IVBSS

Integrated Vehicle-Based Safety Systems Light Vehicle Verification Test Plan

Prepared by

Visteon Corporation

for

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This test plan documents the procedures that were used to verify that the Integrated Vehicle-Based Safety Systems (IVBSS) light vehicle platform met all its performance requirements. The document was prepared by Visteon 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 light vehicle integrated system performed as intended and meets 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
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Glossary and Acronym List

ACC	Adaptive Cruise Control
AMR	Available Maneuvering Room
BZ	Blind Zone
CAMP	Crash Avoidance Metrics Partnership
CAN	Controller Area Network
CPI	(CPOI) – Curve Point of Interest (the point in the road with the highest curvature)
CSW	Curve Speed Warning
DAS	Data Acquisition System
DVI	Driver Vehicle Interface
LFAD	Consists of the Lane Change Merge (LCM) + Forward collision warning (FCW) + arbitration module (ARB) + driver vehicle interface (DVI)
FCW	Forward Collision Warning
FOT	Field Operational Test
HMI	Human Machine Interface
IMS	Independent Measurement System
IVBSS	Integrated Vehicle Based Safety Systems
LC	Lane Change
LCM	Lane Change Merge
LCW	Lane Change Warning
LDW	Lateral drift warning
MT	Multi Threat
NHTSA	National Highway Traffic Safety Administration
NIST	National Institute of Standards and Technology
P1	The first Principle Other Vehicle (i.e., POV1)
P2	The second Principle Other Vehicle (i.e., POV2)
POV	Principle Other Vehicle or the vehicle that interacts with the subject vehicle in a test
RD	Road Departure
RDCW	Road Departure Crash Warning System
RDW	Road Departure Warning
RE	Rear-End
Run	Single trial in a verification scenario
SV	Subject Vehicle
TTC	Time-to-Collision
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 System (IVBSS) light vehicle 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 Visteon 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 light-vehicle 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. Light vehicles encompass passenger cars, vans and minivans, sports utility vehicles, and light pickup trucks with gross vehicle rating less than 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 light vehicle system consists of four 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):

1. Forward collision warning (FCW) – warns drivers of imminent rear-end crashes.
2. Lateral drift warning (LDW) – alerts drivers that they may inadvertently be drifting from the center of their lane to adjacent lane or roadside.
3. 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.
4. Curve speed warning (CSW) – warns drivers of over-speeding when approaching a curve.

Procedures and test conditions presented in this document will be used for verification testing of IVBSS LV 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 light vehicle functional requirements and performance guidelines described in {insert reference numbers for Section 1.6 for each of the final version of these documents}.

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.

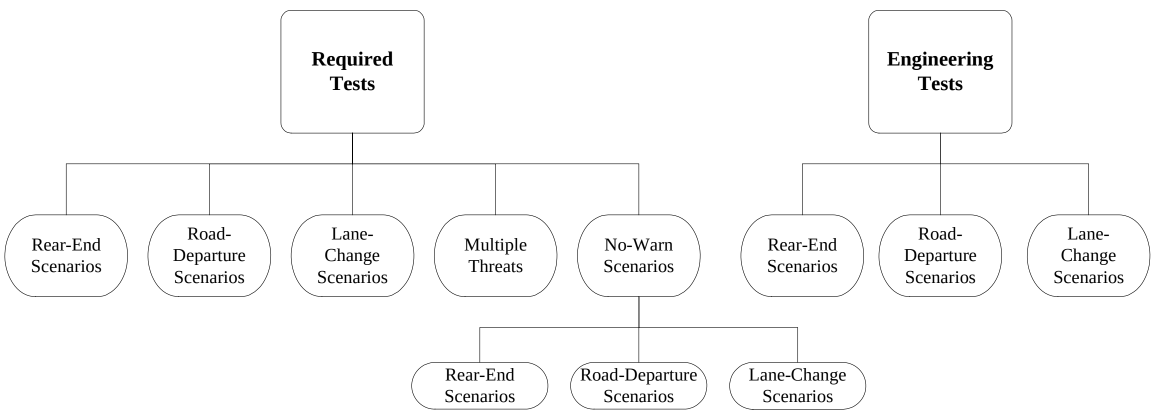

Figure 1: Breakdown of Test Scenarios

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.

Table 1 lists all track tests to be performed by the LV platform.

The test vehicle will be equipped with a data acquisition system (DAS) to record key test parameters. This DAS is built by the University of Michigan Transportation Research Institute to support data collection for Visteon during Phase I of the IVBSS program and to gather data on driver/system performance in the extended pilot and field operational tests during Phase II. NIST will also install an independent measurement system (IMS) on the test vehicle to separately record data on selected test parameters. Professional drivers will be employed to drive the test vehicle and perform the track tests, accompanied by an independent observer. These drivers will have no affiliation with the IVBSS program. The independent observer is a representative from the Volpe National Transportation Systems Center, the independent evaluator of the IVBSS program.

