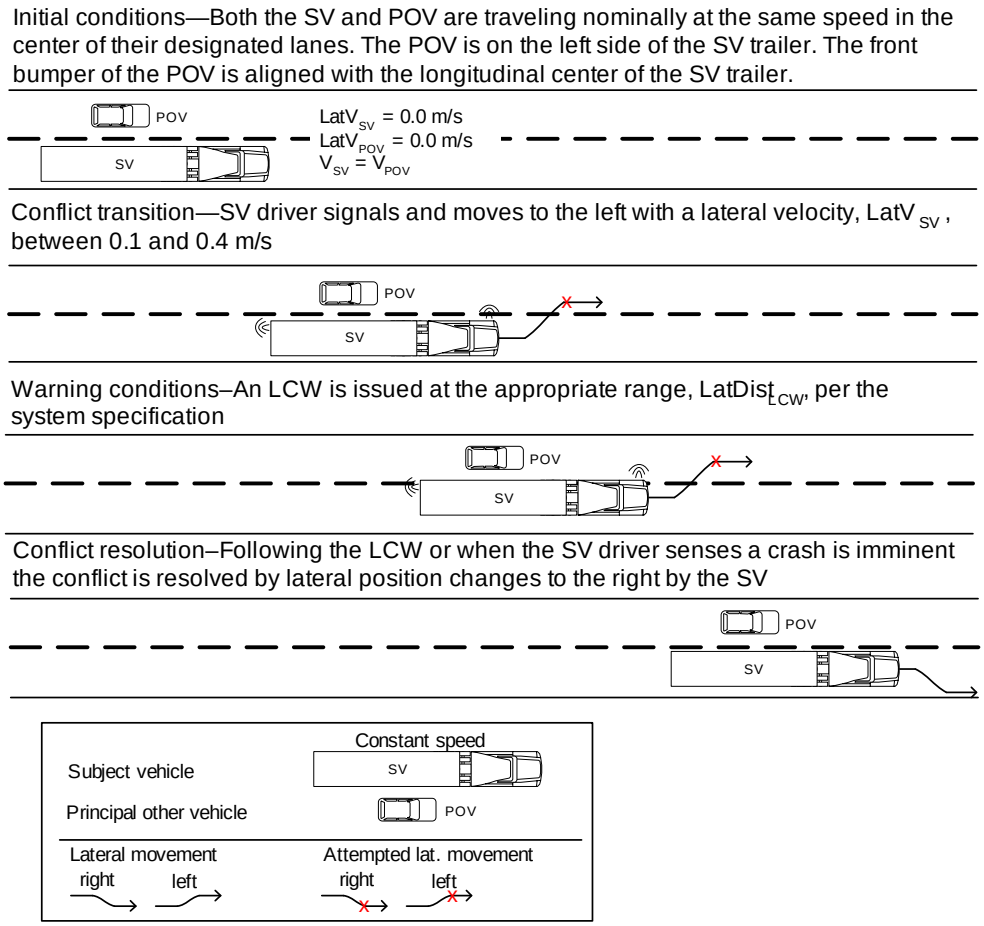


Figure 14. Test concept for lane-change conflict with POV in blind-spot on the left.

3.2.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 33. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

Table 33. Run validity criteria for lane-change conflict with POV in blind-spot (rear bumper) on left.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	17.9 (40 mph)	1.0
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.25	0.15

- Steady-state: The minimum and maximum values of V_{SV} and V_{POV1} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the LCW.
- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the LCW.
- The right-side turn indicator is on at least 1 second prior to the LCW.
- The SV driver does not touch the brake pedal before the LCW is issued.
- The SV starts the lateral movement to the left from the center of the designated lane.
- The POV remains in the center of the adjacent lane at the appropriate longitudinal position as specified for the test.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 34 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 34. Pass/fail criteria for lane-change conflict with POV in blind-spot on left.

Run pass/fail criteria	*Target value*[16]	*± Tolerance*
$LatDist_{LCW}$, m		

[16] The values are dependent of the actual system design and should be determined by the user.

- The value of $LatDist_{LCW}$ at the time of the warning must be within the target value and associated tolerance as shown in the table above.

3.2.3 Exceptions to the standard test conditions

In addition to the default conditions as detailed in the section Definitions and Standard Test Conditions, the following exceptions are necessary for this procedure:

The test is to be run with a tractor and single semi-trailer combination where the semi-trailer is a typical dry-freight van between 45 and 53 feet with a box width of 102 inches and is unloaded in terms of additional cargo or dummy weights.

3.2.4 Test site preparation and special equipment

The test will be conducted on the Skid Pad facility of TRC. This facility is shown in Figure 41. The test will be conduced in lanes 4 and 5 traveling in the southern direction only. For the test, the SV is in lane 4, and the POV is in lane 5. No changes to the existing boundary markers are required for this test.

3.2.5 Driving instructions

Subject vehicle driver:

1. Drive in the center of the designated lane at the desired test speed.
2. On an adequate straight section of track with the POV in position, use the turn indicator to signal to the left. Wait one second and begin a slow lane change maneuver toward the POV.
3. Abort or end the test upon a warning by the LCW system or if a crash is imminent.
4. Return to the center of the designated lane.

Principal other vehicle driver:

1. Drive in the center of the designated lane with the front bumper of your vehicle aligned with the mid-trailer side turn indicator light of the SV trailer. Maintain the desired test speed using either cruise control or manual control of the throttle.

3.3 LC-3. Lane-change conflict with an adjacent POV on curve (Engineering Test)

This test is intended to verify the appropriateness of an LCW when the SV signals and begins to change lanes to the left while the adjacent lane is occupied by another

vehicle that is located longitudinally near the center of the SV trailer. In this test both vehicles are traveling at the same forward speed and are negotiating a moderate radius curve.

3.3.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 15 shows the initial, transitional, warning and conflict resolution conditions for a lane-change conflict. The test begins with both the SV and POV traveling nominally at the same speed in a moderate radius curve and in the center of their designated lanes with the front bumper of the POV aligned with the longitudinal center of the trailer. The conflict initiates by when the SV driver engages the turn signal and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.1 and 0.4 m/s. The test ends when an LCW is issued at the appropriate range, $LatDist_{LCW}$, per the system specification or when the SV driver senses a crash is imminent. The conflict is resolved by a lateral position change by SV.

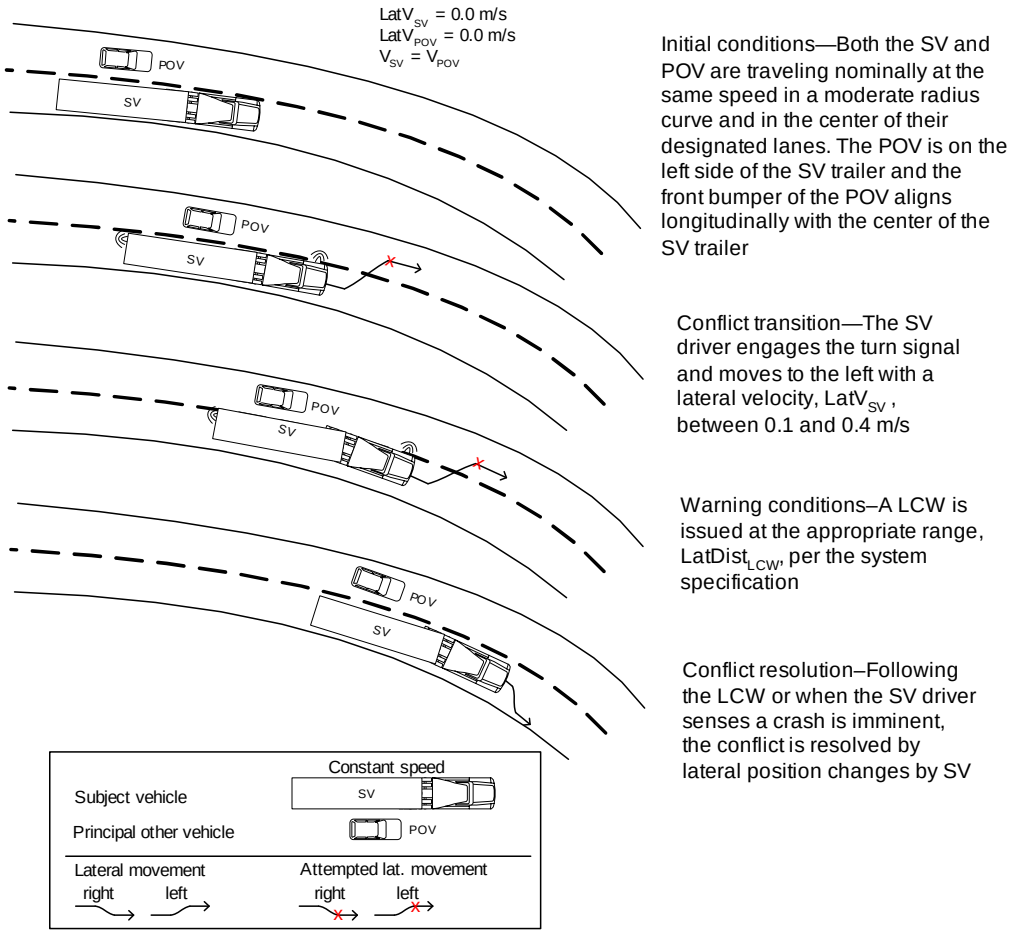


Figure 15. Test concept for lane-change into adjacent POV on curve.

3.3.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 35. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

Table 35. Run validity criteria for lane-change into adjacent POV on curve.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	17.9 (40 mph)	1.0
Curve Radius	280 m	15
Transitional test variables	*Target Value*	*± Tolerance*
Lat$V_{SV,}$ m/s	0.25	0.15

- Steady-state: The minimum and maximum values of V_{SV} and V_{POV1} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the LCW.
- Transitional: The average value of LatV_{SV} is within the tolerance given above over a 1 second window ending at the time of the LCW.
- The right-side turn indicator is on at least 1 second prior to the LCW.
- The SV driver does not touch the brake pedal before the LCW is issued.
- The SV starts the lateral movement to the left from the center of the designated lane.
- The POV remains in the center of the adjacent lane at the appropriate longitudinal position as specified for the test.

- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 36 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 36. Pass/fail criteria for lane-change into adjacent POV on curve.

Run pass/fail criteria	*Target value*[17]	*± Tolerance*
$LatDist_{LCW}$, m		

3.3.3 Exceptions to the standard test conditions

In addition to the default conditions as detailed in the section Definitions and Standard Test Conditions, the following exceptions are necessary for this procedure:

The test is to be run with a tractor and single semi-trailer combination where the semi-trailer is a typical dry-freight van between 45 and 53 feet with a box width of 102 inches and is unloaded in terms of additional cargo or dummy weights.

3.3.4 Test site preparation and special equipment

This is a longitudinal and lateral straight-path test requiring two adjacent lanes and a site large enough for the establishment of steady-state initial conditions and adequate lateral space to perform the test without leaving a paved surface. The test lanes shall have boundary markers on the both sides of each lane such that the IVBSS system can identify and accurately measure the lane width and lane offset distances of the SV. The POV vehicle shall maintain its position in the center of its lane and if available a measure of the lateral-lane offset of the POV shall be used to confirm this condition. The boundary that is approached by the subject vehicle shall be dashed or solid. As outlined in section 7 and shown in Figure 39, this test will be conducted at the Dana test track using Set-up C1.

[17] The values are dependent of the actual system design and should be determined by the user.

3.3.5 Driving instructions

Subject vehicle driver:

1. Drive in the center of the designated lane (center-lane) at the desired test speed.
2. On the designated curved section of track with the POV in position, use the turn indicator to signal to the left. Wait one second and begin a slow lane change maneuver toward the POV.
3. Abort or end the test upon a warning by the LCW system or if a crash is imminent.
4. Return to the center of the designated lane.

Principal other vehicle driver:

- Drive in the center of the designated lane (inner lane at Dana) with the front bumper of your vehicle aligned with the longitudinal center of the SV trailer. Maintain the desired test speed using either cruise control or manual control of the throttle. Do not deviate from the center of the lane while the SV approaches from the right.

3.4 LC-4. Lane-change conflict with an adjacent POV on merge (Engineering Test)

This test is intended to verify the appropriateness of an LCW when the SV signals and begins to merge left into a lane that is occupied by another vehicle that is located in a blind spot of the SV driver. In this test both vehicles are traveling at the same forward speed.

3.4.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 16 shows the initial, transitional, warning and conflict resolution conditions for a lane-change conflict. The test begins with both the SV and POV traveling nominally at the same speed in the center of their designated lanes with the front bumper of the POV aligned with the longitudinal center of the SV trailer. The conflict initiates when the SV driver engages the turn signal and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.2 and 0.6 m/s. The test ends when an LCW is issued at the appropriate range, $LatDist2_{LCW}$, or when the SV driver senses a crash is imminent. The conflict is resolved by the SV moving laterally to the right while the POV driver moves laterally to the left.

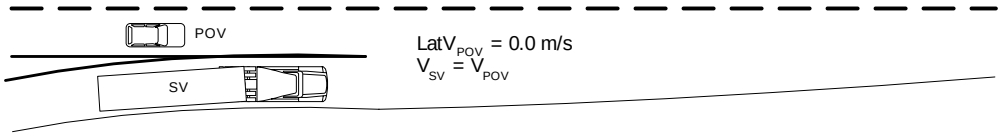
3.4.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 37. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

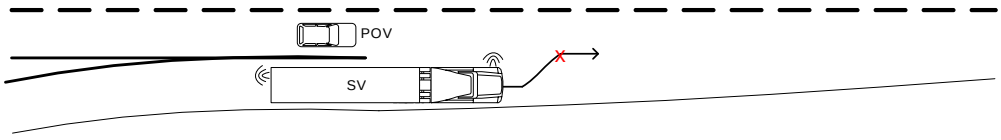
For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition

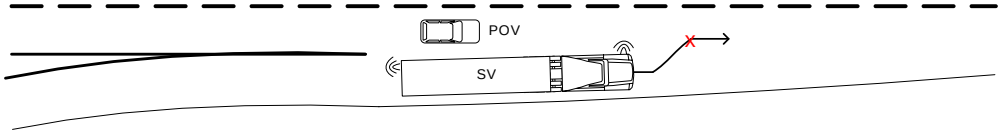
Initial conditions—Both the SV and POV are traveling nominally at the same speed in the center of their designated lanes with POV on the left of the SV trailer. The front bumper of the POV is aligned with the center of the SV trailer.



Conflict transition—SV driver signals and moves to the left with a lateral velocity, LatV $_{SV}$, between 0.2 and 0.6 m/s



Warning conditions–A LCW is issued at the appropriate range, LatDist$_{LCW}$, per the system specification



Conflict resolution–Following the LCW or when the SV driver senses a crash is imminent the conflict is resolved by the SV moving laterally to the right while the POV driver steers to the left

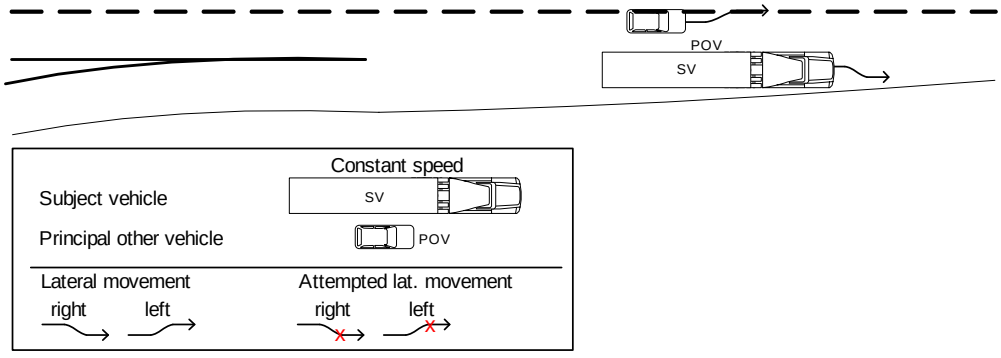


Figure 16. Test concept for lane-change into adjacent POV on merge.

Table 37. Run validity criteria for lane-change into adjacent POV on merge.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	17.9 (40 mph)	1.0
$LOff_{SV}$, m	2.22	0.5

- Steady-state: The minimum and maximum values of V_{SV} and V_{POV1} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the LCW.
- Transitional: The distance from the right front tire of the SV is a constant distance of 1 m from the right-side boundary marker for at least 2 seconds prior to the LCW.
- The left-side turn indicator is on at least 1 second prior to the LCW.
- The SV driver does not touch the brake pedal before the LCW is issued.
- The POV remains in the center of the lane at the appropriate longitudinal position as specified for the test.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 38 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 38. Pass/fail criteria for lane-change into adjacent POV on merge.

Run pass/fail criteria	*Target value*[18]	*± Tolerance*
$LatDist2_{LCW}$, m		

To conduct the test and determine if the warning is issued near the target $LatDist2_{LCW}$ value, two cones will be placed on the track at a predetermined distance into the merging lanes. These cones will mark the beginning and end of a region that ensures the distance between the SV and POV is near the target $LatDist2_{LCW}$ value considering the allowable tolerance and that the SV and POV drivers maintain their prescribed distances from the known boundaries. To derive the location of the cones consider Figure 17.

[18] The values are dependent of the actual system design and should be determined by the user.

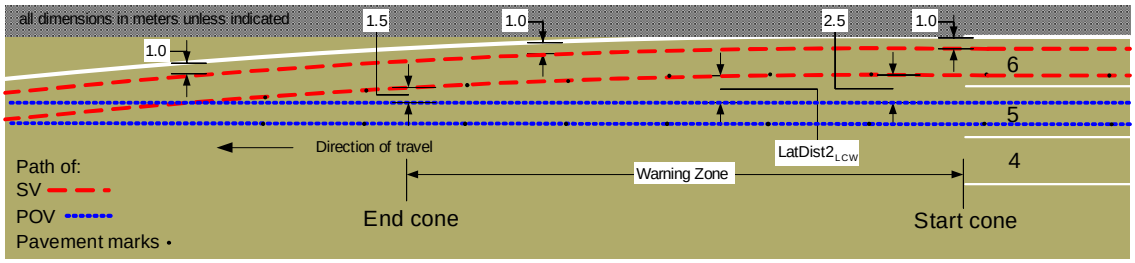


Figure 17. Cone locations for the lane-change into an adjacent POV on a merge.

The location of the cones was determined by measuring the lateral distance between the left-side projected path of the POV and the existing right-side boundary line of lane 6, which narrows into lane 5. Table 39 shows the lateral distance (Y) as function of longitudinal distance (X) starting at end of the existing solid lane boundary lines between lanes 4, 5, and 6 and proceeding to the left in Figure 17. The table also shows $LatDist2_{LCW}$, which is the difference between the lateral distance, and a constant offset that accounts for the track width of both vehicles (2.54 and 1.83 m for the SV and POV, respectively) and the 1 m offset of right-side path of the SV relative to right-side boundary line of lane 6.

Table 39. Measurements to determine the LC-4 warning zone.

X, m	*Y, m*	*$LatDist2_{LCW}$,m*
0.0	7.8	2.5
5.5	7.8	2.5
10.9	7.8	2.5
16.5	7.8	2.4
22.0	7.8	2.4
27.5	7.7	2.4
32.9	7.7	2.3
38.3	7.6	2.3
43.8	7.6	2.2
49.3	7.5	2.1
54.7	7.4	2.0
60.4	7.3	1.9
65.8	7.2	1.8
71.3	7.1	1.7
76.8	6.9	1.5

Given a forward speed of 17.9 m/s (40 mph) the average lateral speed for the warning zone is 0.21 m/s.[19]

[19] This is estimated by taking the ratio between the lateral and longitudinal distance traveled multiplied by the SV forward speed.

3.4.3 Exceptions to the standard test conditions

In addition to the default conditions as detailed in the section Definitions and Standard Test Conditions, the following exceptions are necessary for this procedure:

The test is to be run with a tractor and single semi-trailer combination where the semi-trailer is a typical dry-freight van between 45 and 53 feet with a box width of 102 inches and is unloaded in terms of additional cargo or dummy weights.