Table 1. All Track Tests to be Performed for the Light Vehicle IVBSS Platform

	FORWARD COLLISION WARNING TESTS - Rear-End (RE)
2.1	RE-1. Rear-end conflict with a constant speed POV – **Required Test**
2.2	RE-2. Rear-end conflict with slowing POV (low POV deceleration/low time gap) – **Required Test**
2.3	RE-3. Rear-end conflict with slowing POV (high POV deceleration/high time gap – **Required Test**
2.4	RE-4. Rear-end conflict with stopped POV at 45 mph – **Required Test**
2.5	RE-5. Rear-end conflict with a stopped POV at 30 mph – **Required Test**
2.6	RE-6. Rear-end conflict with slower POV after a lane change by SV – **Required Test**
2.7	RE-7. Rear-end conflict with stopped POV in a curve at 30 mph – ***Engineering Test***
2.8	RE-8. Rear-end conflict with a slower POV in a curve – ***Engineering Test***
2.9	RE-9. Rear-end with constant speed motorcycle (POV) behind minivan – ***Engineering Test***
2.10	RE-10. Rear-end conflict with POV after a cut-in by the POV – ***Engineering Test***
2.11	RE-11. Rear-end conflict with a slower POV1 (P1) after POV2 (P2) cut-out – ***Engineering Test***
2.12	RE-12. Rear-end conflict with a constant speed POV (motorcycle) – **Required Test**
	LANE CHANGE TESTS - (LC)
3.1	LC-1. Lane-change conflict with POV in the right rear blind-spot of the SV – **Required Test**
3.2	LC-2. This test has been changed to RD-8 now.
3.3	LC-3. Lane-change into adjacent POV on curve **– Engineering Test**
3.4	LC-4. Lane-change into adjacent POV on merge **– Required Test**
3.5	LC-5. Lane-change into adjacent POV after passing – ***Engineering Test***
3.6	LC-6. Lane-change into approaching POV – **Required Test**
	ROAD DEPARTURE TESTS - (RD)
4.1	RD-1. Road departure toward opposing traffic lane with low lateral speed – **Required Test**
4.2	RD-2. Road departure toward a clear shoulder with high lateral speed – **Required Test**
4.3	RD-3. Road departure toward a clear shoulder on a curve with a small radii – **Required Test**
4.4	RD-4. Road departure toward a clear shoulder on a curve with a large radii – **Required Test**
4.5	RD-5. Road-departure toward a barrier on the left with good lane marking – ***Engineering Test***
4.6	RD-6. Road-departure toward a curve with excessive speed (warm/dry condition) – **Required Test**
4.7	RD-7. Road-departure toward a curve with excessive speed (cold/wet condition) **– Required Test**
4.8	RD-8. Road departure toward an occupied lane with POV forward on left – **Required Test**
	MULTIPLE THREAT - (MT)
5.1	MT-1. Rear-end followed by a lane-change warning – **Required Test**
5.2	MT-2. Aborted lane-change followed by rear-end followed by a road departure – **Required Test**
	NO-WARNING - (NW)
6.1	NW-1. No warning when SV closely follows POV **– Required Test**
6.2	NW-2. No warning when SV on curve passes stopped POV in adjacent lane on curve **– Required Test**
6.3	NW-3. No warning when faster POV cuts in front of SV at a very close headway gap **– Required Test**
6.4	NW-4. No warning when SV in middle lane approaches slower POV's in left and right adj lanes **– Required Test**
6.5	NW-5. No warning with poor lane keeping and continuous barrier on the left with lane marking **– Required Test**
6.6	NW-6. No warning when SV changes lane into adj POV that is behind the SV rear bumper **– Required Test**
6.7	NW-7. No warning when SV changes lane and POV is two lanes over in blind spot **– Required Test**
6.8	NW-8. No warning when SV is approaching a curve with safe speed in warm/dry condition **– Required Test**

1.3. Definition of test variables 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 3Table 3 lists the pass/fail and test variables along with their definitions and units also as a function of each subsystem and for the multiple threat tests.

Table 2. Acronym and Definition of Various Common Test Variables

V_{SV}	Subject vehicle forward speed, m/s
V_{PN}	N^{th} principal other vehicle forward speed[1], m/s
Ax_{SV}	Longitudinal acceleration of the subject vehicle, m/s^2
Ax_{PN}	Longitudinal acceleration of the N^{th} principal other vehicle, m/s^2
R_{SPN}	Longitudinal Range between the subject vehicle and the N^{th} principal other vehicle[2], m
$(R_{SPN})_{ss}$	Steady State Longitudinal Range between the subject vehicle and the N^{th} principal other vehicle, m
$Rdot_{SPN}$	Range-rate between subject vehicle and N^{th} principal other vehicle, m/s
$LatV_{SV}$	Lateral speed of the subject vehicle, m/s
$LatV_{PN}$	Lateral speed of the N^{th} principal other vehicle, m/s
$LOff_{SV}$	Lateral offset of the subject vehicle relative to lane center, m
Tw_{SV}	SV Track Width, m
TTC	Time to Collision (sec)

[1] Unless otherwise specified this performance measure is derived by adding RdotSPN and $V_{SV.}$

[2] Negative number denotes that POV is behind SV and the value shows the distance between POV front bumper to SV rear bumper

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

RE Pass/fail variables	
R_{FCW}	Range between the subject vehicle and the principal other vehicle at the time of rear-end or forward collision warning.
RD Pass/fail variables	
$LatDist_{RDW}$	The lateral distance from the closest edge of the lane-boundary of interest and the corresponding outside edge of the front wheel of the subject vehicle at the time of the Road Departure Warning (a negative number means the front wheel passed over the closest edge of the line). The equation for deriving $LatDist_{RDW}$ is: $LatDist_{RDW} = (Lw_{SV} / 2) – abs(LOff_{SV}) – (Tw_{SV} / 2)$ Where: Tw_{SV} = SV track width, Lw_{SV} = SV Lane width, $LOff_{SV}$ = SV Lane offset, For LV, SV track width of 1.8 m will be used.
R_{CSW}	Range between the subject vehicle and the curve point of interest at the time of curve speed warning.
LC Pass/fail variables	
$LatDist_{LCW}$	When there is a boundary line between the subject vehicle and the principal other vehicle: $LatDist_{LCW}$ is the lateral distance from the closest edge of the lane-boundary of interest and the corresponding outside edge of the front wheel of the subject vehicle at the time of the Lane Change Warning (a negative number means the front wheel passed over the closest edge of the line). The equation for deriving $LatDist_{LCW}$ is: $LatDist_{LCW} = (Lw_{SV} / 2) – abs(LOff_{SV}) – (Tw_{SV} / 2)$ Where: Tw_{SV} = SV track width, Lw_{SV} = SV Lane width, $LOff_{SV}$ = SV Lane offset, For LV, SV track width of 1.8 m will be used.
$LatDist2_{LCW}$	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 measured at the SV front wheel.

$LatDist_{ss}$	$LatDist_{ss}$ is the steady state lateral distance from the closest edge of the lane boundary of interest and the corresponding outside edge of the front wheel of the subject vehicle, measured at the initiation of the drift. LatDistss establishes the steady state initial lateral distance before a significant steering angle change towards the boundary is detected.
$LatDist2_{ss}$	$LatDist2_{ss}$ is the steady state lateral distance between the SV and the POV, measured where the common lane boundary ends for the merge test. This value establishes the steady state initial lateral distance between SV and POV during the merge test.

*MT Pass/fail variables**

*same as above at the time of each subsystem warning, respectively.

1.4. Criteria for evaluating the 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.

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, given below, that are assumed for each of the tests included in this document. 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).

1.5.1. 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
2. Good atmospheric visibility—defined as an absence of fog and the ability to see clearly for more than 5000 meters.
3. Calm wind conditions—defined as 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).

1.5.2. Pavement quality and type

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

1.5.3. Subject vehicle

The Subject Vehicle (SV) for these tests is defined as a small to mid-range passenger car. 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.

1.5.4. Subject vehicle driver selected IVBSS settings

It is assumed that the IVBSS driver preference is set to the nominal setting for each test unless otherwise specified by the procedure.

1.5.5. IVBSS Adaptive Learning

It is assumed that the IVBSS adaptive learning, including the following is disabled.

- All False Alarm Data Bases
- Driver Behavior Models

1.5.6. 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.

1.5.7. Principal other vehicle

In the tests outlined below, the principal other vehicle (POV or P1) is a small to mid-range passenger car, unless otherwise specified in the test description. 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 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.

1.5.8. Secondary other vehicle

When a secondary other vehicle is needed (POV2 or P2), it shall be a small to mid-range passenger car, unless otherwise specified in the test. The vehicle should be relatively new with good brakes and tires and be equipped with conventional cruise control for consistent speed control.

Additionally, the secondary other vehicle should be equipped with 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.

1.5.9. 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 0.1 km^{-1} and flat is a grade of less than 0.1 percent (Kiefer et al., 1999).

1.5.10. Lane geometry and boundary types

Unless specified in a test, the tests will be conducted using a roadway with two 12 ft (3.66 m) – 15 ft (4.57 m) lanes separated with a dashed or solid white line. The outer boundaries of each lane should be marked with solid white lane boundary markers.

1.5.11. 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) – Light Vehicle Platform, March 17, 2008, Prepared by UMTRI, Visteon, and Cognex for U.S. DOT

2. System Performance Guidelines for a Prototype Integrated Vehicle-Based Safety System (IVBSS) – Light Vehicle Platform, March 17, 2008, Prepared by UMTRI, Visteon, and Cognex for U.S. DOT

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 (FCW) - Rear-end Tests (Required Test)

The tests detailed in this section are longitudinal and involve the SV approaching a slower, slowing or stopped POV from behind.

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

This test is intended to verify the appropriateness of an FCW when the SV approaches a slower moving POV (P1) from behind in the center of the same lane. In this test the SV and P1 are each traveling at constant speeds with a speed differential between the SV and P1 of at least 8.9 m/s (20 mph).

2.1.1. Test Overview and Concept

Figure 2 shows the initial, transitional and final conditions for the rear-end conflict with a constant speed POV (P1). 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 P1 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 upon a warning or when the SV driver senses a crash is imminent, the conflict is resolved by the SV slowing and moving laterally to the left to avoid a crash.

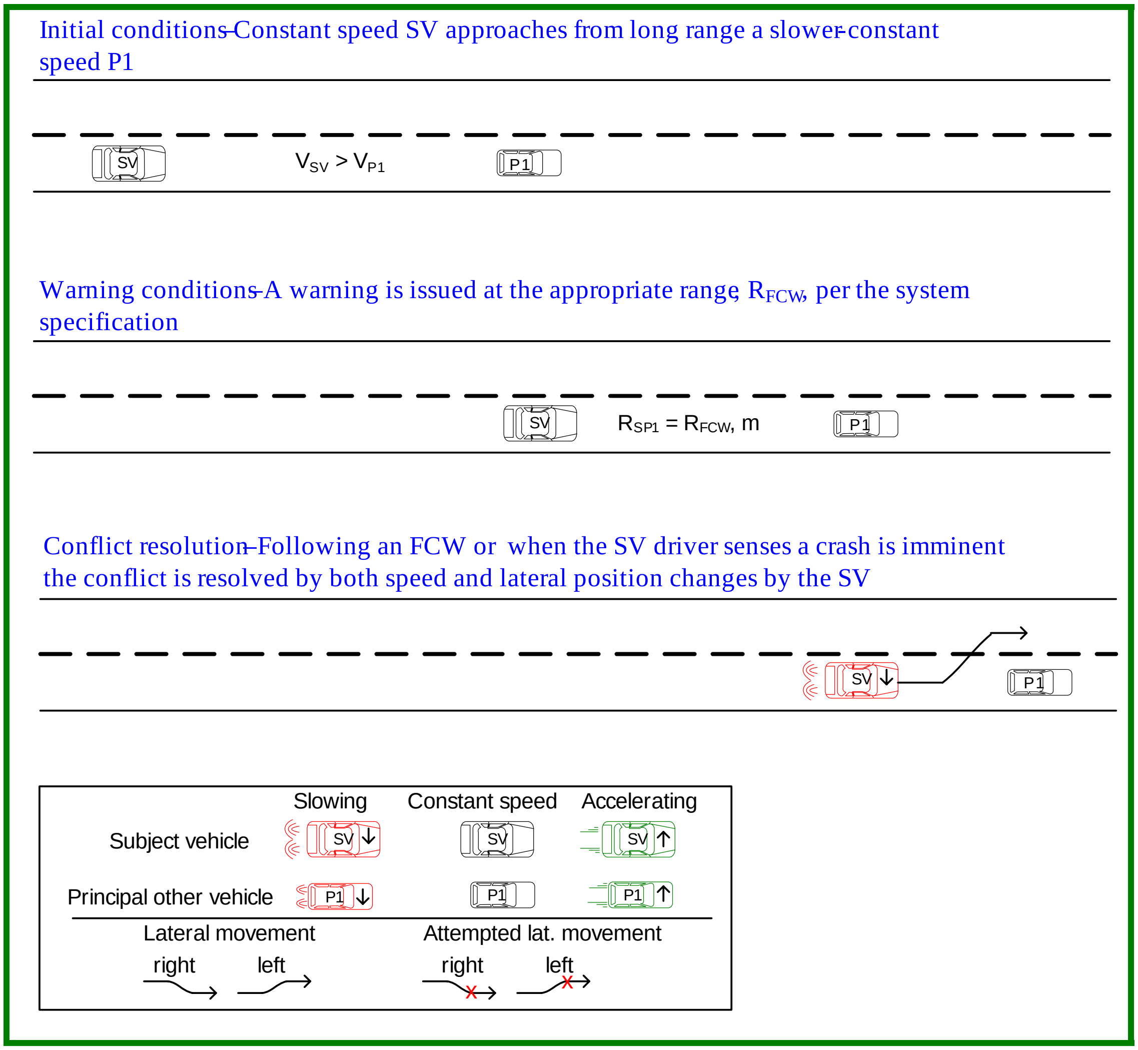

Figure 2: Initial and final conditions for rear-end conflict with a slower constant speed POV (P1).

2.1.2. Performance measures and evaluation criteria

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 5.

Table 5. Run validity criteria for rear-end with a slower constant speed P1

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	22.4 (50 mph)	± 1.12 (2.5 mph)
V_{P1}, m/s	11.2 (25 mph)	± .56 (1.3 mph)
$Rdot_{SP1}$, m/s	-11.2	± 1.68
D1 (Initial R_{SP1}), m	200	N/A
D2, m	150	N/A

Table 6 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 6. Pass/Fail Criteria for rear-end with a slower constant speed POV[3]

Alert Range	R_{FCW}, *m*
Maximum	
Nominal	
Minimum	

2.1.3. Track Setup and Driving Instructions

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 track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix.

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

Figure 3 below is the suggested track layout for conducting this test.