3.4.4 Test site preparation and special equipment

The test will be conducted on the Skid Pad facility of TRC. This facility is shown in Figure 41. The test will be conduced using lanes 5 and 6 at the north end of the facility where lane 6 narrows and merges with lane 5. To conduct the test and determine if the warning is issued near the target $LatDist2_{LCW}$ value, two cones will be placed on the track at a predetermined distance into the merging lanes. These cones will mark the beginning and end of a region that ensures the distance between the SV and POV is near the target $LatDist2_{LCW}$ value considering the allowable tolerance and that the SV and POV drivers maintain their prescribed distances from the known boundaries or temporary chalk markers on the pavement.

3.4.5 Driving instructions

Subject vehicle driver:

1. Drive in the center of the designated lane (center-lane) at the desired test speed.
2. On the designated straight section of track with the POV in position, use the turn indicator to signal to the left and begin to merge into the adjacent lane on the left keeping the distance from the right-side front tire 1 m from the right-side solid boundary line.
3. Abort or end the test upon a warning by the LCW system or if a crash is imminent.
4. Move laterally to the right to avoid the POV

Principal other vehicle driver:

1. Drive in the center of the designated lane with the front bumper of your vehicle aligned with the longitudinal center of the SV trailer. Maintain the desired test speed using either cruise control or manual control of the throttle. Do not deviate from the center of the lane while the SV approaches from the right. Use the left side boundary marker or temporary chalk marks as a guide

to maintain a constant lateral distance from the left boundary and hence a constant lateral position when the right-side boundary marker disappears.

3.5 LC-5. Lane-change conflict with an adjacent POV after passing (Engineering Test)

This test is intended to verify the appropriateness of an LCW when the SV signals and begins to change lanes to the left while the adjacent lane is occupied by another vehicle that is being passed by the SV.

3.5.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 18 shows the initial, transitional, warning and conflict resolution conditions for a lane-change conflict. The test begins when the SV is passing the POV and both vehicles are in the center of their designated lanes. The conflict starts when the front of the POV is sensed by the LCW proximity sensors. The SV driver then engages the turn signal and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.1 and 0.4 m/s. The test ends when an LCW is issued at the appropriate range, $LatDist_{LCW}$, or if the SV driver senses a crash is imminent. The conflict is resolved by the SV moving laterally to the right while the POV driver steers to the left.

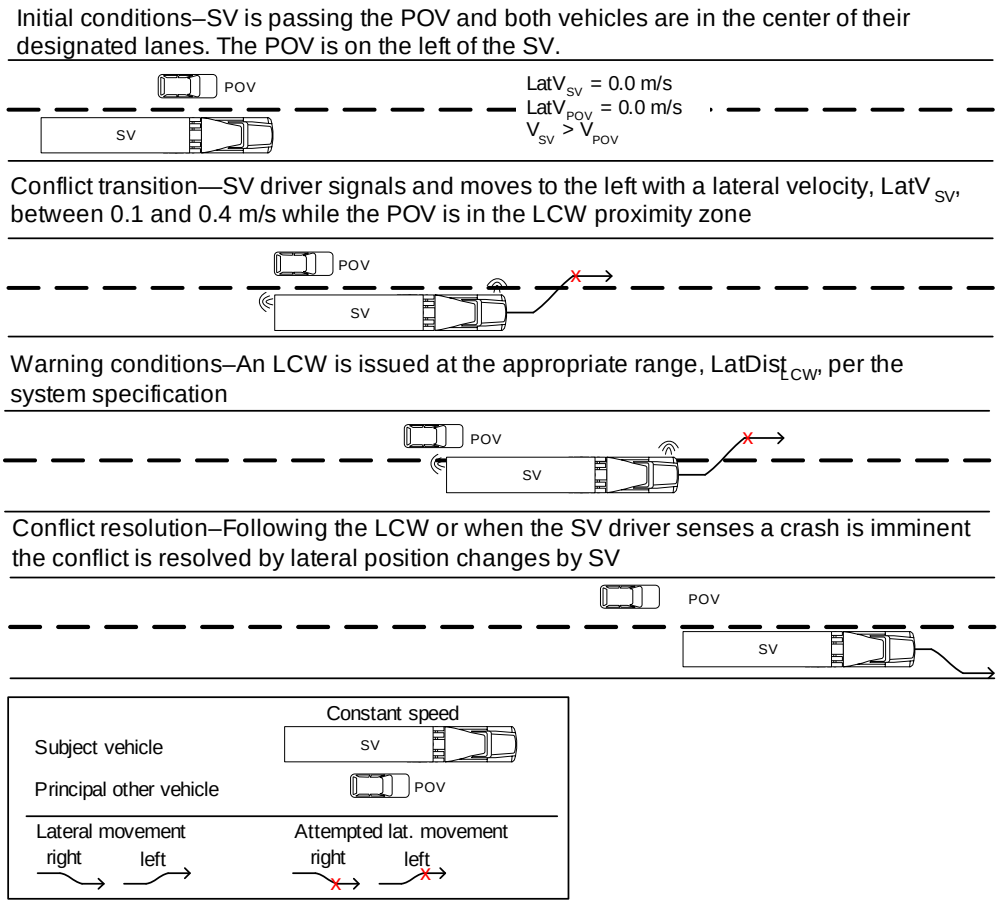


Figure 18. Test concept for lane-change into adjacent POV after passing.

3.5.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 40. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial conditions have been satisfied along with other criteria that if not followed invalidate the run.

Table 40. Run validity criteria for lane-change into adjacent POV after passing.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
V_{POV1}, m/s	15.6 (35 mph)	1.0
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.25	0.15

- Steady-state: The minimum and maximum values of V_{SV} and V_{POV1} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the LCW.
- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the LCW.
- The left-side turn indicator is on at least 1 second prior to the LCW.
- The SV driver does not touch the brake pedal before the LCW is issued.
- The SV starts the lateral movement to the right from the center of the designated lane.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 41 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 41. Pass/fail criteria for lane-change into adjacent POV after passing.

Run pass/fail criteria	*Target value*[20]	*± Tolerance*
$LatDist_{LCW}$, m		

[20] The values are dependent of the actual system design and should be determined by the user.

3.5.3 Exceptions to the standard test conditions

In addition to the default conditions as detailed in the section Definitions and Standard Test Conditions, the following exceptions are necessary for this procedure:

The test is to be run with a tractor and single semi-trailer combination where the semi-trailer is a typical dry-freight van between 45 and 53 feet with a box width of 102 inches and is unloaded in terms of additional cargo or dummy weights.

3.5.4 Test site preparation and special equipment

This is a longitudinal and lateral straight-path test requiring two adjacent lanes and a site large enough for the establishment of steady-state initial conditions and adequate lateral space to perform the test without leaving a paved surface. The test lanes shall have boundary markers on the both sides of each lane such that the IVBSS system can identify and accurately measure the lane width and lane offset distances of the SV. The POV vehicle shall maintain its position in the center of its lane and if available a measure of the lateral-lane offset of the POV shall be used to confirm this condition. The boundary that is approached by the subject vehicle shall be dashed or solid. As outlined in section 7 and shown in Figure 36, this test will be conducted at the Dana test track using Set-up S2.

3.5.5 Driving instructions

Subject vehicle driver:

1. Drive in the center of the center lane at the desired test speed.
2. On an adequate straight section of track pass the slower POV. When the front bumper of the POV is adjacent to the longitudinal center of the trailer, use the turn indicator to signal to the left. Wait two seconds and begin a slow lane change maneuver toward the POV.
3. Abort or end the test upon a warning by the LCW system or if a crash is imminent.
4. Return to the center of the designated lane.

Principal other vehicle driver:

1. Drive in the center of the designated lane at the desired test speed using either cruise control or manual control of the throttle.

3.6 LC-6. Lane-change conflict with an approaching POV (Engineering Test)

This test is intended to verify the appropriateness of an LCW when the SV signals and begins to change lanes to the left while the adjacent lane is about to be occupied by another vehicle that approaching from behind and is passing the SV.

3.6.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 18 shows the initial, transitional, warning and conflict resolution conditions for a lane-change conflict. The test begins when the POV is approaching SV at a slow to moderate closing rate. Both vehicles are in the center of their designated lanes. The conflict starts when the POV is sensed by the LCW rear-looking sensors. The SV driver then engages the turn signal and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.2 and 0.4 m/s. The test ends when an LCW is issued at the appropriate range, $LatDist_{LCW}$, or if the SV driver senses a crash is imminent. The conflict is resolved by the SV moving laterally to the right.

3.6.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 42. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

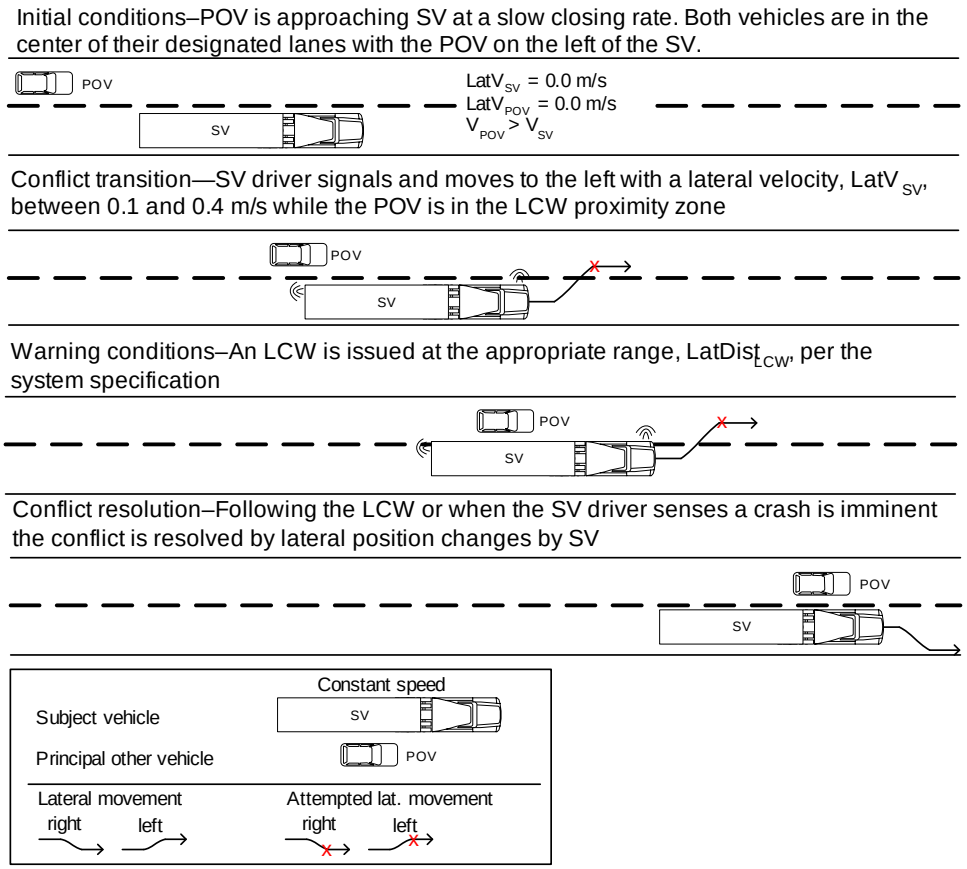


Figure 18. Test concept for lane-change into approaching POV.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

Table 42. Run validity criteria for lane-change into approaching POV.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	1.0
V_{POV1}, m/s	20.1 (45 mph)	1.0
Transitional test variables	*Target Value*	*± Tolerance*
LatV$_{SV,}$ m/s	0.25	0.15

- Steady-state: The minimum and maximum values of V_{SV} and V_{POV1} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the LCW.
- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the LCW.
- The left-side turn indicator is on at least 1 second prior to the LCW.
- The SV driver does not touch the brake pedal before the LCW is issued.
- The SV starts the lateral movement to the left from the center of the designated lane.
- The SV starts the lane change, as the front of the POV is adjacent to trailer.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 43 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 43. Pass/fail criteria for lane-change into approaching POV.

Run pass/fail criteria	*Target value*[21]	*± Tolerance*
$LatDist_{LCW}$, m		

- The value of $LatDist_{LCW}$ at the time of the warning must be within the target value and associated tolerance as shown in the table above.

3.6.3 Exceptions to the standard test conditions

In addition to the default conditions as detailed in the section Definitions and Standard Test Conditions, the following exceptions are necessary for this procedure:

The test is to be run with a tractor and single semi-trailer combination where the semi-trailer is a typical dry-freight van between 45 and 53 feet with a box width of 102 inches and is unloaded in terms of additional cargo or dummy weights.

[21] The values are dependent of the actual system design and should be determined by the user.

3.6.4 Test site preparation and special equipment

This is a longitudinal and lateral straight-path test requiring two adjacent lanes and a site large enough for the establishment of steady-state initial conditions and adequate lateral space to perform the test without leaving a paved surface. The test lanes shall have boundary markers on the both sides of each lane such that the IVBSS system can identify and accurately measure the lane width and lane offset distances of the SV. The POV vehicle shall maintain its position in the center of its lane and if available a measure of the lateral-lane offset of the POV shall be used to confirm this condition. The boundary that is approached by the subject vehicle shall be dashed or solid. As outlined in section 7 and shown in Figure 36, this test will be conducted at the Dana test track using Set-up S2.

3.6.5 Driving instructions

Subject vehicle driver:

1. Drive in the center of the center lane at the desired test speed.
2. On an adequate straight section of track and when the POV driver instructs you to start, turn on your left-side turn signal, wait one second and begin to change lanes to the left.
3. Abort or end the test upon a warning by the LCW system or if a crash is imminent.
4. Return to the center of the designated lane.

Principal other vehicle driver:

1. Drive in the center of the designated lane at the desired test speed using either cruise control or manual control of the throttle.
2. On a straight section of track and when you are approximately 3 m (10 ft) from the rear bumper of the SV trailer instruct the SV driver to signal and start a lane change maneuver to the left.

4 Road Departure Warning Tests

The procedures for conducting five road departure tests are detailed below. Four of the tests are classified as *Required* and test the systems' ability to warn when the vehicle drifts laterally across a boundary marker on straight and curved sections of roadway. The fifth procedure tests the systems' warning capability when drifting across a boundary that is adjacent to a solid barrier such as a guard-rail or Jersey barrier. The fifth test is considered an *Engineering* test.

4.1 RD-1. Road departure toward opposing traffic lane—low lateral speed (Required Test)

This test is intended to verify the appropriateness of an LDW when the SV drifts at a slow rate toward an opposing-traffic lane as designated by two parallel yellow lines. The lateral velocity of the SV with respect to the lane boundary markers should be less than 0.5 m/s.

4.1.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 19 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward an opposing traffic lane with a low lateral speed (or across a solid boundary—the IVBSS LDW system does not distinguish between a double solid line and a single line solid boundary). The top of the figure shows that the SV is traveling at a constant speed in the center of the designated lane. Next, the SV moves to the right with a low lateral velocity between 0.2 and 0.4 m/s. This is followed by a road-departure warning at the appropriate distance from the boundary line per the road departure system specification. Finally the situation is resolved by the SV returning to the center of the original lane.

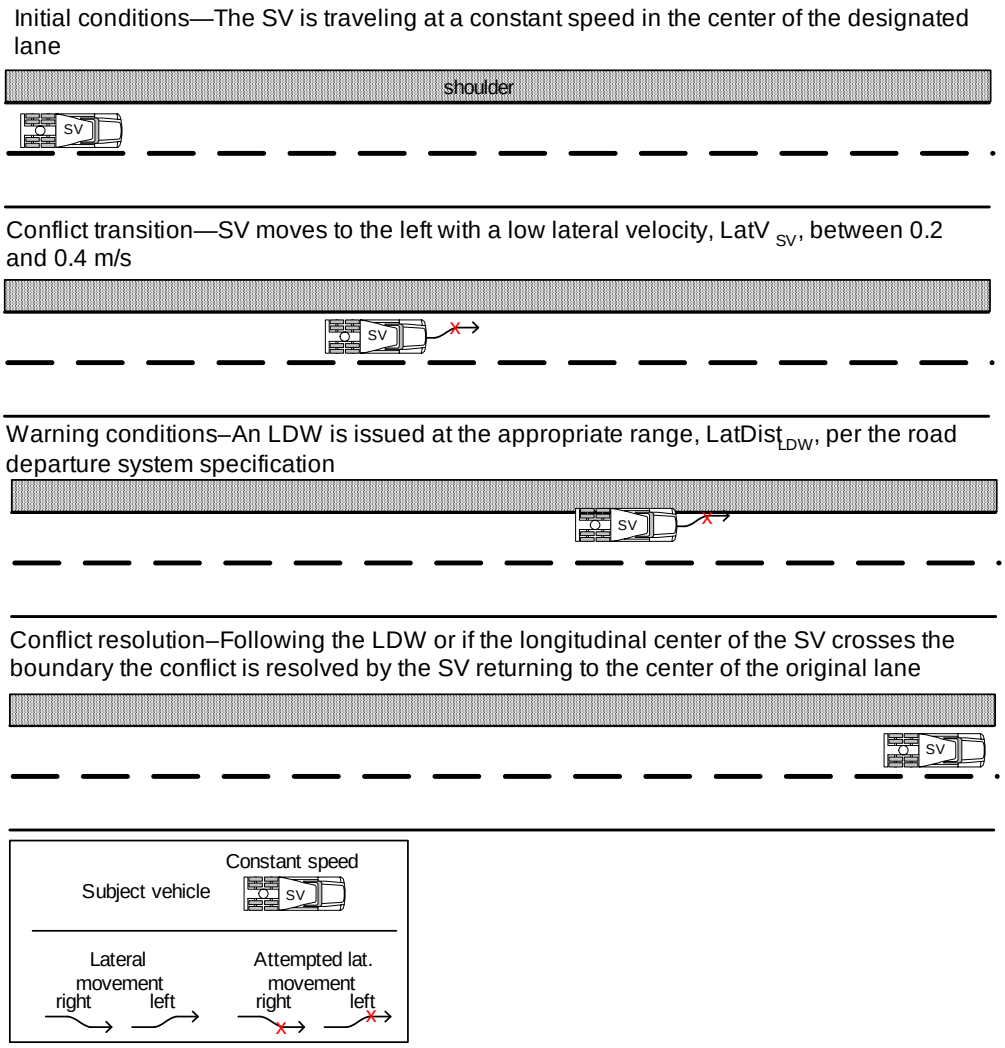


Figure 19. Test concept for road departure toward opposing traffic lane with low lateral speed.

4.1.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 44. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

Table 44. Run validity criteria for road departure toward opposing traffic lane with low lateral speed.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.3	0.1

- Steady-state: The minimum and maximum values of V_{SV} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the RDW
- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the RDW.
- The SV driver does not touch the brake pedal before the RDW is issued.
- The SV starts the lateral movement toward the lane boundary from the center of the designated lane.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 45 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 45. Pass/fail criteria for road departure toward opposing traffic lane with low lateral speed.

Run pass/fail criteria	*Target value*[22]	*± Tolerance*
$LatDist_{RDW}$, m		

- The value of $LatDist_{RDW}$ at the time of the warning must be within the target value and associated tolerance as shown in the table above.

4.1.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

Note: low sun angles are an exception to procedure.

4.1.4 Test site preparation and special equipment

This is a longitudinal and lateral straight-path test requiring a site large enough for the establishment of steady-state initial conditions and adequate lateral space to perform the test without leaving a paved surface. The test lane shall have boundary markers on the both sides of the lane such that the vision based RDW system can identify and accurately measure the lane width distance. The boundary that is approached by the subject vehicle shall be solid. As outlined in section 7 and shown in Figure 35, this test will be conducted at the Dana test track using Set-up S1 with the exception that the direction of travel will be opposite from what is shown in the figure.

4.1.5 Driving instructions

Drive clockwise around the Dana track at the desired speed in the center of the inside lane. At the section of track designated for the test, perform a small heading change steering maneuver to the left to elicit a constant lateral speed. At the time of the LDW warning gradually steer back to the center of the lane.

4.2 RD-2. Road departure toward a clear shoulder—high lateral speed (Required Test)

This test is intended to verify the appropriateness of an LDW when the SV drifts at a high rate toward a clear shoulder as designated by a solid white line. The lateral velocity of the SV relative to the boundary marker should be between 0.6 and 0.8 m/s.

[22] The values are dependent of the actual system design and should be determined by the user.

4.2.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 20 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward an opposing traffic lane with a low lateral speed. The top of the figure shows that the SV is traveling at a constant speed in the center of the designated lane. Next, the SV moves to the right with a lateral velocity between 0.6 and 0.8 m/s toward a clear shoulder. This is followed by a road-departure warning at the appropriate distance from the boundary line per the road departure system specification. Finally the situation is resolved by the SV returning to the center of the original lane.

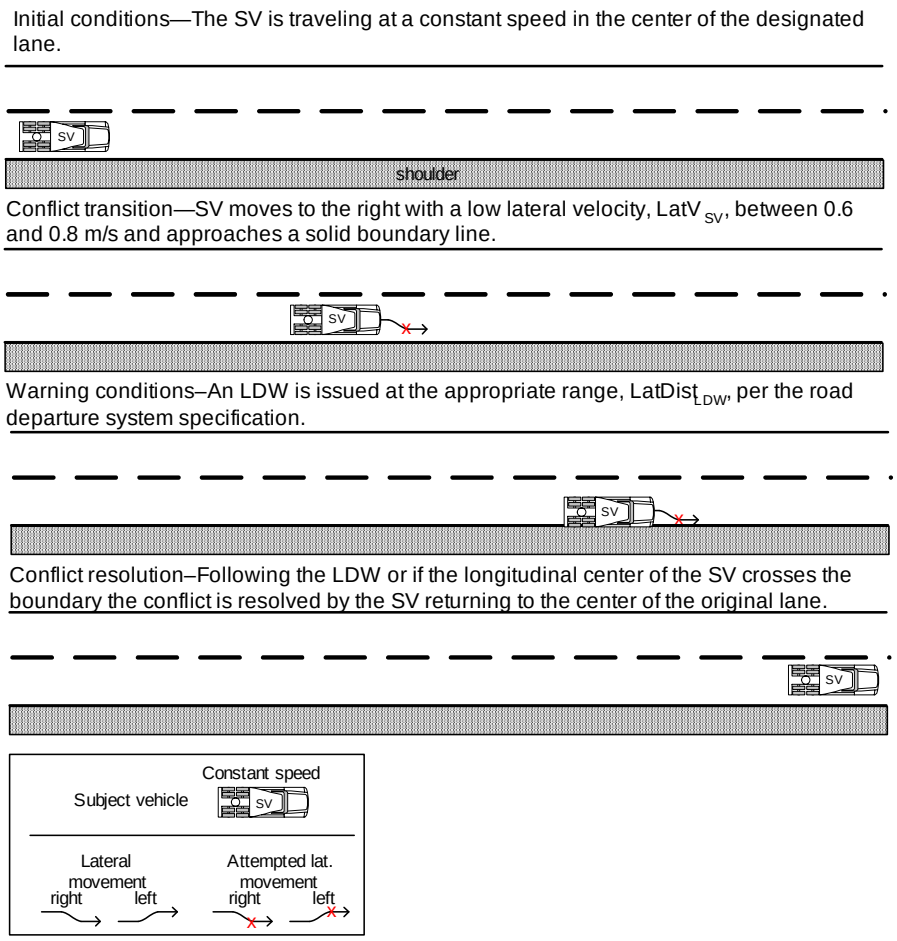


Figure 20. Test concept for road departure toward a clear shoulder with high lateral speed.

4.2.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 47. Pass/fail criteria for road departure toward a clear shoulder with high lateral speed. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are

by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial conditions have been satisfied along with other criteria that if not followed invalidate the run.

Table 46. Run validity criteria for road departure toward a clear shoulder with high lateral speed.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.7	0.1

- Steady-state: The minimum and maximum values of V_{SV} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the RDW.
- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the RDW.
- The SV driver does not touch the brake pedal before the RDW is issued.
- The SV starts the lateral movement toward the lane boundary from the center of the designated lane.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing*

the Required Tests. Table 52 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 47. Pass/fail criteria for road departure toward a clear shoulder with high lateral speed.

Run pass/fail criteria	*Target value*[23]	*± Tolerance*
$LatDist_{RDW}$, m		

- The value of $LatDist_{RDW}$ at the time of the warning must be within the target value and associated tolerance as shown in the table above.

4.2.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

4.2.4 Test site preparation and special equipment

This is a longitudinal and lateral straight-path test requiring a site large enough for the establishment of steady-state initial conditions and adequate lateral space to perform the test without leaving a paved surface. The test lane shall have boundary markers on the both sides of the lane such that the vision based RDW system can identify and accurately measure the lane width distance. The boundary that is approached by the subject vehicle shall be solid. As outlined in section 7 and shown in Figure 35, this test will be conducted at the Dana test track using Set-up S1.

4.2.5 Driving instructions

Drive clockwise around the Dana track at the desired speed in the center of the inside lane. At the section of track designated for the test, perform a small heading change steering maneuver to the right to illicit a constant lateral speed. At the time of the LDW warning gradually steer back to the center of the lane.

4.3 RD-3. Road departure toward a clear shoulder on a small radius curve (Required Test)

This test is intended to verify the appropriateness of an LDW when the SV drifts at a low lateral speed toward a clear shoulder on a curve with a small radii. The lateral velocity of the SV relative to the solid white boundary marker shall be less than 0.5 m/s.

[23] The values are dependent of the actual system design and should be determined by the user.

4.3.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 21 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a clear should on a small radius curve and with a low lateral speed. The top of the figure shows that the SV is traveling at a constant speed in the center of the designated lane. Next, the SV moves to the right with a low lateral velocity between 0.2 and 0.4 m/s toward a solid boundary and a clear shoulder while on a small radius curve. This is followed by a road-departure warning at the appropriate distance from the boundary line per the road departure system specification. Then, finally the situation is resolved by the SV returning to the center of the original lane.

4.3.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 48. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

Table 48. Run validity criteria for road departure toward a clear shoulder on a curve with a small radii and low lateral speed relative to the lane boundary markers.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
Curve Radius, m	185	20
Transitional test variables	*Target Value*	*± Tolerance*
Lat$V_{SV,}$ m/s	0.3	0.1

- Steady-state: The minimum and maximum values of V_{SV} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the RDW

- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the RDW.
- The SV driver does not touch the brake pedal before the RDW is issued.
- The SV starts the lateral movement toward the lane boundary from the center of the designated lane.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

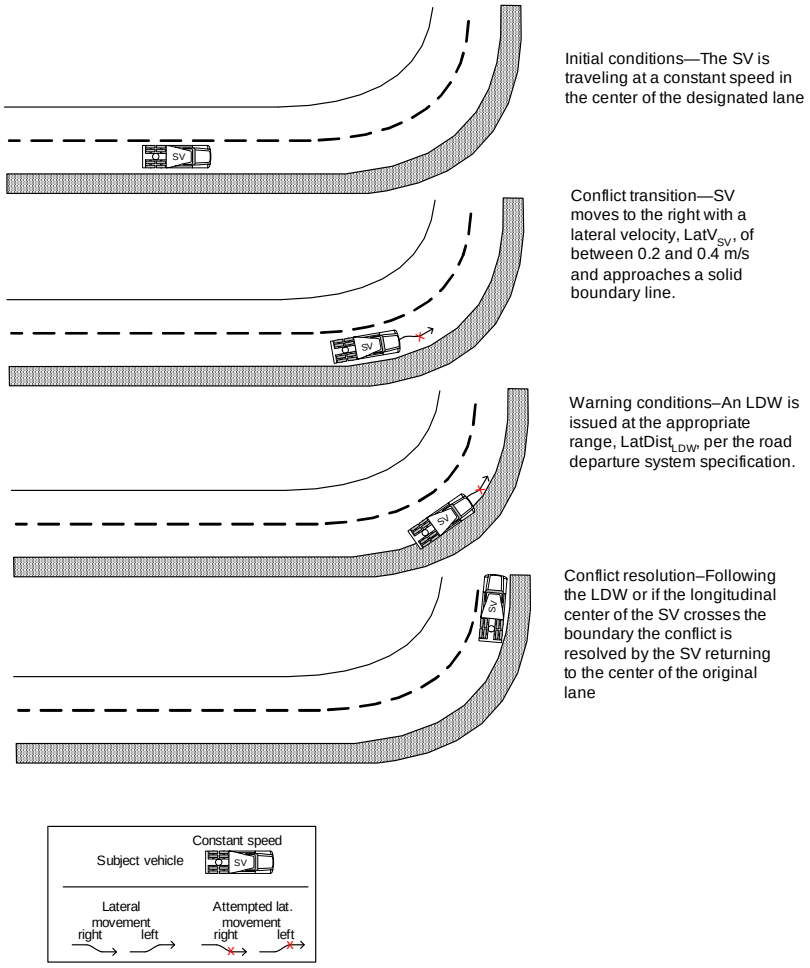


Figure 21. Test concept for road departure toward a clear shoulder on a small radius curve.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 49 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The

note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 49. Pass/fail criteria for road departure toward a clear shoulder on a curve with a small radii and low lateral speed relative to the lane boundary markers.

Run pass/fail criteria	*Target value*[24]	*± Tolerance*
$LatDist_{RDW}$, m		

4.3.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

4.3.4 Test site preparation and special equipment

The test will be conducted on the Vehicle Dynamics Test Area (VDA) of TRC. This facility is shown in Figure 42. The curve for the test is part of the northern loop of the VDA (this is a two-lane loop). For the test the SV is bobtail and travels clockwise around the loop. TRC will paint a temporary solid line 12 ft laterally from the solid line that currently exists on the inside of the inner most lane of the loop. The temporary solid line will extend for approximately 300 m. The SV will drift across this temporary solid line toward the outside of the curve and the unoccupied adjacent lane.

4.3.5 Driving instructions

Drive clockwise around the VDA loop at the desired speed in the center of the inside lane. At the section of track designated for the test, perform a small heading change steering maneuver to the left to elicit a constant lateral speed. At the time of the LDW warning gradually steer back to the center of the lane.

4.4 RD-4. Road departure toward a clear shoulder on a large radius curve (Required Test)

This test is intended to verify the appropriateness of an LDW when the SV drifts at a high lateral speed toward a clear shoulder on a curve with a large radius. The lateral velocity of the SV relative to the solid white boundary marker should be less than 0.5 m/s

4.4.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 22 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a clear should on a large radius curve and with a low lateral speed. The top of the figure shows that the SV is traveling at a constant speed in the

[24] The values are dependent of the actual system design and should be determined by the user.

center of the designated lane. Next, the SV moves to the right with a low lateral velocity between 0.2 and 0.4 m/s toward a clear shoulder while on a large radius curve. This is followed by a road-departure warning at the appropriate distance from the boundary line per the road departure system specification. Then, finally the situation is resolved by the SV returning to the center of the original lane.

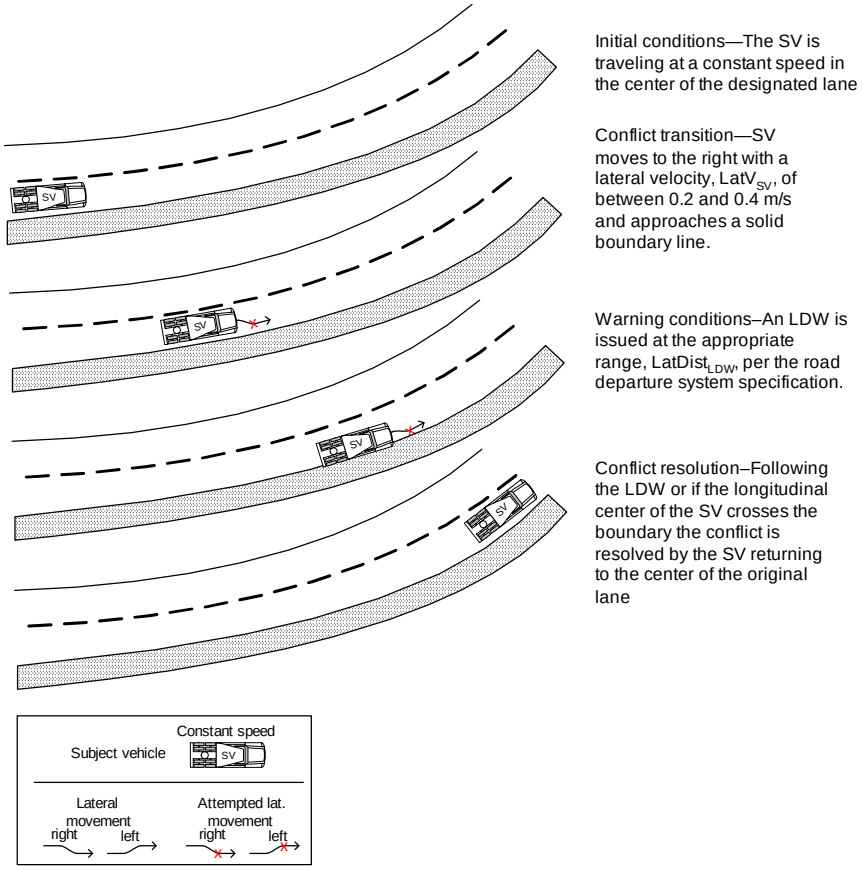


Figure 22. Test concept for road departure toward a clear shoulder on a large radius curve.

4.4.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 50. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

Table 50. Run validity criteria for road departure toward a clear shoulder on a curve with a large radii and high speed.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
Curve radius	280 m	30
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.3	0.1

- Steady-state: The minimum and maximum values of V_{SV} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the RDW
- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the RDW.
- The SV driver does not touch the brake pedal before the RDW is issued.
- The SV starts the lateral movement toward the lane boundary from the center of the designated lane.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 51 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 51. Pass/fail criteria for road departure toward a clear shoulder on a curve with a large radii and high speed.

Run pass/fail criteria	*Target value*[25]	*± Tolerance*
$LatDist_{RDW}$, m		

4.4.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

4.4.4 Test site preparation and special equipment

This is a longitudinal and lateral curved-path test requiring a site large enough for the establishment of steady-state initial conditions and adequate lateral space to perform the test without leaving a paved surface. The test lane shall have boundary markers on the both sides of the lane such that the vision based RDW system can identify and accurately measure the lane width distance. The boundary that is approached by the subject vehicle shall be solid. As outlined in section 7 and shown in Figure 39, this test will be conducted at the Dana test track using Set-up C1.

4.4.5 Driving instructions

Drive counter-clockwise around the Dana track at the desired speed in the center of the inside lane. At the section of track designated for the test, perform a small heading change steering maneuver to the right to illicit a constant lateral speed. At the time of the LDW warning gradually steer back to the center of the lane.

4.5 RD-5. Road departure toward a barrier (Engineering Test)

This test is intended to verify the appropriateness of an LDW when the SV drifts at a low rate toward an adjacent jersey barrier with a solid lane marker. The lateral velocity of the SV relative to the barrier should be less than 0.5 m/s.

4.5.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 23 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a barrier with an adjacent lane boundary marker. The top of the figure shows that the SV is traveling at a constant speed in the center of the designated lane. Next, the SV moves to the left with a low lateral velocity between 0.2 and 0.4 m/s. This is followed by a road-departure warning at the appropriate distance from the line and barrier per the road departure system specification. Finally the situation is resolved by the SV returning to the center of the original lane.

[25] The values are dependent of the actual system design and should be determined by the user.

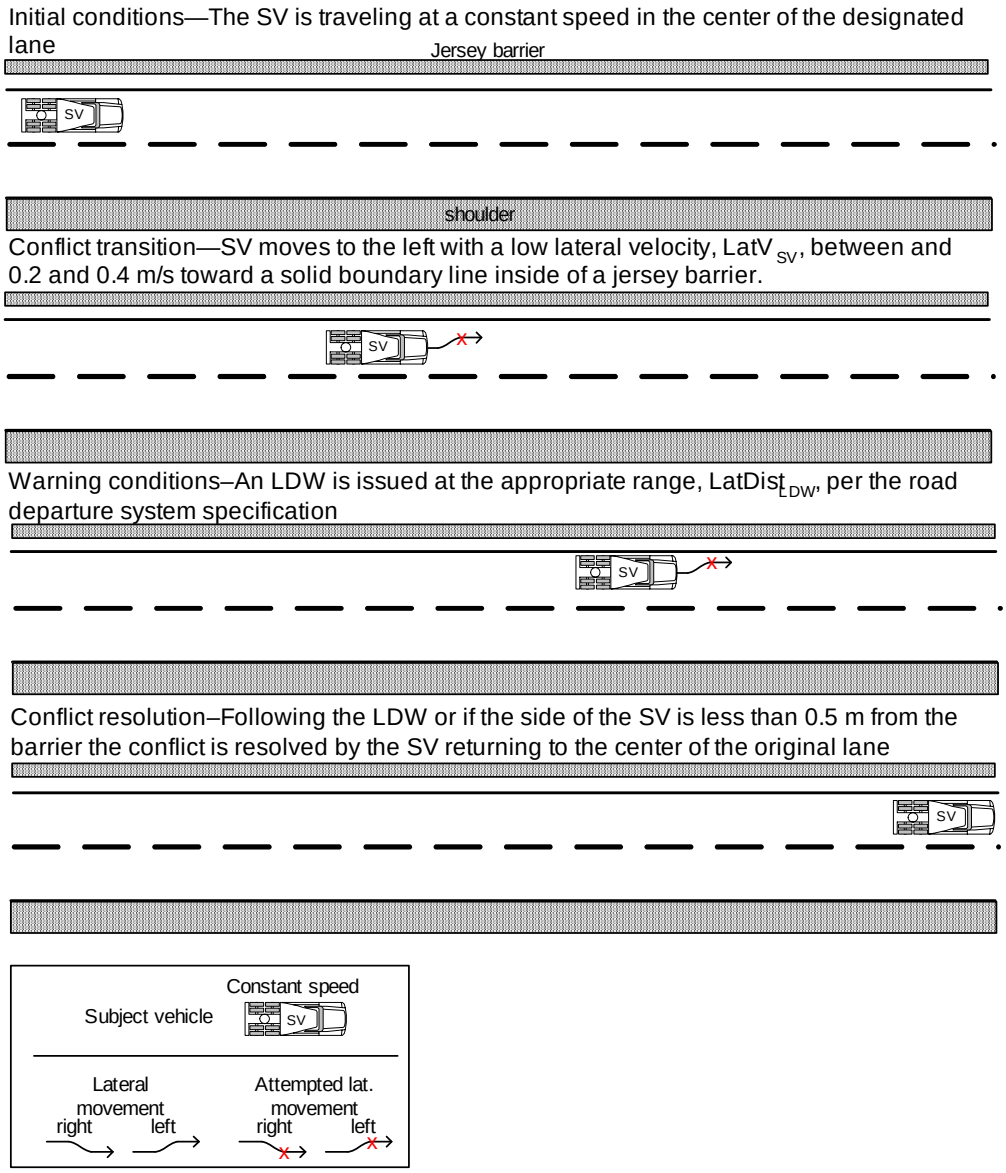


Figure 23. Test concept for road departure toward a barrier with no lane marker.

4.5.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 52. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below

the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

Table 52. Run validity criteria for road departure toward a barrier with no lane marker.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.3	0.1

- Steady-state: The minimum and maximum values of V_{SV} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the RDW
- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the RDW.
- The SV driver does not touch the brake pedal before the RDW is issued.
- The SV starts the lateral movement toward the lane boundary from the center of the designated lane.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 53 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystem. The note(s) below the table explain the procedure for evaluating the performance measures.

Table 53. Pass/fail criteria for road departure toward a barrier with no lane marker.

Run pass/fail criteria	*Target value*[26]	*± Tolerance*
$LatDist_{RDW}$, m		

- The value of $LatDist_{RDW}$ at the time of the warning must be within the target value and associated tolerance as shown in the table above.

4.5.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

4.5.4 Test site preparation and special equipment

This is a longitudinal and lateral straight-path test requiring a site large enough for the establishment of steady-state initial conditions and adequate lateral space to perform the test without leaving a paved surface. The test lane shall have boundary markers on the both sides of the lane such that the vision based RDW system can identify and accurately measure the lane width distance. The boundary that is approached by the subject vehicle shall be solid. As outlined in section 7 and shown in Figure 37, this test will be conducted at the Dana test track using Set-up S3. The distance between the solid boundary line and the Jersey barrier is 1 m.