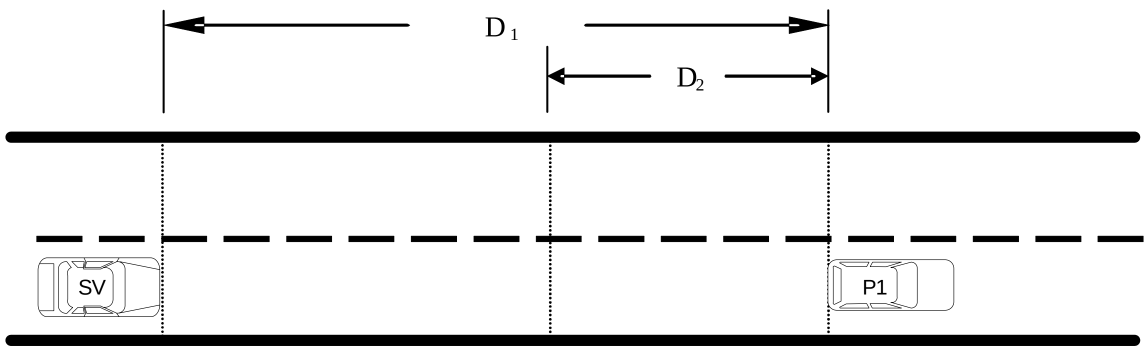

Figure 3: Track Layout for rear-end conflict with a slower (constant speed) P1

All specific speeds and initial conditions for this test are given in Table 5. Referring to Figure 3, both SV and P1 start in the lane 5 of the skid pad track with an initial gap of D1 (200 m). Both SV and P1 should reach their respective steady state constant speeds when the range between SV and P1 is D2 (150 m).

SV Driving Instructions:

1. SV gives signal to P1 to start the test.
2. SV accelerates to 22.4 m/s (50 mph) and engages the cruise control.
3. When the required crash alert occurs or when the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
4. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 11.2 m/s (25 mph) and engages the cruise control.
2. P1 maintains its lane and speed throughout the test.
3. At the completion of test P1 stops and gets ready for the next run.

2.1.4. 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. RE-2 Rear-end conflict with a modestly slowing POV (low POV deceleration/low time gap) (Required Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches from behind (with a short headway time gap), a modestly slowing POV (P1) in the center of the same lane.

This test determines whether the collision alert for the IVBSS occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the warning system to issue timely warnings in response to a modestly decelerating vehicle in front of the subject vehicle.

2.2.1. Test Overview and Concept

This test begins with the subject vehicle (SV) traveling on a straight road at 20.1 m/s (45 mph). Ahead of the subject vehicle, in the same lane at a short headway time gap of about 1.5 sec, is a principal other vehicle, P1, traveling at the same speed of 20.1 m/s (45 mph), which starts slowing down modestly at about 2.0 m/sec^2 (0.2 g).

Figure 4 shows the initial, transitional and final conditions for the rear-end conflict with a modestly slowing POV and a short time gap for the FCW subsystem. The initial conditions are in the top of the figure and show a constant speed SV following a same-speed POV at a predetermined short headway time gap. The next element of the figure shows POV slowing at a steady-state rate of less than 2.0 m/sec^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 or when the SV driver senses a crash is imminent, the conflict is resolved by the SV slowing and moving laterally to the left to avoid a crash.

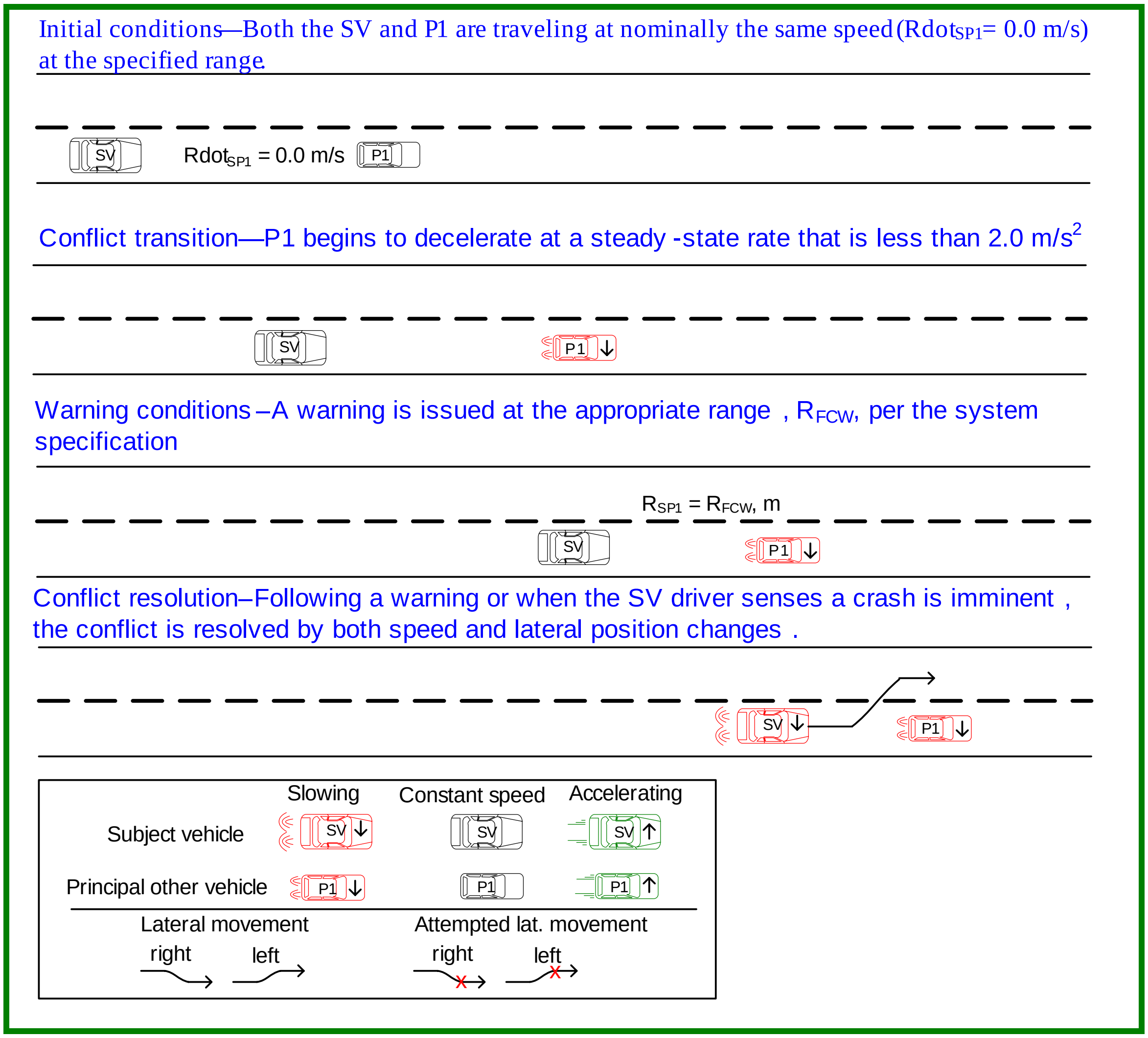

Figure 4: Initial and final conditions for rear-end conflict with a modestly slowing POV (low POV deceleration/low time gap).