4.5.5 Driving instructions

Drive counter-clockwise around the Dana track at the desired speed in the center of the inside lane. At the section of track designated for the test, perform a small heading change steering maneuver to the left to elicit a constant lateral speed. At the time of the LDW warning gradually steer back to the center of the lane.

5 Multiple-Threat Tests

There are two required multiple-threat crash-imminent tests. Each of the tests is intended to simulate conflict scenarios that consist of lateral and longitudinal warnings. The intent of these tests is to verify that the system arbitration algorithms present the driver with appropriate warnings that are inherently intuitive and do not confuse the driver.

[26] The values are dependent of the actual system design and should be determined by the user.

5.1 MT-1. Rear-end followed by a lane-change warning (Required Test)

This test is intended to verify the appropriateness of an FCW and LCW when the SV approaches a slowing POV1 while there is an adjacent POV2 that prevents the SV from changing lanes to maneuver around POV1. In this test the SV and POV2 are traveling at the same forward speed. The test is sequential in that the SV driver responds to an FCW by changing lanes to the right into an occupied lane, which results in an LCW.

5.1.1 Test concept: initial, transitional, warning conditions and conflict resolution

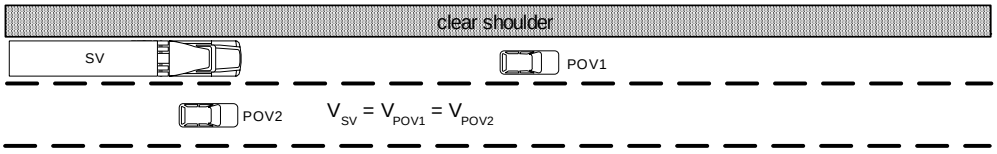
Figure 24 shows the initial, transitional and final conditions for the multiple threat conflict involving an FCW followed by an LCW. The initial conditions are in the top of the figure and show both the SV and POV2 traveling at the same speed in the center of their designated lanes with the front bumper of POV2 aligned with the front bumper of the SV. Initially, POV1 is traveling at the same speed as the SV in the center of the SV lane. The center part of the figure shows that an FCW warning should occur when POV1 slows modestly creating a forward conflict with the SV. Following the FCW, the SV driver signals and moves to the right with a lateral velocity, $LatV_{SV}$, between 0.1 and 0.6 m/s. An LCW is issued at the appropriate range, $LatDist_{LCW}$. After the LCW issued the conflict is resolved by POV2 moving laterally to allow the SV to pass on the right of POV1.

5.1.2 Performance measures and criteria for pass/fail determination

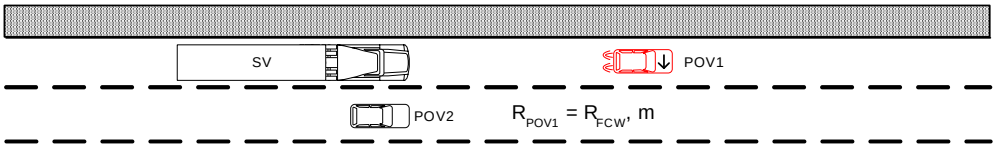
For a run of this test to be considered valid, the initial and transitional conditions for the run must be satisfied. These conditions are given in Table 54, which is separated into two sections; the top section shows the target steady-state initial conditions for the test, while the bottom sections shows transitional kinematics that induce a conflict. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

Rear-end followed by a lane-change warning

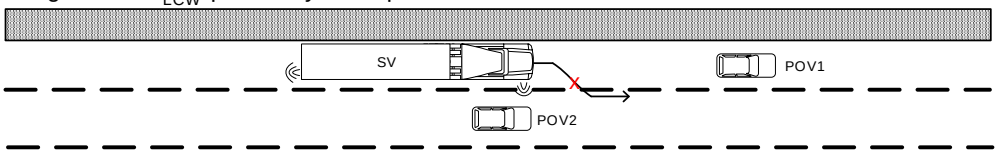
Initial conditions—Both the SV and POV2 are traveling at the same speed in the center of their designated lanes with the POV2 on the right side of the SV. The front bumper of POV2 is aligned with the front bumper of the SV. POV1 is also traveling at the same speed as the SV in the center of the SV lane.



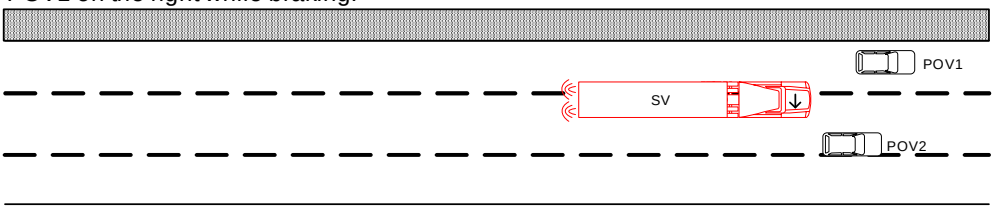
First warning condition–POV1 slows modestly and an FCW is issued at the appropriate range, R_{FCW}, per the system specification.



Second warning condition–SV driver signals to the right and moves to the right with a lateral velocity, $LatV_{SV}$, between 0.1 and 0.6 m/s. An LCW is issued at the appropriate range, $LatDist_{LCW}$, per the system specification



Conflict resolution–Following the LCW or if the right front wheel of the SV crosses the boundary line the conflict is resolved by POV2 moving to the right allowing the SV to pass POV1 on the right while braking.



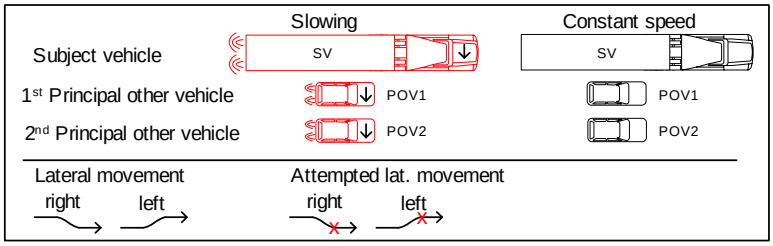


Figure 24. Test concept for a rear-end followed by a lane-change warning

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition. Note: there may be more than one transitional event in procedures that involve multiple threats and multiple POVs.

Table 54. Run validity criteria for a rear-end followed by a lane-change warning.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
V_{POV1}, m/s	20.1 (45 mph)	1.0
V_{POV2}, m/s	20.1 (45 mph)	1.0
R_{POV1}, m	60	4.0
Transitional test variables	*Target Value*	*± Tolerance*
$Ax_{POV1,}$ m/s^2	-3.0	1.0
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.35	0.25
Time between alerts, s	3	2

- Steady-state: The minimum and maximum values of $V_{SV,}$ V_{POV1} and V_{POV2} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the FCW.
- Transitional: The average acceleration of the POV1 is within the desired range from the start of braking by the POV1 and the time of the FCW.
- Transitional: The minimum and maximum values of V_{SV} are within the desired range from the start of braking by the POV1 and the time of the FCW.

- The left-side turn indicator is on at least 1 second prior to the LCW.
- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the LCW.

- The SV driver does not touch the brake pedal before the LCW is issued.

- The SV starts the lateral movement to the right from the center of the designated lane.

- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involve successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 55 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystems. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 55. Pass/fail criteria for a rear-end followed by a lane-change warning.

Run pass/fail criteria	*Target value*[27]	*± Tolerance*
R_{FCW}, m		
$Rdot_{FCW}$, m/s		
$LatDist_{LCW}$, m		

- The value of R_{POV} and $Rdot_{FCW}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.
- The value of $LatDist_{LCW}$ at the time of the warning must be within the target value and associated tolerance as shown in the table above.

5.1.3 Exceptions to the standard test conditions

In addition to the default conditions as detailed in the section Definitions and Standard Test Conditions, the following exceptions are necessary for this procedure:

The test is to be run with a tractor and single semi-trailer combination where the semi-trailer is a typical dry-freight van between 45 and 53 feet with a box width of 102 inches and is unloaded in terms of additional cargo or dummy weights.

5.1.4 Test site preparation and special equipment

The test will be conducted on the Skid Pad facility of TRC. This facility is shown in Figure 41. The test will be conduced in lanes 4 and 5 of the TRC Skid pad traveling in a northern direction only. The SV is in lane 4, POV1 is in lane 4, and POV2 is in lane 5.

The initial conditions for the test will be staged using range measurements by the IVBSS. Initially, all vehicles will travel at the same speed with the driver of POV1 modulating the throttle to establish the desired initial range, while POV2 is in position adjacent to the SV in the foremost blind spot on the right. Upon valid initial conditions the experimenter will instruct the POV1 driver to brake creating an FCW conflict.

[27] The values are dependent of the actual system design and should be determined by the user.

Following the FCW, the SV driver engages the turn-signal to the right and begins a non-aggressive lane change across a solid boundary into lane 5, which is occupied by POV2.

5.1.5 Driving instructions

Subject vehicle driver:

1. Drive in the center of the designated lane at the desired test speed.
2. On an adequate straight section of track, with the POV1 and POV2 in position, instruct POV1 to begin the deceleration event.
3. Upon an FCW, instruct the POV1 to abort the test to the left. Then turn on the right directional signal and wait 1 second before starting a modest lane change to the right toward POV2
4. Upon an LCW instruct POV2 to abort while steering back into the original lane.

Principal other vehicle (No 1) driver:

1. At the desired speed the POV1 engages the cruise control and makes small adjustments to speed if necessary while staying in the center of the designated lane.
2. When instructed by the driver of the SV or experimenter, begin to decelerate steadily using a window-mounted accelerometer.
3. Upon the *abort* command or when the FCW is issued accelerate while steering to the left and to clear a path for the SV.

Principal other vehicle (No 2) driver:

1. Drive in the center of the designated lane with the front bumper of your vehicle aligned with the front bumper of the SV. Maintain the desired test speed using either cruise control or manual control of the throttle.
2. Upon a warning by the LCW system or if the POV2 driver senses a crash is imminent the test is aborted steer to the right to clear a path for the SV.

5.2 MT-2. Lane-change followed by rear-end warning (Required Test)

This test is intended to verify the appropriateness of nearly simultaneous LCW and FCW when an adjacent POV2 prevents the SV from changing lanes while an FCW is generated by a slowing POV1.

5.2.1 Test concept: initial, transitional, warning conditions and conflict resolution

Figure 25 shows the initial, transitional and final conditions for the multiple threat conflict involving an LCW followed quickly by an FCW. The initial conditions are in the top of the figure and show both the SV and POV2 traveling at the same speed in the center of their designated lanes with the front bumper of POV2 aligned with the longitudinal center of the semi-trailer. POV1 is traveling at the same speed than SV and is in the center of the same lane as SV. An LCW occurs when the SV driver signals and moves to the left toward POV2 with a lateral velocity, $LatV_{SV}$, between 0.1 and 0.4 m/s. Simultaneous with the attempted lane change into POV2, POV1 slows prompting a forward conflict with the SV and inducing an FCW at R_{FCW} as specified by the designers of the FCW system. Following the FCW, the SV driver slows and moves to the right to maneuver around POV1.

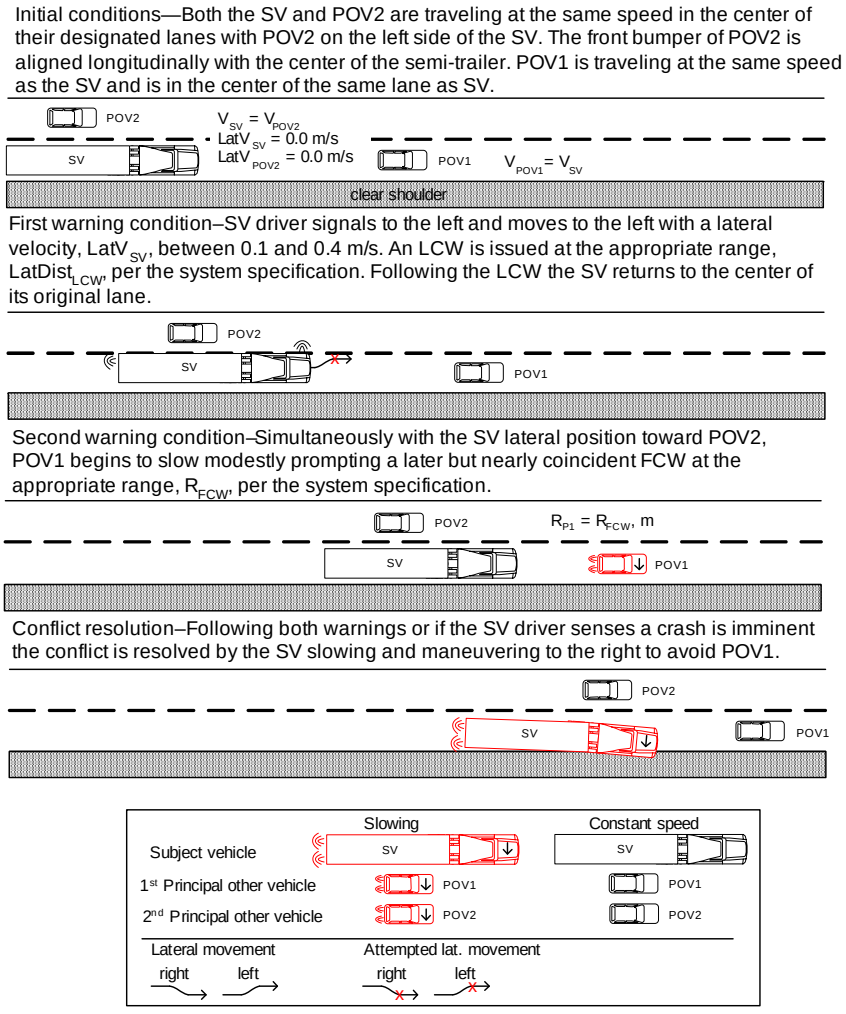


Figure 25. Test concept for a lane-change followed by a rear-end warning

5.2.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for the run must be satisfied. These conditions are given in Table 56. The table is separated into two sections; the top section shows the target steady-state initial conditions for the test, while the bottom sections shows transitional kinematics that induce a conflict. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition. Note: there may be more than one transitional event in procedures that involve multiple threats and multiple POVs.

Table 56. Run validity criteria for a lane-change followed by a rear-end warning.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
V_{POV1}, m/s	20.1 (45 mph)	1.0
V_{POV2}, m/s	20.1 (45 mph)	1.0
R_{POV1}, m	45	5
Transitional test variables	*Target Value*	*± Tolerance*
$Ax_{POV1,}$ m/s^2	-1.5	.5
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.25	0.15
Time between alerts,s	2	1

- Steady-state: The minimum and maximum values of V_{SV} and V_{POV2} do not exceed the target values and their associated tolerances over a 2 second window ending at the time of the LCW.
- The SV starts the lateral movement to the left from the center of the designated lane.

- Transitional: The average value of $LatV_{SV}$ is within the tolerance given above over a 1 second window ending at the time of the LCW.
- The left-side turn indicator is on at least 1 second prior to the LCW.
- Steady-state: The minimum and maximum values of V_{SV}, V_{POV1} and $Rdot_{POV}$ over a 2 second window ending at the time of the FCW cannot exceed the target values and their associated tolerances given above.
- Steady-state: The initial sensing range is greater than 90 m
- The SV driver does touch the brake pedal between the LDW and the FCW.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*. Table 57 below gives the acceptable values and their tolerances for evaluating if the warning was issued per the design intent of the IVBSS subsystems. The note(s) below the table explain the procedure for evaluating the pass/fail performance measures.

Table 57. Pass/fail criteria for a lane-change followed by a rear-end warning.

Run pass/fail criteria	*Target value*[28]	*± Tolerance*
$LatDist_{LCW}$, m		
R_{FCW}, m		
$Rdot_{FCW}$, m/s		

- The value of $LatDist_{LCW}$ at the time of the warning must be within the target value and associated tolerance as shown in the table above.
- The value of R_{POV1} and $Rdot_{POV1}$ at the time of the warning must be within the target value and associated tolerance for each measure shown in the table above.

5.2.3 Exceptions to the standard test conditions

In addition to the default conditions as detailed in the section Definitions and Standard Test Conditions, the following exceptions are necessary for this procedure:

The test is to be run with a tractor and single semi-trailer combination where the semi-trailer is a typical dry-freight van between 45 and 53 feet with a box width of 102 inches and is unloaded in terms of additional cargo or dummy weights.

[28] The values are dependent of the actual system design and should be determined by the user.

5.2.4 Test site preparation and special equipment

This is a longitudinal and lateral straight-path test requiring two adjacent lanes and a site large enough for the establishment of steady-state initial conditions and adequate lateral space to perform the test without leaving a paved surface. The test lanes shall have boundary markers on the both sides of each lane such that the IVBSS system can identify and accurately measure the lane width and lane offset distances of the SV. The POV1 and POV2 vehicle shall maintain its position in the center of its lane and if available a measure of the lateral-lane offset of each vehicle shall be used to confirm this condition. The boundary that is approached by the SV shall be dashed or solid. As outlined in section 7 and shown in Figure 36, this test will be conducted at the Dana test track using Set-up S2.

5.2.5 Driving instructions

Subject vehicle driver:

1. Drive in the center of the designated lane at the desired test speed.
2. On an adequate straight section of track with the POV in position, use the turn indicator to signal to the left. Wait one second and begin a slow lane change maneuver toward the POV.
3. Abort or end the test upon a warning by the LCW system or if a crash is imminent.
4. Return to the center of the designated lane.
3. Upon a warning by the FCW system or if the SV driver senses a crash is imminent abort the test.
5. Brakes appropriately while steering to the right to avoid the POV1.

Principal other vehicle driver (No 1):

1. At the desired speed the POV engages the cruise control and makes small adjustments to speed if necessary while staying in the center of the designated lane.
2. When instructed by the experimenter decelerate steadily using a window mounted accelerometer
3. Upon the *abort* command from the SV experimenter, accelerate and steer to the left.

Principal other vehicle driver (No 2):

1. Drive in the center of the designated lane with the front bumper of your vehicle aligned with the mid-trailer side turn indicator light of the SV trailer. Maintain the desired test speed using either cruise control or manual control of the throttle.
2. When instructed by the experimenter, abort the run by slowing while steering to the clear shoulder or lane on the left.

6 No-Warn Tests

This section of the report details the No-Warn test procedures for the IVBSS Heavy Truck platform. These tests where selected to test that the system as implemented does not give a warning in situations when it would be perceived by the SV driver as inappropriate and unwarranted given the intra-kinematic relationship between the SV and a POV(s) in the case of the Rear-end and Lane-change merge subsystems. For the road departure subsystem the No-warn test is designed to test that no warning is issued when the SV driver is wandering slightly in a lane with an adjacent jersey barrier.

6.1 NW-1. No FCW when SV closely follows POV (Required Test)

The purpose of this test is to verify that the FCW system does not issue a warning in situations where the kinematics between the SV and POV do not create a conflict situation that is near the reaction time of the SV driver and the performance ability of the SV itself. That is, an FCW should not be issued in benign longitudinal closing situations given the ability of a driver to perceive and react to a potential conflict within the longitudinal deceleration control authority of the SV.

6.1.1 Test concept and initial and final conditions

Figure 26. Test concept for a no-warn test in which the SV closes is a general outline of a no-warn situation when the SV closes slowly and follows the POV. The figure shows that initially the SV and POV have a time gap of 3.5 s or more and the SV is traveling a slightly higher speed than the POV. The center of the figure shows that at or near a time gap of 2.5 s the SV slows to match the speed of the POV. Finally, the two vehicles remain in that relative position for an extended period of time. In this no-warn scenario there should not be an FCW issued during the entire sequence of events.

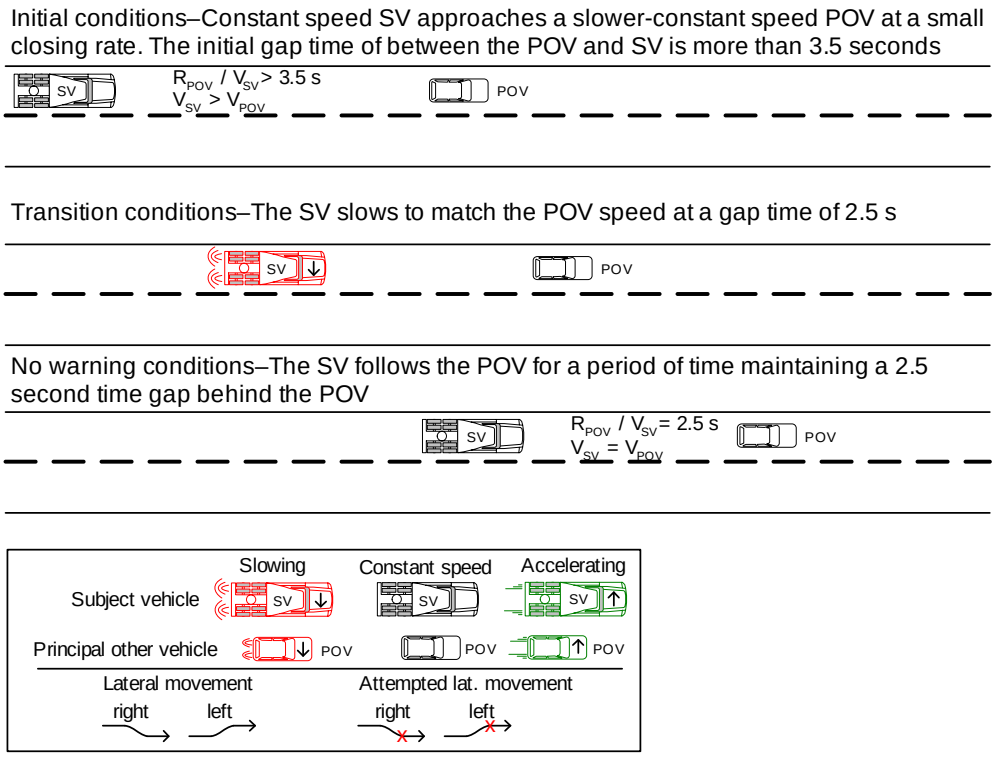


Figure 26. Test concept for a no-warn test in which the SV closes slowly and follows a POV

6.1.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 58. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state final condition.

Table 58. Run validity criteria for a no-warn test when the SV closes slowly and follows a POV

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	17.9 (40 mph)	1.0
$Rdot_{POV1}$, m/s	0.0	1.5
R_{POV1}, m	71.6	8.0
Transitional test variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	3.0
Final test variables	Target Value	± Tolerance
V_{SV}, m/s	17.9 (40 mph)	1.0
$Rdot_{POV1}$, m/s	0.0	1.5
R_{POV1}, m	44.8	2.0

- Steady-state: The minimum and maximum values of V_{SV}, V_{POV1}, R_{POV1} and $Rdot_{POV1}$ do not exceed the target values and their associated tolerances over a 1 second window ending at the start of the transition event by the SV.
- Transitional: The average speed of the SV is within the desired range from the start of the transition period to the start of the final test conditions.
- Final condition: The minimum and maximum values of V_{SV} and R_{POV1} are within the target values for a period of 5 seconds when the desired time gap is reached by the SV.
- The SV driver does not touch the brake pedal during the test.
- Both the SV and POV remain in the center of the designated lane for the duration of the test.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*.

6.1.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

6.1.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, straight-path test requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section

7 and shown in Figure 39, this test will be conducted at the Dana test track using Set-up S1.

6.1.5 Driving instructions

Subject vehicle driver:

1. Reach the desired speed and range along a straight section of the track and engage the cruise control to maintain the desired condition thru the curve (when there will be no range values). Drive in the center of the designated lane.
2. After the curve and when both vehicles are on the straight section of track, manually increase speed by the indicted amount to close on the POV.
3. At the new designated range release the throttle and return to the initial design speed.
4. Continue following the POV at the desired range and speed for at least 5 seconds.

Principal other vehicle driver:

1. At the desired speed the engage the cruise control while staying in the center of the designated lane.

6.2 NW-2. No FCW when passing a stopped POV in an adjacent lane on a curve (Required Test)

This test is designed to show that the FCW system should not issue a warning when the SV passes a stopped POV in the center of an adjacent lane on a curve.

6.2.1 Test concept and initial and final conditions

Figure 27 shows the initial, transitional and final conditions for a test where the SV passes a stopped POV in an adjacent lane while on a curve. For this test the SV shall be traveling at a constant speed in the center of the inside lane on a curve of constant radius. The POV is stopped in the center of the same curve in an adjacent lane to the ‘outside’ of the designated SV lane. The position of the POV on the curve is such that the SV has reached a steady-state yaw-rate condition before the POV has entered the FCW radar beam of the SV.

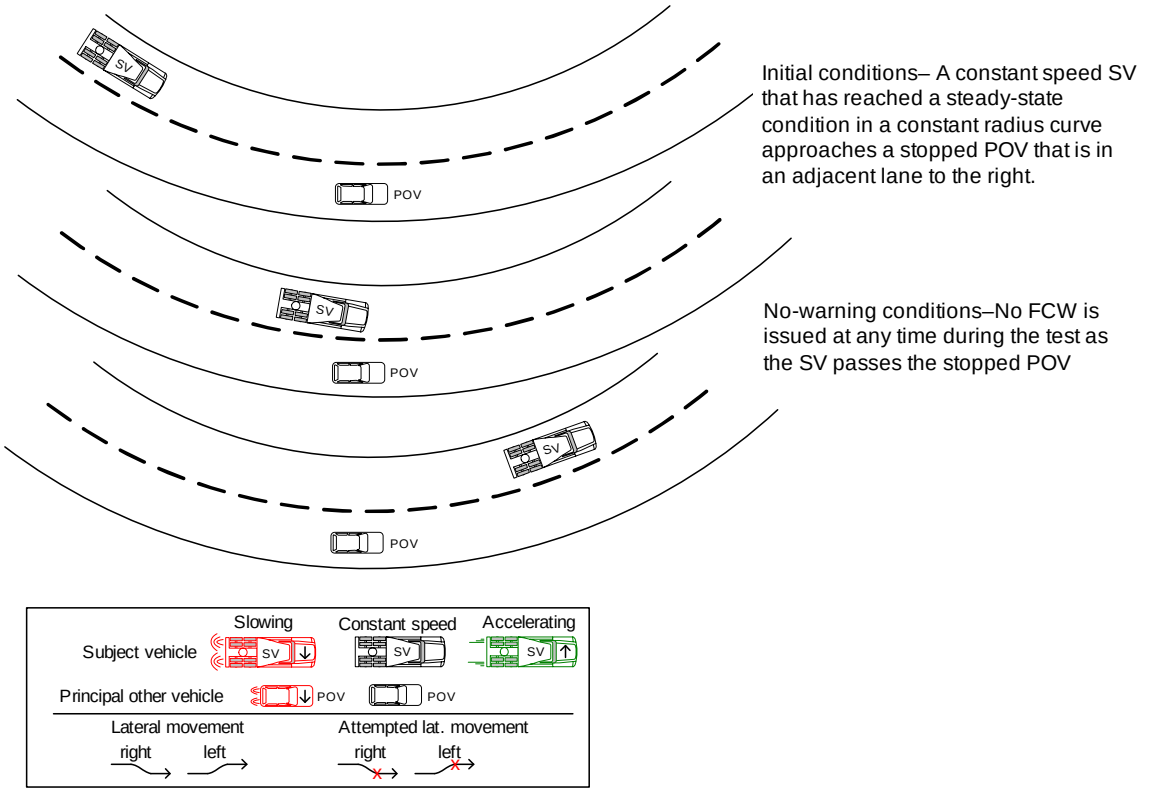


Figure 27. Test concept for a no-warn test in which the SV passes a stopped POV in an adjacent lane on a curve.

6.2.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 59. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state final condition.

Table 59. Run validity criteria for a no-warn test when the SV passes a stopped POV in an adjacent lane on a curve.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
Curve Radius, m	285	20

- Steady-state: The minimum and maximum values of V_{SV} over 2 second window ending at the time when the SV passes the POV cannot exceed the target values and their associated tolerances given above.
- The SV driver does not touch the brake pedal at any time approaching the stopped POV.
- Both the SV remains in the center of the designated lane.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*.

6.2.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

6.2.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, curved-path test requiring a site large enough for the establishment of steady-state initial conditions, including a steady-state yaw-rate by the SV, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 39, this test will be conducted at the Dana test track using Set-up C1. For this test the POV should be parked in the center of the designated lane with at least 100 m of constant-radius track available for the SV approach.

6.2.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates, in the center of the selected lane, to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.

2. The SV driver then continues along the center of the selected lane at the commanded speed closing on and passing the adjacent-lane POV in the curved section of the test track.

6.3 NW-3. No FCW when a faster POV cuts in front of the SV (Required Test)

The purpose of this test is to verify that the FCW system does not issue a warning in situations when the POV passes and changes lanes in front of the SV while still separating from the SV.

6.3.1 Test concept and initial and final conditions

Figure 28 show the initial, transitional, and final conditions for a no-warn test when the SV in which a faster moving POV changes lanes in front of the SV. For this test the SV is traveling at a constant speed in the center of its designated lane. Initially, the POV is traveling faster than the POV in an adjacent lane and passes the SV before changing into the lane occupied by the SV. The POV and SV then separate at a constant rate.

6.3.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 60. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

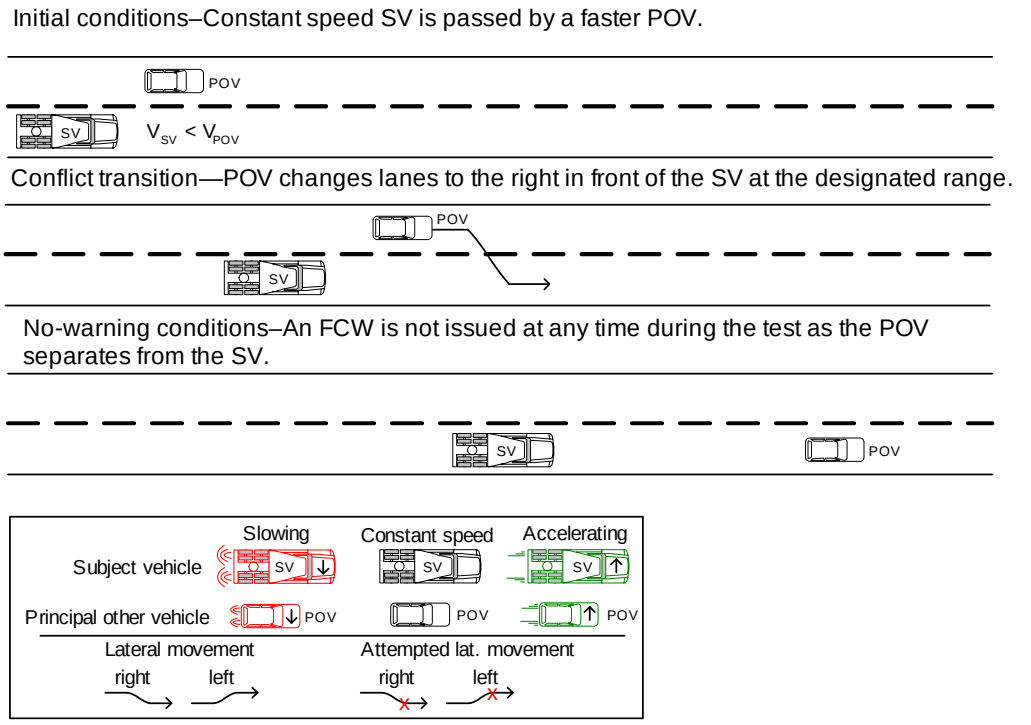


Figure 28. Test concept for a no-warn test when a faster POV cuts in front of the SV and separates.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state final condition.

Table 60. Run validity criteria for a no-warn test in which a faster POV cuts in front of the SV and separates.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	20.1 (45 mph)	1.0

Transitional test variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	1.0
V_{POV1}, m/s	20.1 (45 mph)	1.0
R_{POV1}, m	15 m	5.0
$LatV_{POV1,}$ m/s	0.2	0.1

- Steady-state: The minimum and maximum values of V_{SV} and V_{POV1} do not exceed the target values and their associated tolerances over a 2 second window ending at the start of the transition event by the POV.
- Transitional: The range at which the SV identifies the POV as the closest in path vehicle when the POV maneuvers in front of the SV is within the range and tolerance above
- The SV driver does not touch the brake pedal during the test.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*.

6.3.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

6.3.4 Test site preparation and special equipment

This is longitudinal conflict, straight-path test involving a lane-change maneuver by the POV and requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. As outlined in section 7 and shown in Figure 36, this test will be conducted at the Dana test track using Set-up S2.

6.3.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates in the center of the center lane at Dana to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.

2. On a straight section of track and when the POV is at the desired range, instruct the POV driver to begin a modest lane-change maneuver to the right in front of the SV.

3. The SV driver then continues along the center of the center lane at the commanded speed while the POV separates from the SV

Principal other vehicle driver:

1. Follow the SV in an adjacent lane to the left matching the SV speed.
2. When both vehicles are in a straight section of track, increase speed to the designated test speed and pass in the adjacent lane.
3. When instructed by the SV or experimenter, make a modest lane change to the right in front of the SV.
4. Stay in the center of the SV lane and separate from the SV until the experimenter informs you that the run has ended.

6.4 NW-4. No FCW when passing between two slower moving POVs in adjacent lanes (Required Test)

The purpose of this test is to verify that the FCW system does not given a warning when the SV passes between two slower moving POVs that occupy two adjacent lanes to the right and left of the SV respectively.

6.4.1 Test concept and initial and final conditions

Figure 29 shows the initial and no-warn conditions for an FCW test in which the SV passes between two slower moving POVs that are in the center of adjacent lanes.

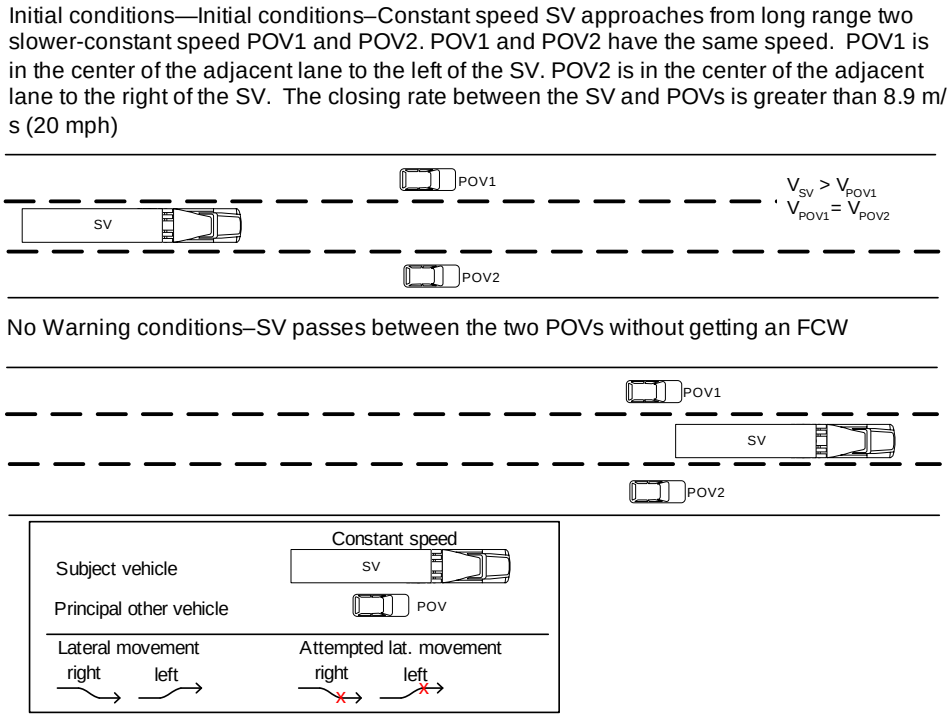


Figure 29. Test concept for a no-warn test when a faster moving SV passes between two slower moving POVs

6.4.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 61. The table shows the target steady-state initial conditions for the test. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

Table 61. Run validity criteria for a no-warn test when a faster SV passes between two POVs in adjacent lanes.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	24.6 (55 mph)	1.0
V_{POV1}, m/s	13.4 (30 mph)	1.0
V_{POV2}, m/s	13.4 (30 mph)	1.0
$Rdot_{POV1}$, m	-11.2	1.5
Initial R_{POV1}, m	150	10.0

- Steady-state: The minimum and maximum values of V_{SV}, $V_{POV1,}$ V_{POV2} and $Rdot_{POV}$ over a 2 second window ending at the time that the SV front bumper reaches the rear of either POV.
- Steady-state: The initial sensing range is greater than 140 m
- The SV and POV drivers do not touch the brake pedal for the entire run.
- Both the SV and POV(s) remains in the center of the designated lane the end of the run.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*.

6.4.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

6.4.4 Test site preparation and special equipment

This is strictly a longitudinal conflict, straight-path test requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the conflict to occur, and sufficient room for the conflict to be resolved safely. The test shall be conducted with two passenger cars as the POVs. As outlined in section 7 and shown in Figure 36, this test will be conducted at the Dana test track using Set-up S2. The initial conditions for the test will be staged using a set of cones. See section 7 for a more explicit explanation including detailed figures of how these tests will be staged. Section 7 also includes tables for estimating the time and distance needed to stage the test given the constraints of the facility chosen. The placement of the cones, relative to the start of the straight section of track given in S1, for this particular test is shown below in Table 62 (a negative distance means the cone is placed before the straight section of track). The cones are labeled to indicate their purpose. The general scenario for executing the test is:

- SV travels around the track at the desired test speed in the center of the designated lane.
- Both POVs are stopped at cone 2.
- When the SV passes cone 1 the driver or experimenter instructs the POVs to start.
- The POV drivers accelerates at the nominally constant rate of 1.5 m/s^2 (the POVs driver is assisted by a windshield mounted accelerometer) for 9 seconds to reach the desired speed in the space between cones 2 and 3 while staying in the center of the designated lane.
- If staged correctly the POVs will reach cone 3 simultaneously with the SV entering the straight section of the track with the desired initial conditions.

Table 62. Cone location for no-warn when SV passes between two adjacent POVs

Cone	*Distance, m*	*Label/Purpose*
1	-220	SV commands POVs to start
2	90	From a stop the POVs accelerates at 1.5 m/s^2
3	150	POVs at specified speed in 9 seconds

6.4.5 Driving instructions

Subject vehicle driver:

1. The driver accelerates, in the center of the selected lane, to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.

2. At the specified speed, and upon passing cone 1, the driver (or accompanied experimenter) commands the POV drivers to start driving.

3. The SV driver then continues along the center of the selected lane at the commanded speed closing on the POVs in a straight section of the test track.
4. Upon passing the POVs the test is ended and the experimenter tells the POV drivers that the test is over.

Principal other vehicle drivers:

1. From a stopped position located at cone 2 (either in or adjacent to selected lane) the driver waits for the experimenter in the SV to give the start command.
2. The POV driver then accelerates steadily to the desired speed using cone 3, a window mounted accelerometer, and an estimated time window.
3. At the desired speed the POV engages the cruise control and makes small adjustments to speed if necessary while staying in the center of the designated lane.
4. Upon the *abort* command from the SV experimenter, the POV drivers slow to a stop

6.5 NW-5. No LDW with poor lane keeping and a barrier on the left (Required Test)

The purpose of this test is to verify that the IVBSS system does not give LDW when the SV driver wanders in a lane that is adjacent to a barrier.

6.5.1 Test concept and initial and final conditions

The concept of this no-warn test is shown in Figure 30. The figure shows a Jersey barrier on the left adjacent to a solid boundary line and a dashed boundary on the right of the SV. The test begins with the SV in the center of the designated lane with a constant forward speed. The SV driver then does a slow lateral drift to the left toward the barrier while near the center of the lane. This is then followed by a slow lateral drift to the right-side boundary line. Finally, the driver returns to the center of the lane. The lateral dithering by the SV shall be at low lateral velocity while maintaining a lane position of approximately 0.35 m lateral distance from the center of the lane.