2.2.2. Performance measures and evaluation criteria

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.

Table 7. Run validity criteria for RE conflict with a modestly slowing POV (low deceleration/low time gap)

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
$Rdot_{SP1}$ (Steady State), m/s	0	± 2.0
D1 (Initial R_{SP1}), m	40	N/A
D2 ($(R_{SP1})_{SS}$), m	30	± 3.0
$Rdot_{SP1}$ (at alert time), m/s	-5.0	N/A
A_{xP1}, m/sec^2	- 2.0 (.2g)	± 0.5

Table 8 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 8. Pass/Fail Criteria for RE conflict with a modestly slowing POV (low deceleration/low time gap)[4]

Alert Range	*R_{FCW}, m*
Maximum	
Nominal	
Minimum	

2.2.3. Track Setup and Driving Instructions

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 track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix.

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

Figure 5 below is the suggested track layout for conducting this test.

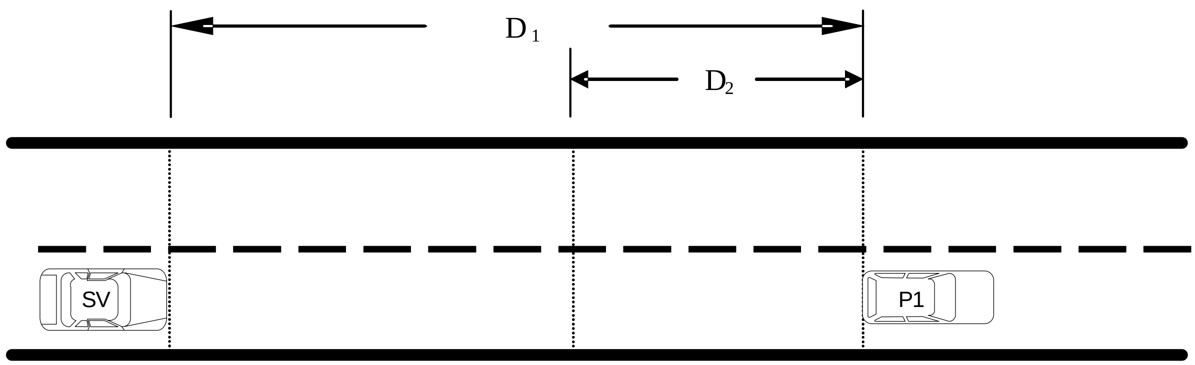

Figure 5: Track Layout for rear-end conflict with a modestly slowing P1 (low P1 deceleration/low time gap)

All specific speeds and initial conditions for this test are given in Table 7. Referring to Figure 5, both SV and P1 start in the lane 5 of the skid pad track with an initial gap of D1 (40 m). Both SV and P1 should reach their respective steady state constant speeds and a constant headway, when the range between SV and P1 is D2 (30 m).

SV Driving Instructions:

1. SV gives signal to P1 to start the test.
2. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
3. SV driver monitors the range displayed on the monitor and slowly creeps upon the P1 vehicle till he reaches a headway gap of 30 m.
4. After reaching this steady state headway gap of 30 m, and maintaining this gap for about 2 seconds, SV driver signals the P1 driver to start decelerating at about 2 m/sec^2 (.2g).
5. When the required crash alert occurs or when the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
6. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
2. After receiving the signal from SV to start decelerating, P1 driver applies and maintains a steady state brake pressure to achieve a constant low-level deceleration of about 2 m/sec^2 (0.2g). P1 driver could use the decelerometer mounted in the vehicle to gauge vehicle's deceleration.
3. At the completion of test P1 stops and gets ready for the next run.

2.2.4. 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. RE-3 Rear-end conflict with an aggressively slowing POV (high POV deceleration/high time gap) (Required Test)

This test is intended to verify the appropriateness of an FCW when the SV approaches from behind (with a large headway time gap), an aggressively slowing POV (P1) in the center of the same lane.

This test determines whether the collision alert for the IVBSS occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the warning system to issue timely warnings in response to an aggressively decelerating vehicle in front of the subject vehicle.

2.3.1. Test Overview and Concept

This test begins with the subject vehicle (SV) traveling on a straight road at 20.1 m/s (45 mph). Ahead of the subject vehicle, in the same lane at a large headway time gap of about 3.0 sec, is principal other vehicle, P1, traveling at the same speed of 20.1 m/s (45 mph), which starts slowing down aggressively at about 3.5 m/sec^2 (0.35 g).

Figure 6 shows the initial, transitional and final conditions for the rear-end conflict with an aggressively slowing POV and a large time gap for the FCW subsystem. The initial conditions are in the top of the figure and show a constant speed SV following a same-speed POV at a predetermined large headway time gap. The next element of the figure shows POV slowing at a steady-state rate of more than 3.5 m/s^2. Next, the figure illustrates that a warning should occur when the SV reaches 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, the conflict is resolved by the SV slowing and moving laterally to the left to avoid a crash.

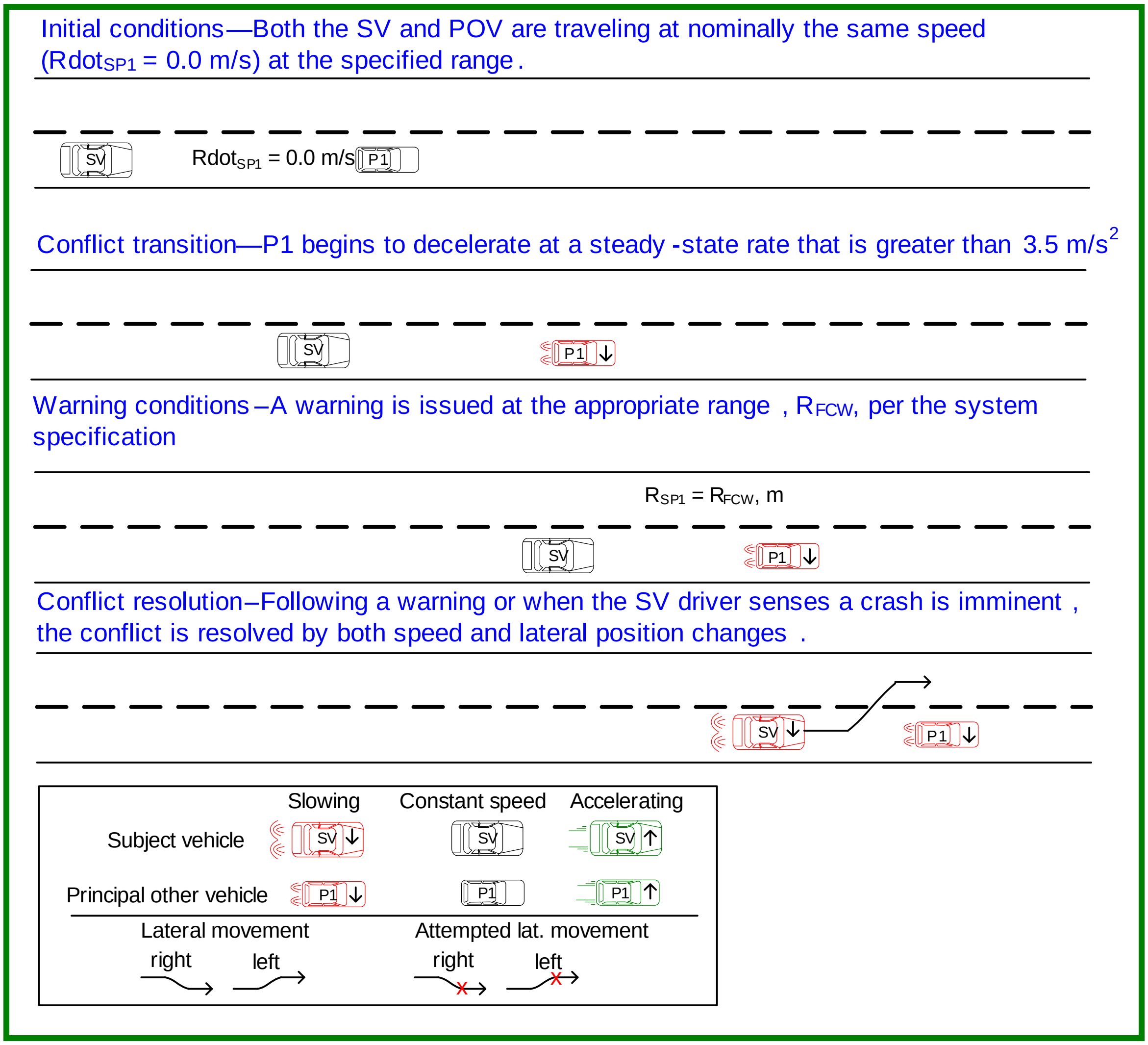

Figure 6: Initial and final conditions for rear-end conflict with an aggressively slowing POV (high POV deceleration/high time gap).

2.3.2. Performance measures and evaluation criteria

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.

Table 9. Run validity criteria for rear-end conflict with an aggressively slowing POV (high deceleration/high time gap)

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
$Rdot_{SP1}$, m/s	0	± 2.0
D1 (Initial R_{SP1}), m	80	N/A

D2 ($(R_{SP1})_{SS}$), m	60	± 5.0
A_{xP1}, m/sec^2	- 3.5 (.35 g)	± 1.0 or (-0.2, +0.8)

Table 10 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 10. Pass/Fail Criteria for rear-end conflict with an aggressively slowing POV (high deceleration/high time gap)[5]

Alert Range	*R_{FCW}, m*
Maximum	
Nominal	
Minimum	

2.3.3. Track Setup and Driving Instructions

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 track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix.

Figure 7 below is the suggested track layout for conducting this test.

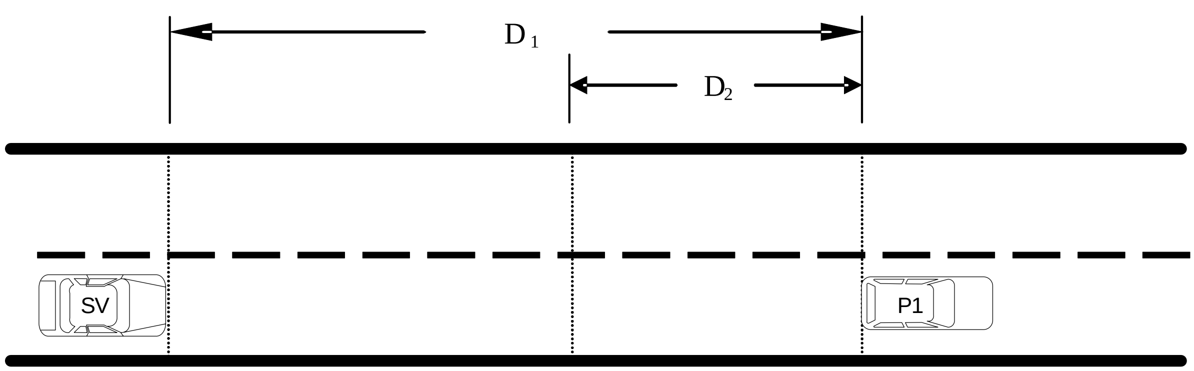

Figure 7: Track Layout for rear-end conflict with an aggressively slowing POV (high POV deceleration/high time gap)

All specific speeds and initial conditions for this test are given in Table 9. Referring to Figure 7, both SV and P1 start in the lane 5 of the skid pad track with an initial gap of D1 (80 m). Both SV and P1 should reach

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

their respective steady state constant speeds and a constant headway gap, when the range between SV and P1 is D2 (60 m).

SV Driving Instructions:

1. SV gives signal to P1 to start the test.
2. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
3. SV driver monitors the range displayed on the monitor and slowly creeps upon the P1 vehicle till he reaches a constant headway gap of 60 m.
4. After reaching this steady state headway gap of 60 m and maintaining this gap for about 2 seconds, SV driver signals the P1 driver to start decelerating at about 3.5 m/sec^2 (.35 g).
5. When the required crash alert occurs or when the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
6. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
2. After receiving the signal from SV to start decelerating, P1 driver applies and maintains a steady state brake pressure to achieve a constant high-level deceleration of about 3.5 m/sec^2 (0.35 g). P1 driver could use the decelerometer mounted in the vehicle to gauge vehicle’s deceleration.
3. At the completion of test P1 stops and gets ready for the next run.

2.3.4. Exceptions to the standard test conditions

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

2.4. RE-4 Rear End conflict with Stopped POV at 45 mph (Required Test)

The test determines whether the countermeasure’s required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to issue timely warnings in response to a stopped vehicle approached at moderate speed.

2.4.1. Test Overview and Concept

This test begins with the subject vehicle (SV) traveling on a straight road at 20.1 m/s (45 mph). Ahead of the SV, in the same lane, is a single principal other vehicle, P1 stopped in the lane of travel.

Figure 8 shows the initial, transitional and final conditions for the rear-end conflict with a stopped P1. The initial conditions are in the top of the figure and show a constant speed SV approaching from long range a stopped P1. 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, the conflict is resolved by the SV slowing and moving laterally to the left to avoid a crash.