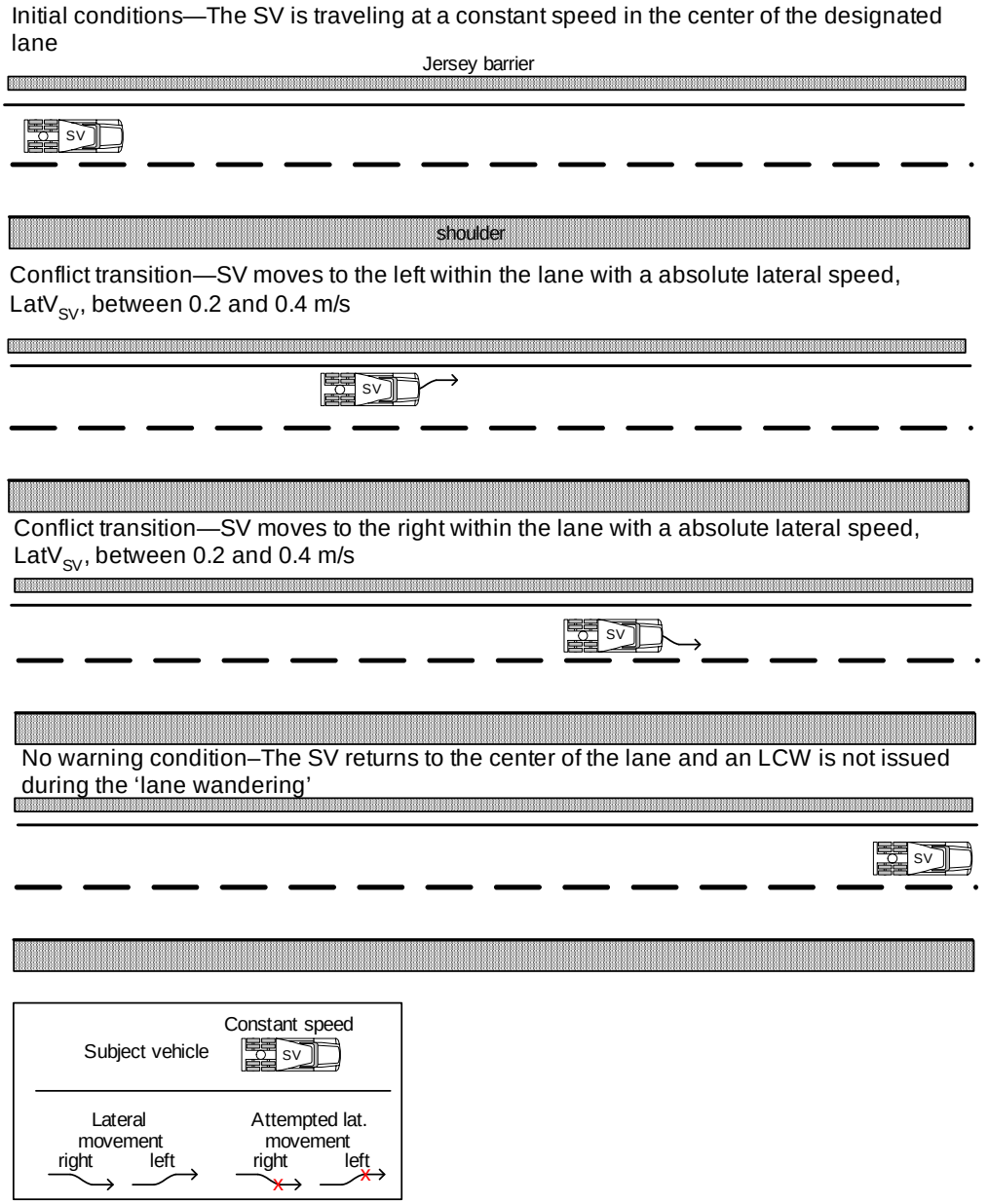


Figure 30. Test concept for a no-warn test with poor lane-keeping and a barrier on the left

6.5.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 63. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below

the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition

Table 63. Run validity criteria for no-warn test with poor lane keeping and a barrier on the left

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	1.0
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.3	0.1
$LOff_{SV}$, m	0.35	0.1

- Steady-state: The minimum and maximum values of V_{SV} do not exceed the target values for the entire run.
- Transitional: The maximum value of abs($LatV_{SV}$) is within the range given above for both lateral drifts to the left and right.
- The SV driver does not touch the brake for the entire run.
- The SV starts the lateral movement toward the barrier and lane boundary from the center of the designated lane.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*.

6.5.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

6.5.4 Test site preparation and special equipment

This is a longitudinal and lateral straight-path test requiring a site large enough for the establishment of steady-state initial conditions and adequate lateral space to perform the test without leaving a paved surface. The test lane shall have boundary markers on the both sides of the lane such that the vision based RDW system can identify and accurately measure the lane width distance. The boundary that is approached by the subject vehicle shall be solid. As outlined in section 7 and shown in Figure 39, this test will be conducted at the Dana test track using Set-up S3.

6.5.5 Driving instructions

Subject vehicle driver:

- At the desired speed, engage the cruise control and maintain a position in the center of the designated lane.
- At the start of the barrier section of track drift slowly toward the barrier.
- When instructed by the experimenter change direction and begin drifting back to the center of the lane.
- Wait one second, and slowly drift toward the right-side lane boundary line and when instructed by the experimenter return to the center of the lane.

6.6 NW-6. No LCW when SV changes lanes in front of a close POV (Required Test)

This test is designed to verify that the IVBSS system does not issue an LCW when the SV changes lanes in front of a POV that is a short distance behind the rear bumper of the SV trailer. In this test both vehicles are traveling at the same speed for the duration of the test.

6.6.1 Test concept and initial and final conditions

Figure 31 shows the initial, transitional, and final conditions for a lane-change event in which a LCW should not be issued. The test begins with the SV and POV traveling nominally at the same speed in the center of their designated lanes with the front bumper of the POV a predetermined distance behind the rear bumper of the SV trailer. The no-warn transition begins when the SV driver signals and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.1 and 0.4 m/s making a complete lane change in front of the POV. The test ends when the SV is in the center of the POV lane and an LCW has not been issued.

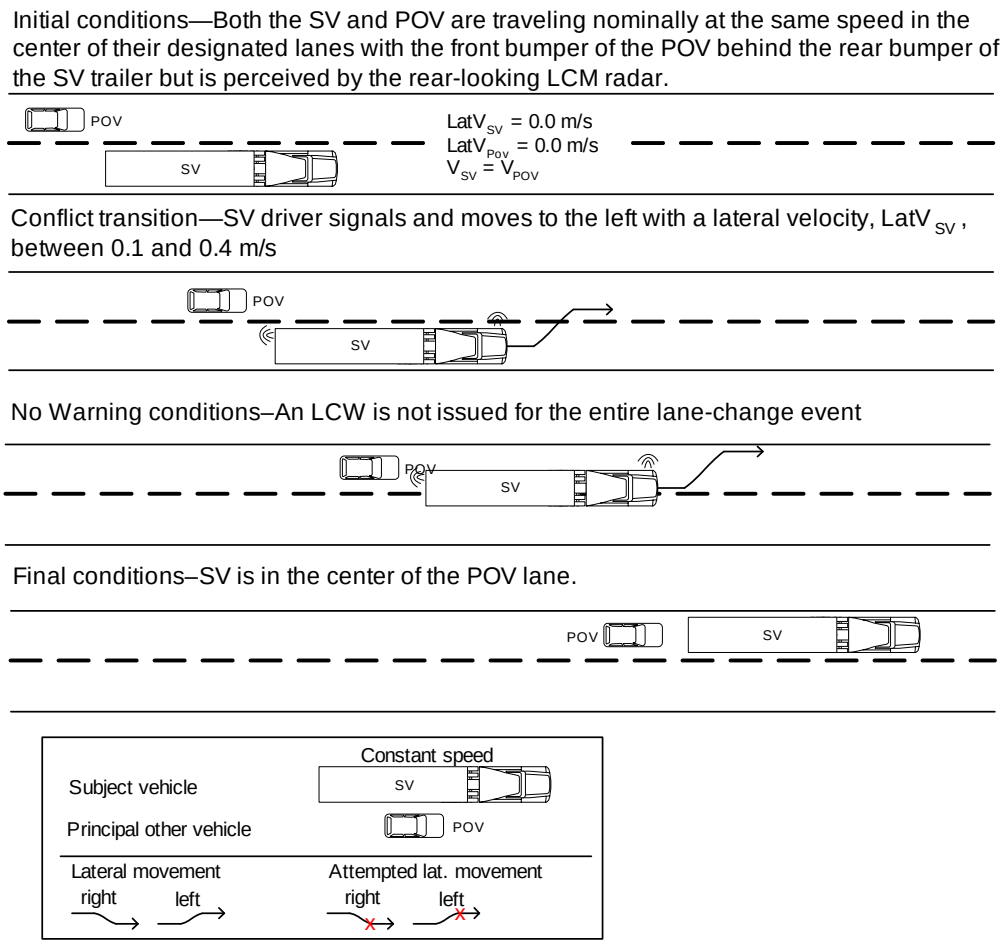


Figure 31. Test concept for a no-warn test when the SV changes lanes in front of the POV

6.6.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for the run must be satisfied. These conditions are given in Table 64. The table shows the target steady-state initial conditions for the test. In some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as

applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.

- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition. Note: there may be more than one transitional event in procedures that involve multiple threats and multiple POVs.

Table 64. Run validity criteria for a no-warn test in which the SV changes lanes in front of the POV.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
V_{POV1}, m/s	20.1(45 mph)	1.0
R_{SV}, m	10	5.0
Transitional test variables	*Target Value*	*± Tolerance*
$LatV_{SV,}$ m/s	0.25	0.15

- Steady-state: The minimum and maximum values of V_{SV}, V_{POV1}, and R_{SV} do not exceed the target values and their associated tolerances over a 2 second window ending at the start of the transition event by the SV.
- The POV is positioned at the desired range behind the rear bumper of the SV during the time of the lane change. If instrumented, data collected from the POV is used to verify this condition. If not instrumented, best judgment of the POV driver is used.
- Transitional: The lateral velocity of the SV, $LatV_{SV}$, reaches a peak value as shown above during the SV lane change.
- Transitional: The minimum and maximum values of V_{SV} and V_{POV1} remain within the desired range from the start of the lane change to the end to the run.
- The SV and POV drivers do not touch the brake pedal during the run.
- The POV remains in the center of the designated lane during the entire test.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*.

6.6.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

6.6.4 Test site preparation and special equipment

This is longitudinal conflict, straight-path test involving a lane-change maneuver by the SV and requiring a site large enough for the establishment of steady-state initial conditions, adequate distance for the transition to occur, and sufficient room for the re-establishment of a steady-state condition. As outlined in section 7 and shown in Figure 36, this test will be conducted at the Dana test track using Set-up S2.

6.6.5 Driving instructions

Subject vehicle driver:

1. Accelerate in the center of the center lane at Dana to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.
2. On a straight section of track and when instructed by the experimenter, turn on the left directional signal, wait one second and make a modest lane change to the left in front of the POV.
3. In the new lane, maintain a steady lateral displacement in the center of the lane until the experimenter informs you the run is finished.

Principal other vehicle driver:

1. Follow the SV in the center of the adjacent lane to the left matching the SV speed. Engage the cruise control or drive manually to match as closely as possible the speed of the SV.
2. When positioned at the desired distance behind the SV, instruct the experimenter that you are in position.
3. Maintain speed, center position in the lane, and distance behind the SV until the experimenter instructs you that the run if finished.

6.7 NW-7. No LCW when SV changes lanes while a POV is two lanes over (Required Test)

The intent of this test is show that he LCW system does not give a warning when the SV changes lanes into an unoccupied center lane while there is a POV two lanes over in a blind spot.

6.7.1 Test concept and initial and final conditions

Figure 32 shows initial, transitional and no-warn conditions for this test. The test starts with both the SV and POV traveling at the same speed in the center of their designated lanes. Between the SV and POV lanes there is a third unoccupied lane. The transition event begins when the SV driver signals to the left and makes a moderate lane change maneuver into the center lane while the POV remains in the center or its lane and aligned longitudinally in what would be considered a blind spot relative to the SV driver. Once the lateral centerline of the SV has passed over the lane boundary marker the SV driver cancels the turn indicator and finishes the lane change maneuvering to the center of the new lane.

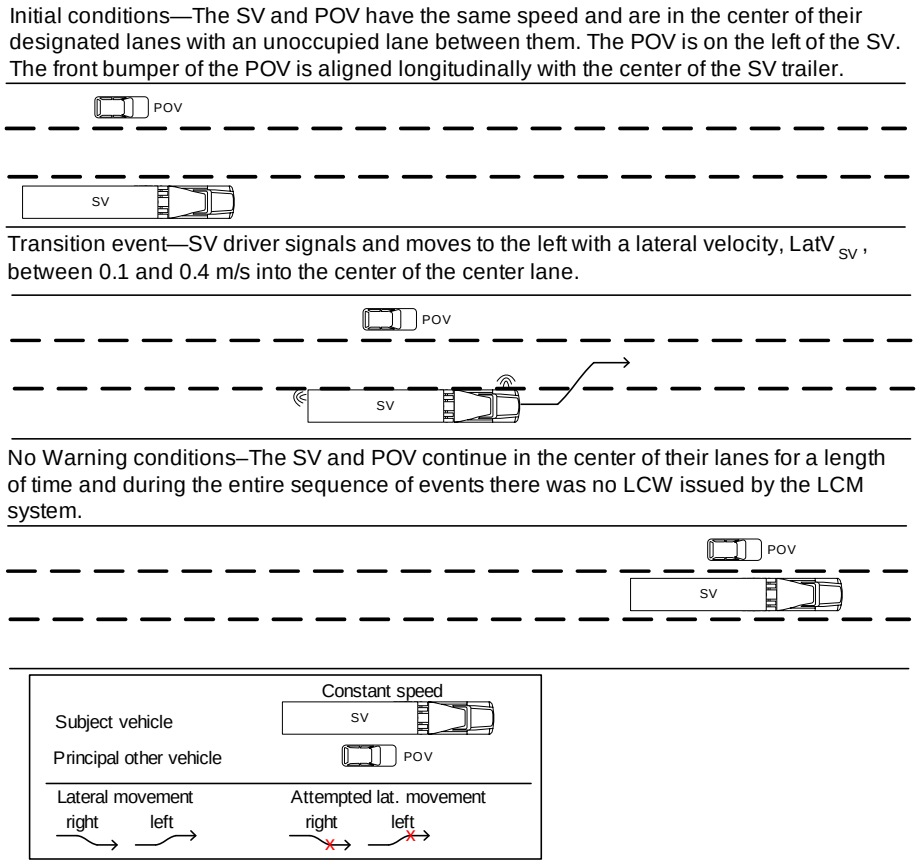


Figure 32. Test concept for a no-warn when the SV changes lanes while a POV is two lanes over in a blind spot.

6.7.2 Performance measures and criteria for pass/fail determination

For a run of this test to be considered valid, the initial and transitional conditions for that run must be satisfied. These conditions are given in Table 65. The table is separated into two sections; the top section shows the target steady-state initial conditions for the test, while the bottom sections shows transitional kinematics that induce a conflict. In

some procedures the initial conditions are by nature conflict laden and a transitional event is not necessary, while in other procedures there maybe more than one transitional event. The table shows the performance measure variable, its target value, and acceptable tolerance. The notes below the table give the rules for evaluating if the initial and transitional conditions have been satisfied along with other criteria that if not followed invalidate the run.

For evaluation purposes the following time windows have been defined:

- Steady-state: the time from the start of the run until a transitional action, a warning or the end of the run as determined by the experimenter and as applicable in the no-warn scenarios or procedures that are aborted due to concern of the SV driver or experimenter.
- Transitional: the time from the start of a transitional action to the time of a warning, the end of the run, or a return to a steady-state condition.

Table 65. Run validity criteria for SV changes lanes while a POV is two lanes over in a blind spot.

Steady-state variables	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	1.0
V_{POV1}, m/s	20.1 (45 mph)	1.0
Transitional test variables	*Target Value*	*± Tolerance*
Lat$V_{SV,}$ m/s	0.25	0.15

- Steady-state: The minimum and maximum values of V_{SV} and V_{POV1} do not exceed the target values and their associated tolerances over a 2 second window ending at the start of the transition event by the SV.
- Transitional: The SV driver performs a modest lane change with a target lateral speed given above.
- The turn signal of the SV is cancelled only after the SV has reached the center of the new lane.
- The SV driver does not touch the brake pedal during the test.
- All standard test-conditions, test-settings and test-site criteria for this run are followed.

The criteria for passing a *Required* test involves successfully executing the test multiple times and thus ensuring that the system performance is repeatable and robust. The criteria for passing the test as a whole are given in Section 1.4 *Criteria for Passing the Required Tests*.

6.7.3 Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

6.7.4 Test site preparation and special equipment

The test will be conducted on the Skid Pad facility of TRC. This facility is shown in Figure 41. The test will be conduced in lanes 4, 5, and 6. The test will be conducted while traveling in the northern direction only with the SV initially in lane 6 and the POV in lane 4. The SV then makes a lane change to the left into the center of lane 5 while the POV remains in lane 4 for the entire test. No changes to the existing boundary markers are required for this test.

6.7.5 Driving instructions

Subject vehicle driver:

1. Accelerate in the center of the center lane at Dana to the desired speed and engages the cruise control. If necessary, the driver should use the cruise-control speed-adjustment buttons to attain the desired speed.
2. On a straight section of track and when instructed by the experimenter, turn on the left directional signal, wait at least one second and make a modest lane change to the left into the unoccupied center lane.
3. When in the new lane, cancel the turn signal after the SV has reached the center of the new lane and maintain a steady lateral displacement in the center of the lane until the experimenter informs you the run is finished.

Principal other vehicle driver:

1. Accelerate to the desired speed in the center of the desired lane and engage the cruise control or drive manually to match as closely as possible the speed of the SV and the desired test speed.
2. When at the desired longitudinal position relative to the SV trailer, instruct the experimenter that you are in position.
3. Maintain speed, center position in the lane, and longitudinal position relative to the SV until the experimenter instructs you that the run is finished.

7 Test sites and lane boundary marker drawings

This section details where each of the test procedures will be conducted showing the facility used as well as the location on the track for the test. The drawings also illustrate how the track is currently stripped and how it will be changed to accommodate the tests outlined above. A majority of these tests will be conducted at the Dana facility in Ottawa Lake Michigan. The remaining tests will be conducted at the Transportation Research Center, in East Liberty, Ohio.

7.1 Dana Test Track in Ottawa Lake, Michigan

Dana's Technical Resource Park (TRP) facilities include a test track and proving grounds of 330 acres and a wide range of test surfaces. For these procedures the oval test track will be used. A picture of the track is shown in Figure 33. The track is a 3-lane, 1 3/4-mile test track with 14 to 15 ft. lane widths of Portland concrete with asphalt berm.

Figure 33. Satellite view of the Dana test-track (scale is located near the northern straight section).

The current boundary and pavement type layout for the Dana test track is shown in Figure 34. 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 do seem to get larger in the center and outer lanes. In the curves this trend is even more pronounced and the outer lane on average can be as wide as 5.0 m (16.4 ft). The outer boundary of the outside lane is also a 4 inch continuous white line around the entire track. A shoulder that is 0.91 m (2.9 ft) bounds the outside of the outer lane and is made of asphalt. Both the eastern and western curves also have a continuous metal guard rail outside of the shoulder.

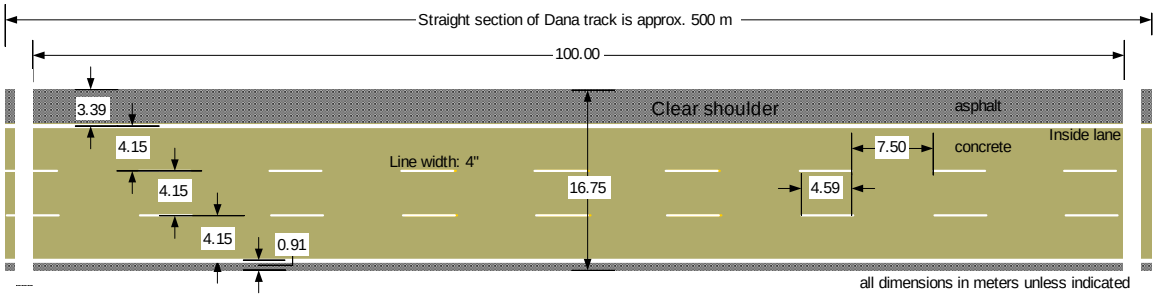


Figure 34. Boundary and pavement type drawing for the Dana Test track.