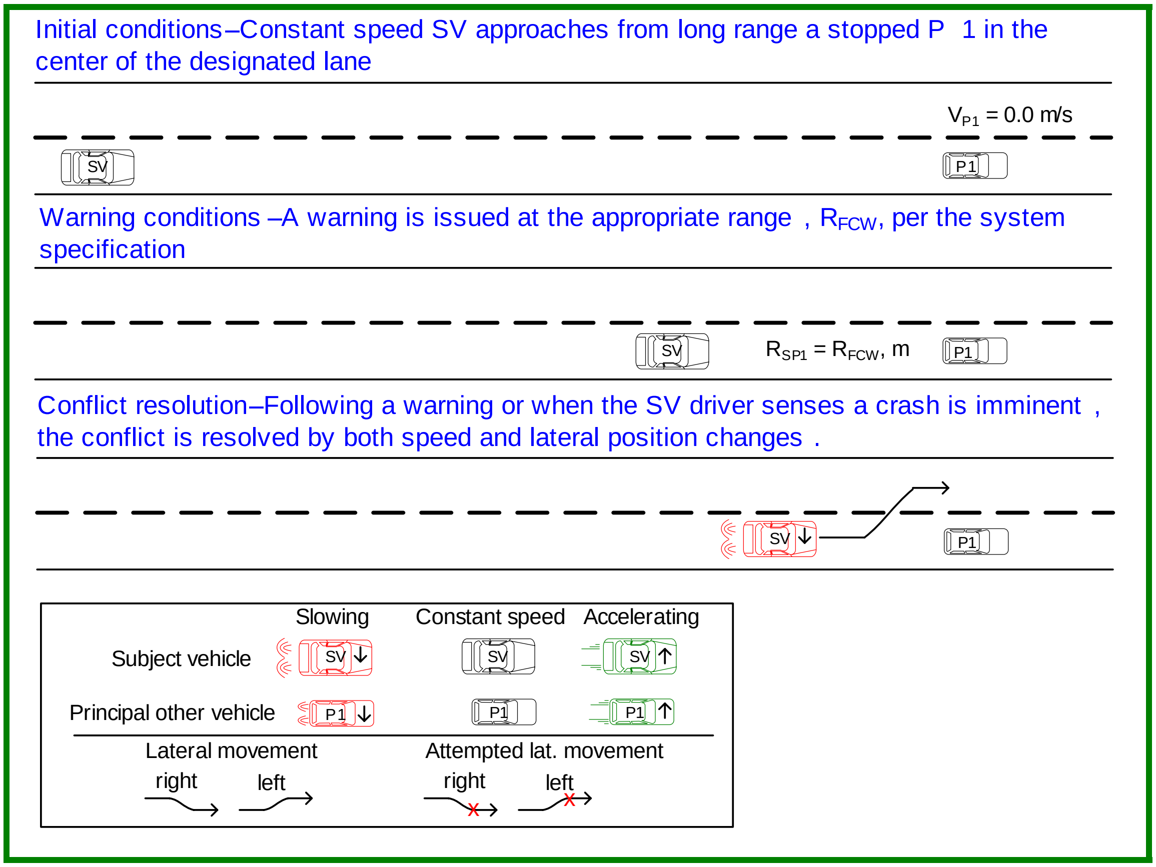

Figure 8: Initial and final conditions for rear-end conflict with stopped POV at 45 mph.

2.4.2. Performance measures and evaluation criteria

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 12.

Table 12. Run validity criteria for rear-end conflict with a stopped P1 at 45 mph

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	0	N/A
$Rdot_{SP1}$, m/s	-20.1	± 1.0
D1 (Initial R_{SP1}), m	250	N/A
D2 ((Rsp1)ss), m	150	N/A

Table 13 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 13. Pass/Fail Criteria for rear-end conflict with stopped POV at 45 mph[6]

Alert Range	*R_{FCW}, m*
Maximum	
Nominal	
Minimum	

2.4.3. Track Setup and Driving Instructions

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 track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix.

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

Figure 9 below is the suggested track layout for conducting this test.

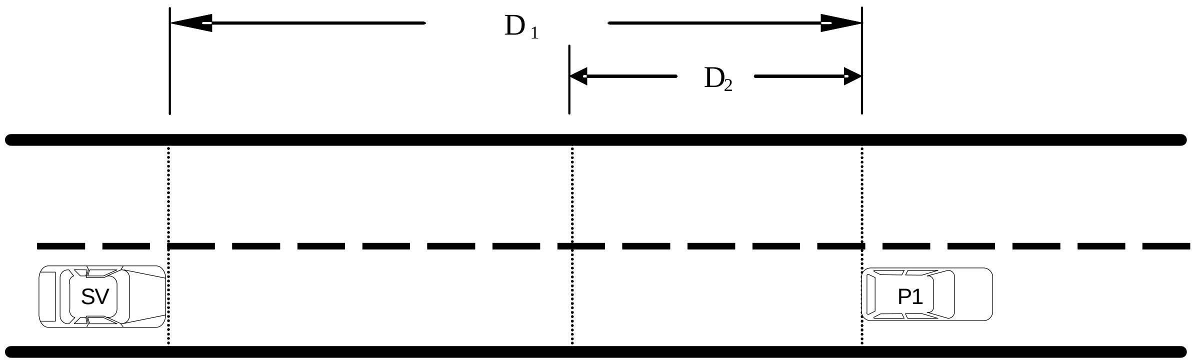

Figure 9: Track Layout for rear-end conflict with stopped P1 at 45 mph

All specific speeds and initial conditions for this test are given in Table 12. Referring to Figure 9, both SV and P1 are stopped in the lane 5 of the skid pad track with an initial gap of D1 (250 m). SV should reach its steady state constant speed when the range between SV and P1 is D2 (150 m).

SV Driving Instructions:

1. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
2. When the required crash alert occurs or when the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
3. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. P1 remains stopped in its designated lane 5.
2. The driver of P1 stays out of his vehicle during the entire test sequence for all the test runs.

2.4.4. Exceptions to the standard test conditions

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

2.5. RE-5 Rear End conflict with Stopped POV at 30 mph (Required Test)

The test determines whether the countermeasure's required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to issue timely warnings in response to a stopped vehicle approached at slow speed.

2.5.1. Test Overview and Concept

This test begins with the subject vehicle (SV) traveling on a straight road at 13.4 m/s (30 mph). Ahead of the SV, in the same lane, is a single principal other vehicle, P1 stopped in the lane of travel.

Figure 10 shows the initial, transitional and final conditions for the rear-end conflict with a stopped P1. The initial conditions are in the top of the figure and show a constant speed SV approaching from long range a stopped P1. 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, the conflict is resolved by the SV slowing and moving laterally to the left to avoid a crash.