Figure 35 to Figure 40 shows the direction of travel around the track and the areas on the track where each test scenarios will be conducted. The test type and kinematics of the test determine the number of lanes used. Generally, most tests will be conducted on both the northern and southern straight sections of tracks using the middle and inside lanes. The most comprehensive lane boundary tacking by the LDW system occurs when the SV is in the inside lane, hence the direction of travel and staging of the scenarios that depend on boundary tracking dictates the direction of travel around the track.

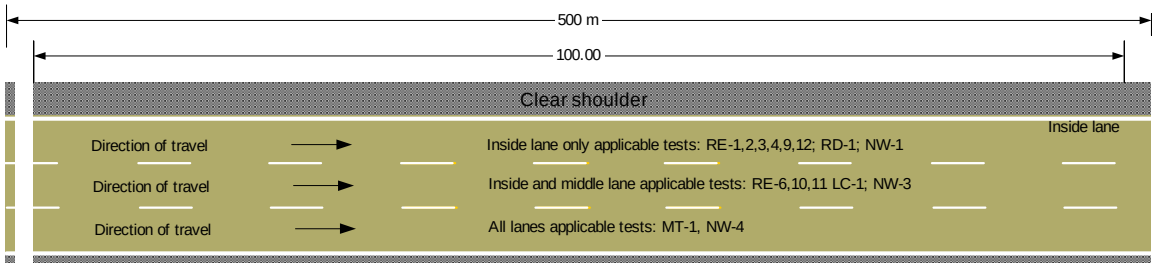


Figure 35. Dana track set-up S1: Lane boundary markings (both Northern and Southern straight sections will be used)

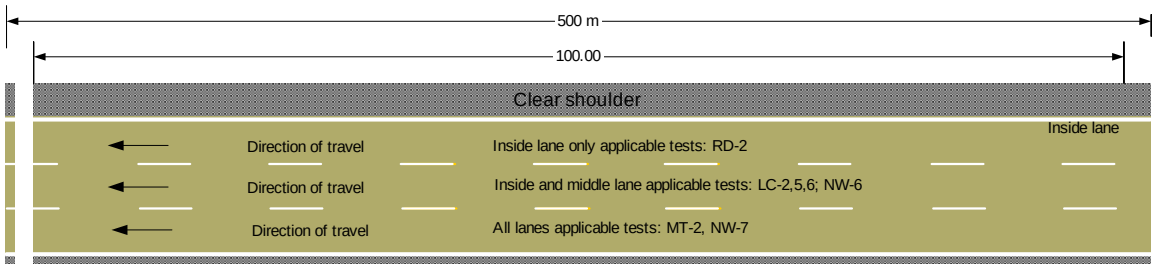


Figure 36. Dana track set-up S2: Lane boundary markings (both Northern and Southern straight sections will be used)

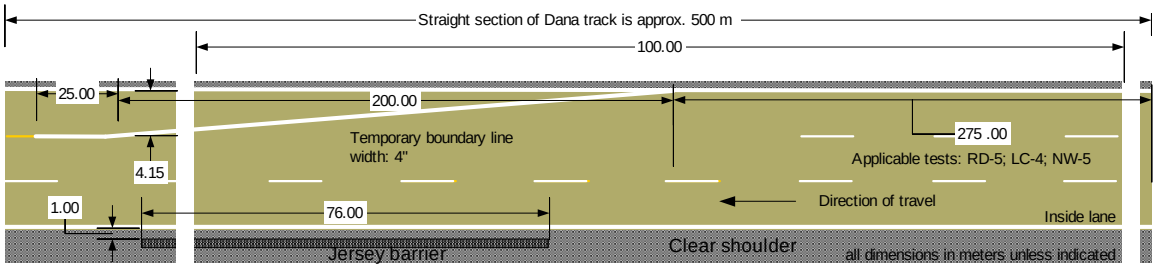
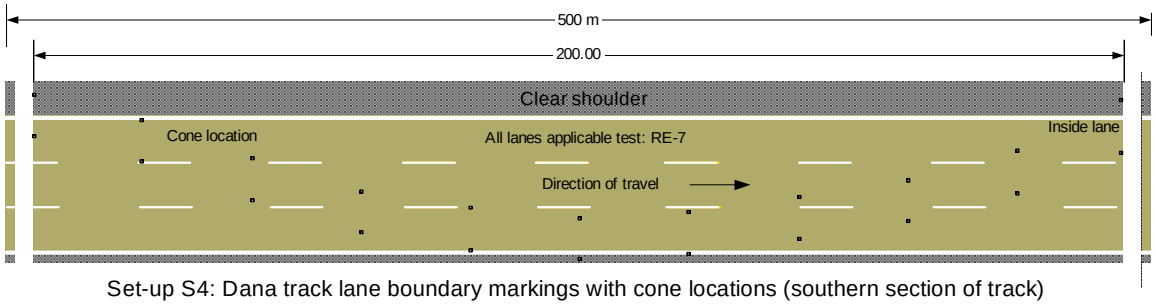


Figure 37. Dana track set-up S3: Lane boundary markings (Northern Straight)

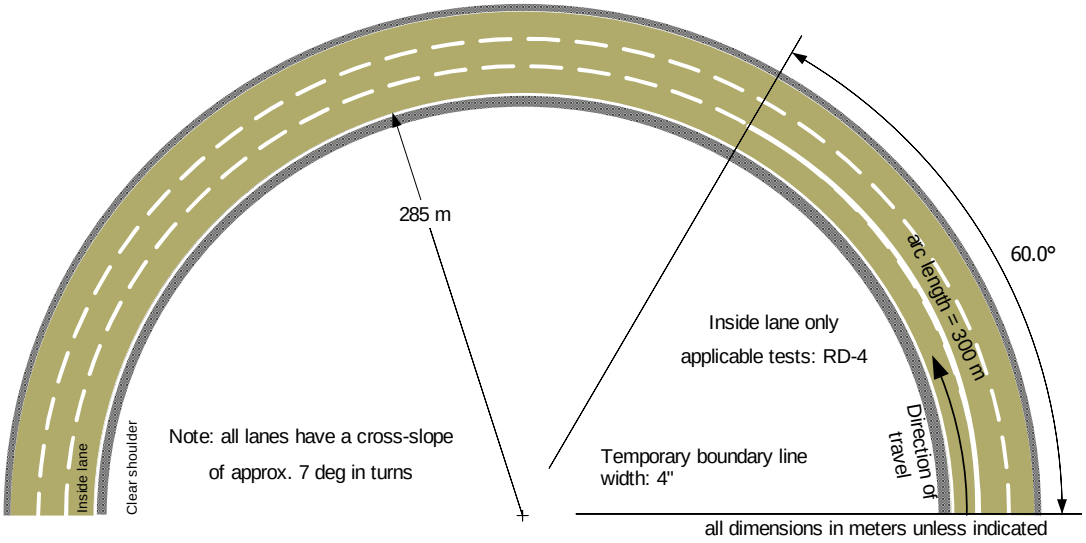


Set-up S4: Dana track lane boundary markings with cone locations (southern section of track)

Figure 38. Dana track set-up S4: Lane boundary markings and cone location for a 500 m radius curve (Southern straight only)

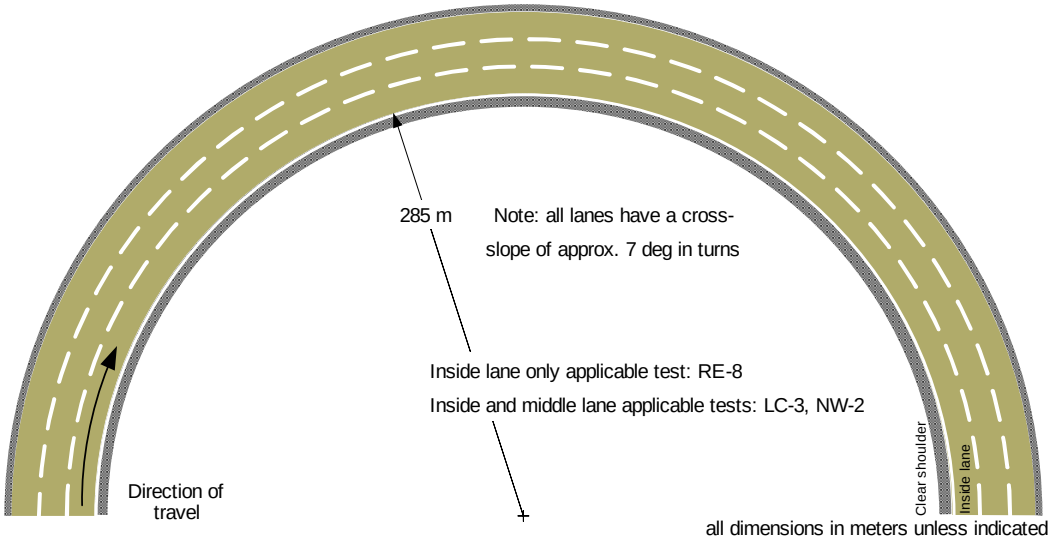
Table 66. Cone location for RE-7; Stopped vehicle in a curve

Cone set	*Longitudinal Distance, m*	*Lateral Distance, m*	
		Inside Cone	*Outside Cone*
1	0.0	0.0	3.6
2	20.0	3.0	6.6
3	40.0	7.1	10.8
4	60.0	10.2	13.9
5	80.0	12.2	15.9
6	100.0	13.2	16.8
7	120.0	13.1	16.8
8	140.0	12.0	15.6
9	160.0	9.8	13.4
10	180.0	6.5	10.2
11	200.0	2.2	5.9



Set-up C1: Dana track lane boundary markings (eastern curve)

Figure 39. Dana track set-up C1: Lane boundary markings (Eastern curve)



Set-up C2: Dana track lane boundary markings (western and eastern curve)

Figure 40. Dana track set-up C2: Lane boundary markings (Eastern and Western curve)

7.2 Transportation Research Center

Only two facilities of the TRC are included in the procedures given above, namely, the Skid Pad and Vehicle Dynamics Area.

7.2.1 Skid Pad at the Transportation Research Center

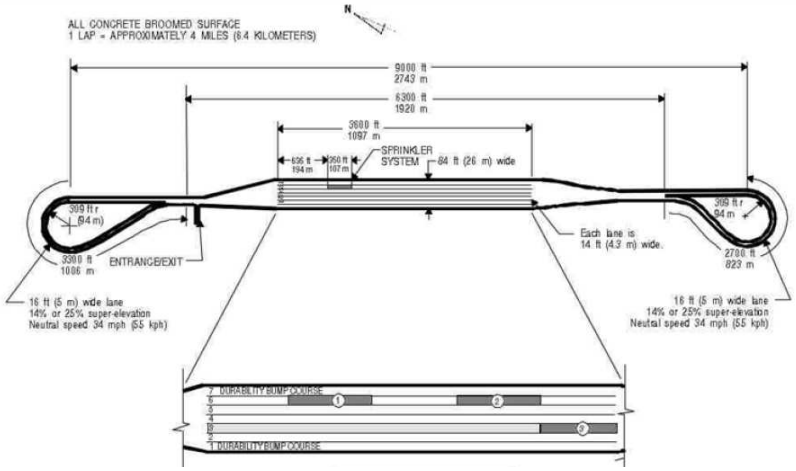


Figure 41. The TRC Multi-Lane Skid Pad Course

7.2.2 Vehicle Dynamics Area at the Transportation Research Center

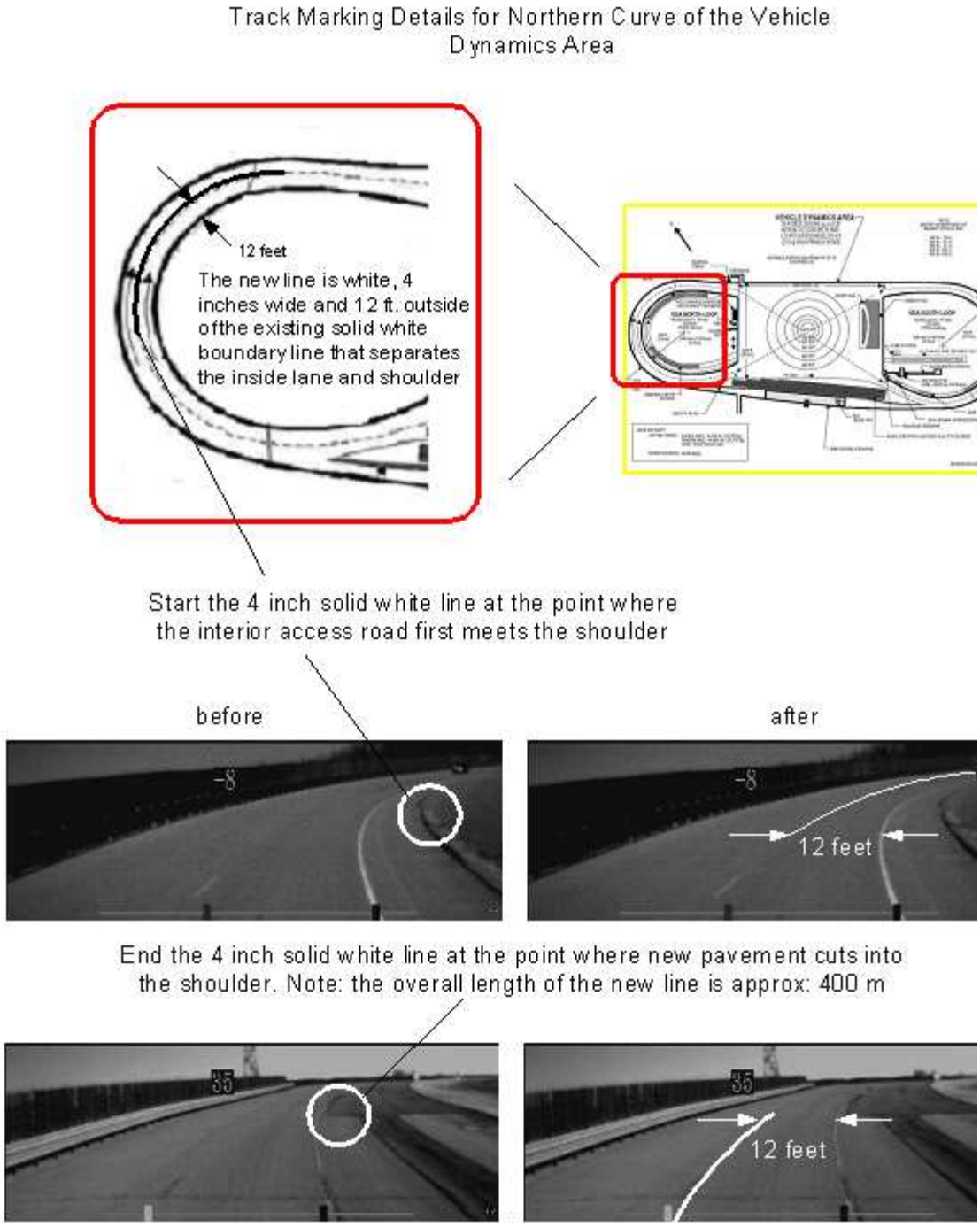


Figure 42. The TRC Vehicle Dynamics Test Area (VDA)

7.3 Distance calculations to establish SV and POV initial Conditions

Table 67. Start and end cone placement assuming a constant acceleration a 0 mph range-rate

POV Ax	Delta V
1.5	0

SV Speed		POV Speed		POV to speed est.		SV 'Go' Cone
mph	m/s	mph	m/s	Time, s	Dist, m	Location, m
35	15.7	35	15.7	10.4	81.7	-163.3
40	17.9	40	17.9	11.9	106.7	-213.3
45	20.1	45	20.1	13.4	135.0	-270.0
50	22.4	50	22.4	14.9	166.7	-333.3
55	24.6	55	24.6	16.4	201.7	-403.3
60	26.8	60	26.8	17.9	240.0	-480.0
65	29.1	65	29.1	19.4	281.7	-563.4

POV start cone location, m

Desired initial range between SV and POV, m

SV Speed	40	60	80	100	120	140	160	180
35	-41.7	-21.7	-1.7	18.3	38.3	58.3	78.3	98.3
40	-66.7	-46.7	-26.7	-6.7	13.3	33.3	53.3	73.3
45	-95.0	-75.0	-55.0	-35.0	-15.0	5.0	25.0	45.0
50	-126.7	-106.7	-86.7	-66.7	-46.7	-26.7	-6.7	13.3
55	-161.7	-141.7	-121.7	-101.7	-81.7	-61.7	-41.7	-21.7
60	-200.0	-180.0	-160.0	-140.0	-120.0	-100.0	-80.0	-60.0
65	-241.7	-221.7	-201.7	-181.7	-161.7	-141.7	-121.7	-101.7

SV Speed	Initial Htm, s							
35	2.6	3.8	5.1	6.4	7.7	8.9	10.2	11.5
40	2.2	3.4	4.5	5.6	6.7	7.8	8.9	10.1
45	2.0	3.0	4.0	5.0	6.0	7.0	8.0	8.9
50	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.0
55	1.6	2.4	3.3	4.1	4.9	5.7	6.5	7.3
60	1.5	2.2	3.0	3.7	4.5	5.2	6.0	6.7
65	1.4	2.1	2.8	3.4	4.1	4.8	5.5	6.2

POV at speed cone location = desired initial range

Table 68. Start and end cone placement assuming a constant acceleration a 5 mph closing range-rate

POV Ax	Delta V
1.5	5

SV Speed		POV Speed		POV to speed est.		SV 'Go' Con
mph	m/s	mph	m/s	Time, s	Dist, m	Location, m
35	15.7	30	13.4	8.9	60.0	-140.0
40	17.9	35	15.7	10.4	81.7	-186.7
45	20.1	40	17.9	11.9	106.7	-240.0
50	22.4	45	20.1	13.4	135.0	-300.0
55	24.6	50	22.4	14.9	166.7	-366.7
60	26.8	55	24.6	16.4	201.7	-440.0
65	29.1	60	26.8	17.9	240.0	-520.0

POV start cone location, m

Desired initial range between SV and POV, m

SV Speed	30	50	70	90	110	130	150	170
35	-30.0	-10.0	10.0	30.0	50.0	70.0	90.0	110.0
40	-51.7	-31.7	-11.7	8.3	28.3	48.3	68.3	88.3
45	-76.7	-56.7	-36.7	-16.7	3.3	23.3	43.3	63.3
50	-105.0	-85.0	-65.0	-45.0	-25.0	-5.0	15.0	35.0
55	-136.7	-116.7	-96.7	-76.7	-56.7	-36.7	-16.7	3.3
60	-171.7	-151.7	-131.7	-111.7	-91.7	-71.7	-51.7	-31.7
65	-210.0	-190.0	-170.0	-150.0	-130.0	-110.0	-90.0	-70.0

SV Speed	Initial Htm, s							
35	1.9	3.2	4.5	5.7	7.0	8.3	9.6	10.9
40	1.7	2.8	3.9	5.0	6.1	7.3	8.4	9.5
45	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.4
50	1.3	2.2	3.1	4.0	4.9	5.8	6.7	7.6
55	1.2	2.0	2.8	3.7	4.5	5.3	6.1	6.9
60	1.1	1.9	2.6	3.4	4.1	4.8	5.6	6.3
65	1.0	1.7	2.4	3.1	3.8	4.5	5.2	5.8

POV at speed cone location = desired initial range

Table 69. Start and end cone placement assuming a constant acceleration a 10 mph closing range-rate

POV Ax	Delta V
1.5	10

SV Speed		POV Speed		POV to speed est.		SV 'Go' Con
mph	m/s	mph	m/s	Time, s	Dist, m	Location, m
35	15.7	25	11.2	7.5	41.7	-116.7
40	17.9	30	13.4	8.9	60.0	-160.0
45	20.1	35	15.7	10.4	81.7	-210.0
50	22.4	40	17.9	11.9	106.7	-266.7
55	24.6	45	20.1	13.4	135.0	-330.0
60	26.8	50	22.4	14.9	166.7	-400.0
65	29.1	55	24.6	16.4	201.7	-476.7

POV start cone location, m

	Desired initial range between SV and POV, m							
SV Speed	40	60	80	100	120	140	160	180
35	-1.7	18.3	38.3	58.3	78.3	98.3	118.3	138.3
40	-20.0	0.0	20.0	40.0	60.0	80.0	100.0	120.0
45	-41.7	-21.7	-1.7	18.3	38.3	58.3	78.3	98.3
50	-66.7	-46.7	-26.7	-6.7	13.3	33.3	53.3	73.3
55	-95.0	-75.0	-55.0	-35.0	-15.0	5.0	25.0	45.0
60	-126.7	-106.7	-86.7	-66.7	-46.7	-26.7	-6.7	13.3
65	-161.7	-141.7	-121.7	-101.7	-81.7	-61.7	-41.7	-21.7

SV Speed	Initial Htm, s							
35	2.6	3.8	5.1	6.4	7.7	8.9	10.2	11.5
40	2.2	3.4	4.5	5.6	6.7	7.8	8.9	10.1
45	2.0	3.0	4.0	5.0	6.0	7.0	8.0	8.9
50	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.0
55	1.6	2.4	3.3	4.1	4.9	5.7	6.5	7.3
60	1.5	2.2	3.0	3.7	4.5	5.2	6.0	6.7
65	1.4	2.1	2.8	3.4	4.1	4.8	5.5	6.2

POV at speed cone location = desired initial range

Table 70. Start and end cone placement assuming a constant acceleration a 15 mph closing range-rate

POV Ax	Delta V
1.5	15

SV Speed		POV Speed		POV to speed est.		SV 'Go' Con
mph	m/s	mph	m/s	Time, s	Dist, m	Location, m
35	15.7	20	8.9	6.0	26.7	-93.3
40	17.9	25	11.2	7.5	41.7	-133.3
45	20.1	30	13.4	8.9	60.0	-180.0
50	22.4	35	15.7	10.4	81.7	-233.3
55	24.6	40	17.9	11.9	106.7	-293.3
60	26.8	45	20.1	13.4	135.0	-360.0
65	29.1	50	22.4	14.9	166.7	-433.4

POV start cone location, m

	Desired initial range between SV and POV, m							
SV Speed	40	50	70	90	100	120	130	150
35	13.3	23.3	43.3	63.3	73.3	93.3	103.3	123.3
40	-1.7	8.3	28.3	48.3	58.3	78.3	88.3	108.3
45	-20.0	-10.0	10.0	30.0	40.0	60.0	70.0	90.0
50	-41.7	-31.7	-11.7	8.3	18.3	38.3	48.3	68.3
55	-66.7	-56.7	-36.7	-16.7	-6.7	13.3	23.3	43.3
60	-95.0	-85.0	-65.0	-45.0	-35.0	-15.0	-5.0	15.0
65	-126.7	-116.7	-96.7	-76.7	-66.7	-46.7	-36.7	-16.7

SV Speed	Initial Htm, s							
35	2.6	3.2	4.5	5.7	6.4	7.7	8.3	9.6
40	2.2	2.8	3.9	5.0	5.6	6.7	7.3	8.4
45	2.0	2.5	3.5	4.5	5.0	6.0	6.5	7.5
50	1.8	2.2	3.1	4.0	4.5	5.4	5.8	6.7
55	1.6	2.0	2.8	3.7	4.1	4.9	5.3	6.1
60	1.5	1.9	2.6	3.4	3.7	4.5	4.8	5.6
65	1.4	1.7	2.4	3.1	3.4	4.1	4.5	5.2

POV at speed cone location = desired initial range

Table 71. Start and end cone placement assuming a constant acceleration a 20 mph closing range-rate

POV Ax	Delta V
1.5	20

SV Speed		POV Speed		POV to speed est.		SV 'Go' Con
mph	m/s	mph	m/s	Time, s	Dist, m	Location, m
35	15.7	15	6.7	4.5	15.0	-70.0
40	17.9	20	8.9	6.0	26.7	-106.7
45	20.1	25	11.2	7.5	41.7	-150.0
50	22.4	30	13.4	8.9	60.0	-200.0
55	24.6	35	15.7	10.4	81.7	-256.7
60	26.8	40	17.9	11.9	106.7	-320.0
65	29.1	45	20.1	13.4	135.0	-390.0

POV start cone location, m

Desired initial range between SV and POV, m

SV Speed	40	60	80	100	120	140	160	180
35	25.0	45.0	65.0	85.0	105.0	125.0	145.0	165.0
40	13.3	33.3	53.3	73.3	93.3	113.3	133.3	153.3
45	-1.7	18.3	38.3	58.3	78.3	98.3	118.3	138.3
50	-20.0	0.0	20.0	40.0	60.0	80.0	100.0	120.0
55	-41.7	-21.7	-1.7	18.3	38.3	58.3	78.3	98.3
60	-66.7	-46.7	-26.7	-6.7	13.3	33.3	53.3	73.3
65	-95.0	-75.0	-55.0	-35.0	-15.0	5.0	25.0	45.0

SV Speed	Initial Htm, s							
35	2.6	3.8	5.1	6.4	7.7	8.9	10.2	11.5
40	2.2	3.4	4.5	5.6	6.7	7.8	8.9	10.1
45	2.0	3.0	4.0	5.0	6.0	7.0	8.0	8.9
50	1.8	2.7	3.6	4.5	5.4	6.3	7.2	8.0
55	1.6	2.4	3.3	4.1	4.9	5.7	6.5	7.3
60	1.5	2.2	3.0	3.7	4.5	5.2	6.0	6.7
65	1.4	2.1	2.8	3.4	4.1	4.8	5.5	6.2

POV at speed cone location = desired initial range

Table 72. Start and end cone placement assuming a constant acceleration a 25 mph closing range-rate

POV Ax	Delta V
1.5	25

SV Speed		POV Speed		POV to speed est.		SV 'Go' Con
mph	m/s	mph	m/s	Time, s	Dist, m	Location, m
35	15.7	10	4.5	3.0	6.7	**-46.7**
40	17.9	15	6.7	4.5	15.0	**-80.0**
45	20.1	20	8.9	6.0	26.7	**-120.0**
50	22.4	25	11.2	7.5	41.7	**-166.7**
55	24.6	30	13.4	8.9	60.0	**-220.0**
60	26.8	35	15.7	10.4	81.7	**-280.0**
65	29.1	40	17.9	11.9	106.7	**-346.7**

POV start cone location, m

Desired initial range between SV and POV, m

SV Speed	40	60	80	100	120	140	150	160
35	**33.3**	**53.3**	**73.3**	**93.3**	**113.3**	**133.3**	**143.3**	**153.3**
40	**25.0**	**45.0**	**65.0**	**85.0**	**105.0**	**125.0**	**135.0**	**145.0**
45	**13.3**	**33.3**	**53.3**	**73.3**	**93.3**	**113.3**	**123.3**	**133.3**
50	**-1.7**	**18.3**	**38.3**	**58.3**	**78.3**	**98.3**	**108.3**	**118.3**
55	**-20.0**	**0.0**	**20.0**	**40.0**	**60.0**	**80.0**	**90.0**	**100.0**
60	**-41.7**	**-21.7**	**-1.7**	**18.3**	**38.3**	**58.3**	**68.3**	**78.3**
65	**-66.7**	**-46.7**	**-26.7**	**-6.7**	**13.3**	**33.3**	**43.3**	**53.3**

SV Speed	Initial Htm, s							
35	2.6	3.8	5.1	6.4	7.7	8.9	9.6	10.2
40	2.2	3.4	4.5	5.6	6.7	7.8	8.4	8.9
45	2.0	3.0	4.0	5.0	6.0	7.0	7.5	8.0
50	1.8	2.7	3.6	4.5	5.4	6.3	6.7	7.2
55	1.6	2.4	3.3	4.1	4.9	5.7	6.1	6.5
60	1.5	2.2	3.0	3.7	4.5	5.2	5.6	6.0
65	1.4	2.1	2.8	3.4	4.1	4.8	5.2	5.5

POV at speed cone location = desired initial range

8 Appendix A. Test Conditions Specifics

8.1 Solar Zenith Angle

Solar zenith angle is the angle from vertical to the sun: 0 degrees means the sun is directly overhead; 90 degrees places the sun near the horizon. A solar zenith angle of 96 degrees is commonly used as the definition of civil twilight. For the purpose of these tests, 90 degrees was used as the threshold between daylight and darkness. Lighting conditions were considered to be "light" for solar zenith angles less than 90 degrees and "dark" for angles equal or greater than 90 degrees.

The solar zenith angle is calculated from latitude, longitude, and universal time, using formulae obtained from the National Oceanic and Atmospheric Administration at http://www.srrb.noaa.gov/highlights/sunrise/solareqns.PDF. Figure A-1 plots the calculated solar zenith angle as a function of local time for the Northern Indiana region of the U.S. The spread of the band of data points results from (1) the influence of the time of the year, (2) the influence of the range of latitude in the region, and (3) the influence of the east-west location of the region relative to time zone.

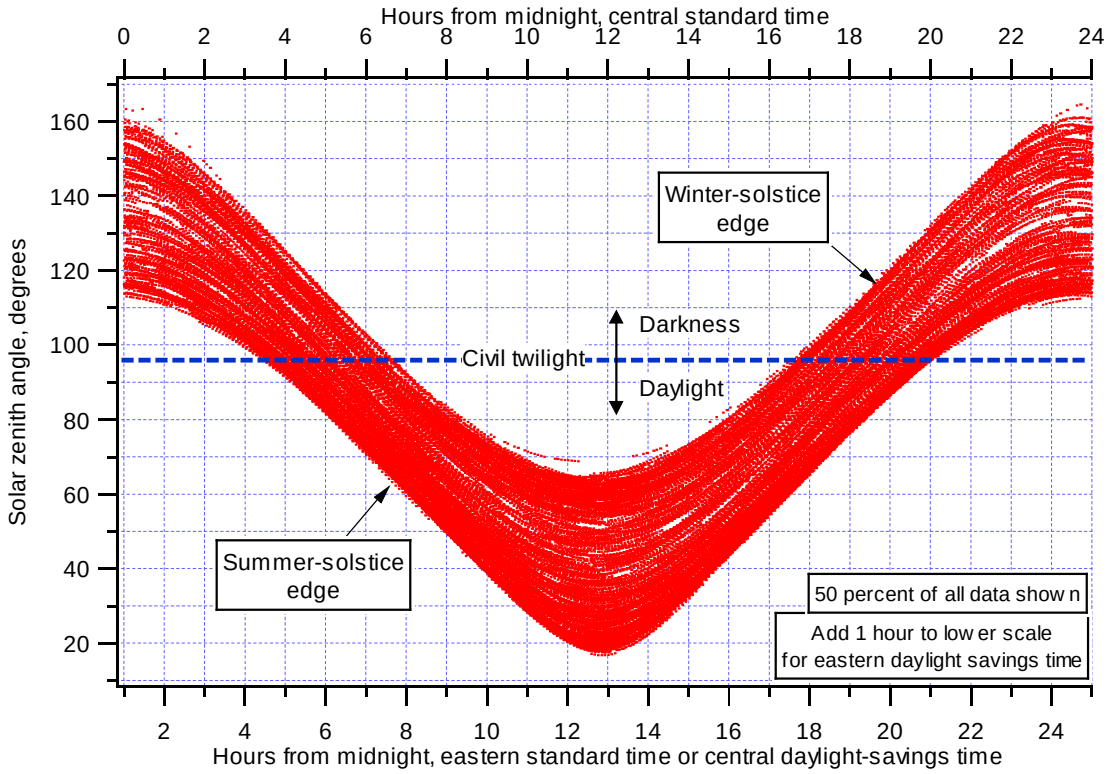


Figure A-1. Solar zenith angle

8.2 Environment and pavement types

The test shall be performed on good quality paved or concrete surfaces with the following general descriptions to guide the testing environment:

"Daytime" illumination is defined as the natural outdoors illumination that occurs when the solar zenith angle is at least less than 80 degrees.

"Good" atmospheric visibility conditions are defined as a visibility of at least 5 miles as recorded by the nearest FAA weather station.

"Calm conditions" exist if sustained wind speeds are less than 15 mph and wind gusts are less than 25 mph.

8.3 Subject vehicle

The subject vehicle is a Class 8 tractor and a 53 foot dry-cargo van trailer.

8.4 Subject vehicle Instrumentation

The subject vehicle shall include a data acquisition system to record data from the IVBSS system and other primary kinematic and functional measures of the vehicle. These include the vehicle state measures, warning levels, and any intermediate measures necessary to fully understand how the system functions. The SV instrumentation shall also include at least a video recording of the forward scene at a sampling frequency of 10 Hz or greater.

8.5 Primary and Secondary other vehicles

The POV and secondary POV shall be one of the following as specified for a given test.

"Passenger car" is defined as a mid-sized sedan.

"A truck" is defined as a Class 8 tractor and dry-cargo van trailer at least 40 ft in length.

"Motorcycle" is defined as a commercially available 125cc to 650cc-class motorcycle without alterations to its reflectors, lights, or fenders, and without after-market add-ons that might affect its visibility to countermeasure sensors.

8.6 Primary and secondary other vehicle instrumentation

Generally, no instrumentation other than a stop watch or manual accelerometer is needed by the driver of a primary or secondary other vehicle. However, when possible

the POV shall be equipped with conventional cruise control to minimize speed deviations during a test.

8.7 Road geometry

"Straight" road is tentatively set at a horizontal curvature of less than 0.1° per 100 meters.

"Curved" road is tentatively set at a horizontal curvature of more than 0.1° per 100 meters.

"Flat road" is set at a vertical curvature of greater than 600-m per percent change in grade.

"Dry" conditions describe any surface that has no visible evidence of water including discoloration of the pavement due to wetness.

"Wet" conditions describe any surface that has no visible dry areas and has been doused with water to the point that running water was present on the surface in the prior 30 minutes.

"Smoothly paved" conditions describe any paved track surface with pavement in relatively good condition.

8.8 Lane geometry and boundary types

Boundaries are classified as "good quality" if the lane markings having the following:

- The lane markings must be parallel to the center of the road
- The painted lane markings must be either single solid (continuous) lines or single dashed lines. Neither side of any lane used in the test can be marked with double-solid lines nor a combination of parallel solid and dashed lines, such as the markings found on a two-way, two-lane road, with no passing in one direction.
- The painted lane markings must be either yellow or white.
- The painted lane markings must be between 3.5 and 5.5 inches wide.
- If a painted lane marker is dashed, the following must hold:
    a. The length of all dashes must be between two and 10 meters.
    b. The space between two dashes may not be less than twice the length of either dash or greater than four times the length of either dash, where the

length of each dash is its "ideal" length, which is not reduced by wear or torn off sections of marker.

- Raised pavement markers are acceptable but not required.

9 Appendix B. The NIST Independent Measurement System

This appendix describes physical aspects of the Independent Measurement System (IMS) that the National Institute of Standards and Technology (NIST) will use to collect data during IVBSS track and on-road verification tests. The IMS components are shown in Figure B-1, B-2, and B-3.

A clamp-on roof rack mounts to the hood of a vehicle (left side of Figure B-1) and carries three cameras and two laser scanners. The roof rack and its dimensions are shown in Figure B-2.

The majority of the remaining IMS electronics reside in an enclosure depicted in Figure B-3. We are evaluating a wheel speed measurement device that attaches by suction cups to the fender adjacent to the rear wheel. The device, an emitter-detector switch, senses wheel rotation from reflective tape on the tire.

The IMS power consumption is listed in Table B-1. The peak power is approximately 240 watts, or 20 amps at 12 volts. A side and front view of the IMS as installed on the Eaton/International Test Vehicle for IVBSS is shown in Figure B-4 below.

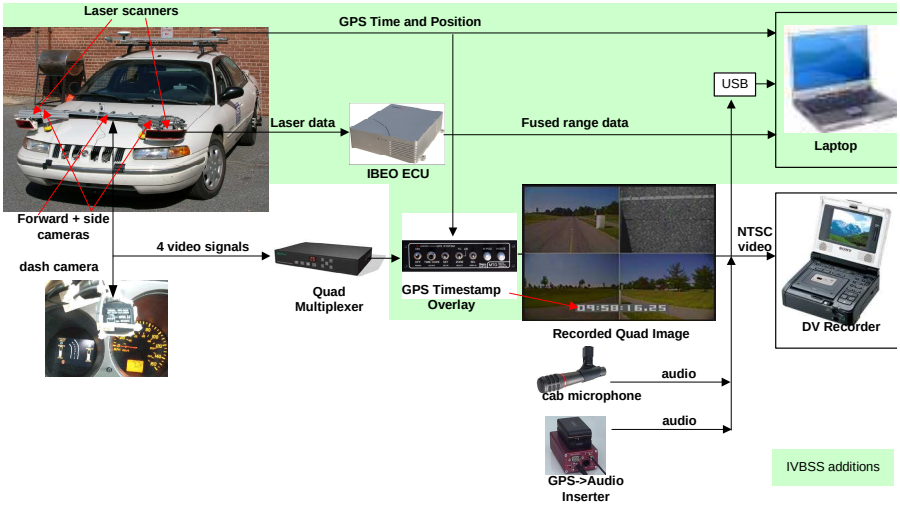


Figure B-1. The Independent Measurement System data flow diagram

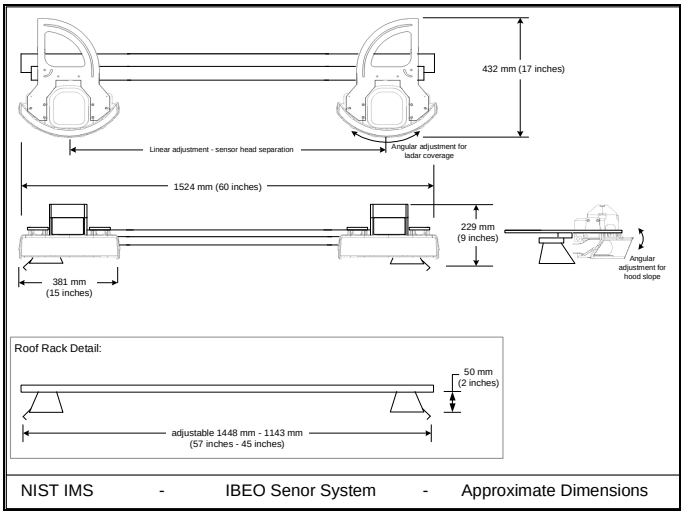


Figure B-2. Independent Measurement System sensor roof rack

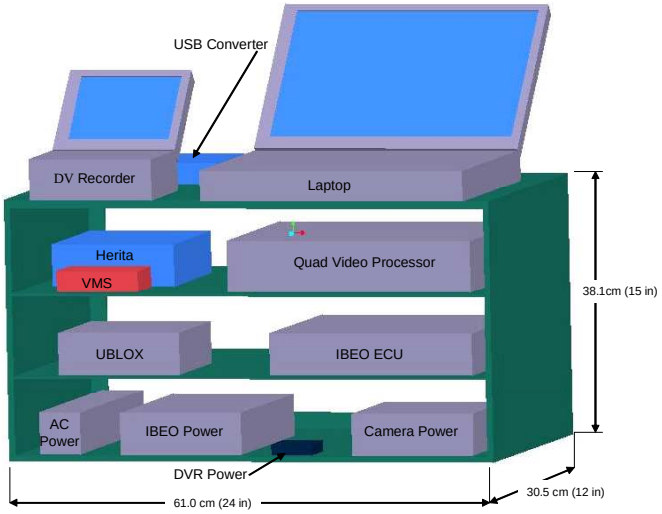


Figure B-3. Independent Measurement System enclosure

Figure B-4. Front and side view of IVBSS heavy-truck with the IMS installed