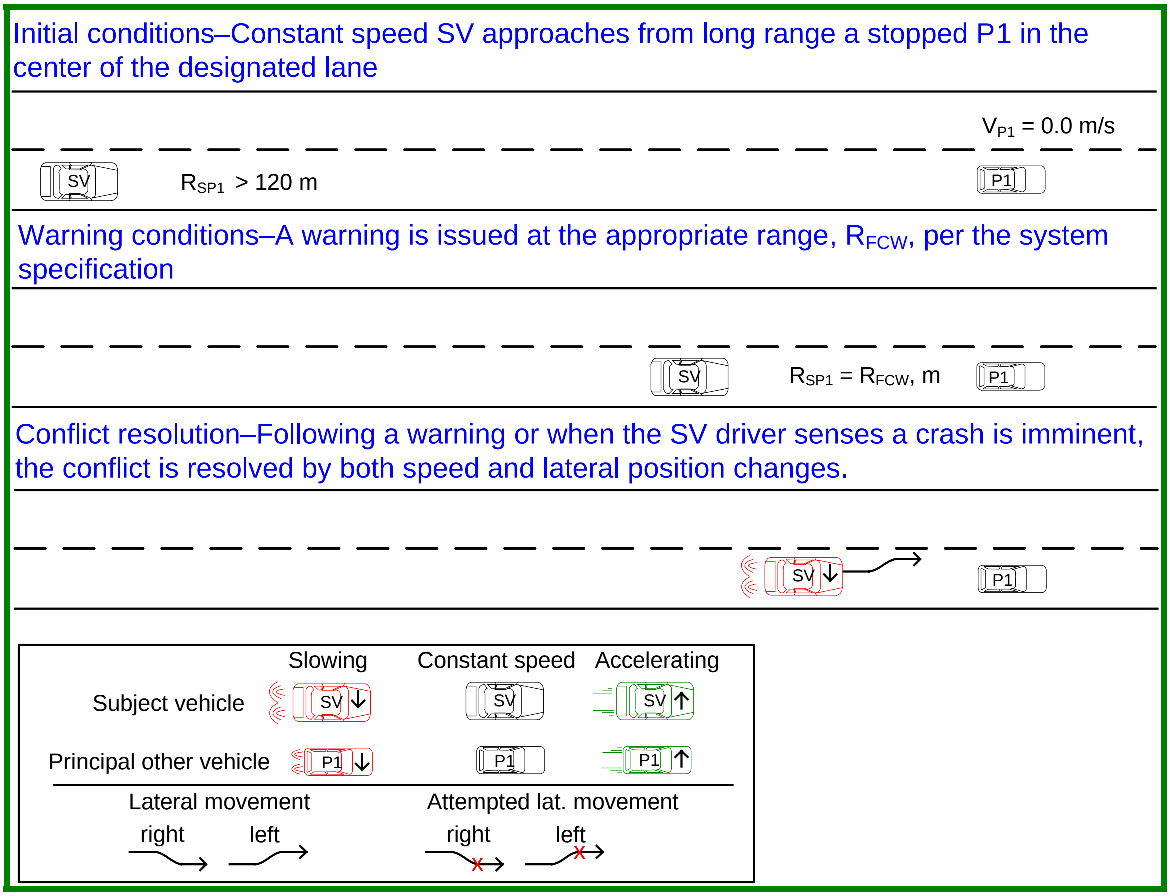

Figure 10: Initial and final conditions for rear-end conflict with stopped POV at 30 mph.

2.5.2. Performance measures and evaluation criteria

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 12.

Table 14. Run validity criteria for rear-end conflict with a stopped P1 at 30 mph

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	13.4 (30 mph)	± 0.7 (1.5 mph)
V_{P1}, m/s	0	N/A
$Rdot_{SP1}$, m/s	-13.4	± 0.7
D1 (Initial R_{SP1}), m	250	N/A
D2 ((Rsp1)ss), m	150	N/A

The purpose of running an Engineering test is to characterize system performance and determine system limitations. This also involves executing the test multiple times and ensuring that the system performance is repeatable and robust. Table 15 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 15. Pass/Fail Criteria for rear-end conflict with stopped POV at 30 mph[7]

Alert Range	R_{FCW}, *m*
Maximum	
Nominal	
Minimum	

2.5.3. Track Setup and Driving Instructions

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 track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix.

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

Figure 12 below is the suggested track layout for conducting this test.

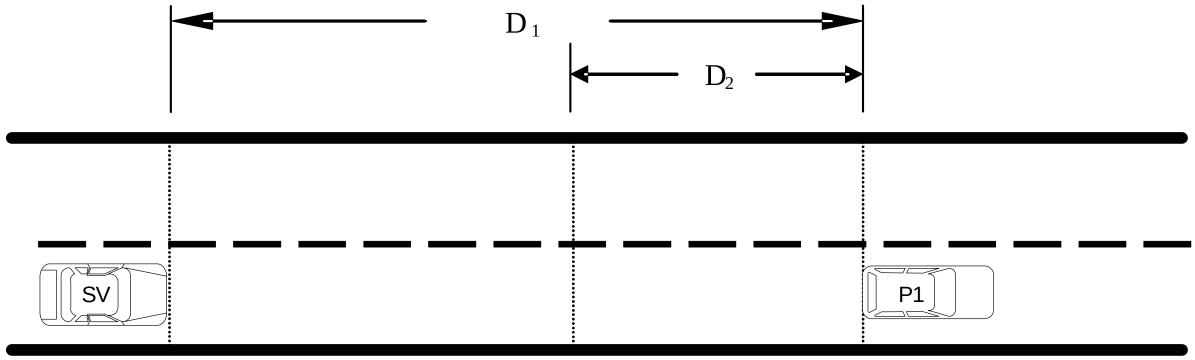

Figure 12: Track Layout for rear-end conflict with stopped P1 at 30 mph

All specific speeds and initial conditions for this test are given in Table 12. Referring to Figure 12, both SV and P1 are stopped in the lane 5 of the skid pad track with an initial gap of D1 (250 m). SV should reach its steady state constant speed when the range between SV and P1 is D2 (150 m).

SV Driving Instructions:

1. SV accelerates to 13.4 m/s (30 mph) and engages the cruise control at 13.4 m/s (30 mph).
2. When the required crash alert occurs or when the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
3. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. P1 remains stopped in its designated lane 5.
2. The driver of P1 stays out of his vehicle during the entire test sequence for all the test runs.

2.5.4. 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. RE-6 Rear End conflict with slower POV after a lane change by 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 to approach from behind a moderately slower moving P1.

The lane change by the SV should be completed when the time to collision (TTC) with P1 is about 5-6 seconds.

2.6.1. Test Overview and Concept

This test begins with the SV traveling at 20.1 m/s (45 mph) on a straight, flat road in the left lane of a divided highway. Ahead of the SV, in the right lane, is the P1 vehicle going at a lower speed.

Figure 13 shows the initial, transitional and final conditions for the rear-end conflict with a slower P1 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 P1 that is traveling in an adjacent lane to the right of the SV. Then, at a predetermined range, the driver of the SV changes lanes to the right, to be behind P1. 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, the conflict is resolved by the SV slowing and moving laterally to the left.

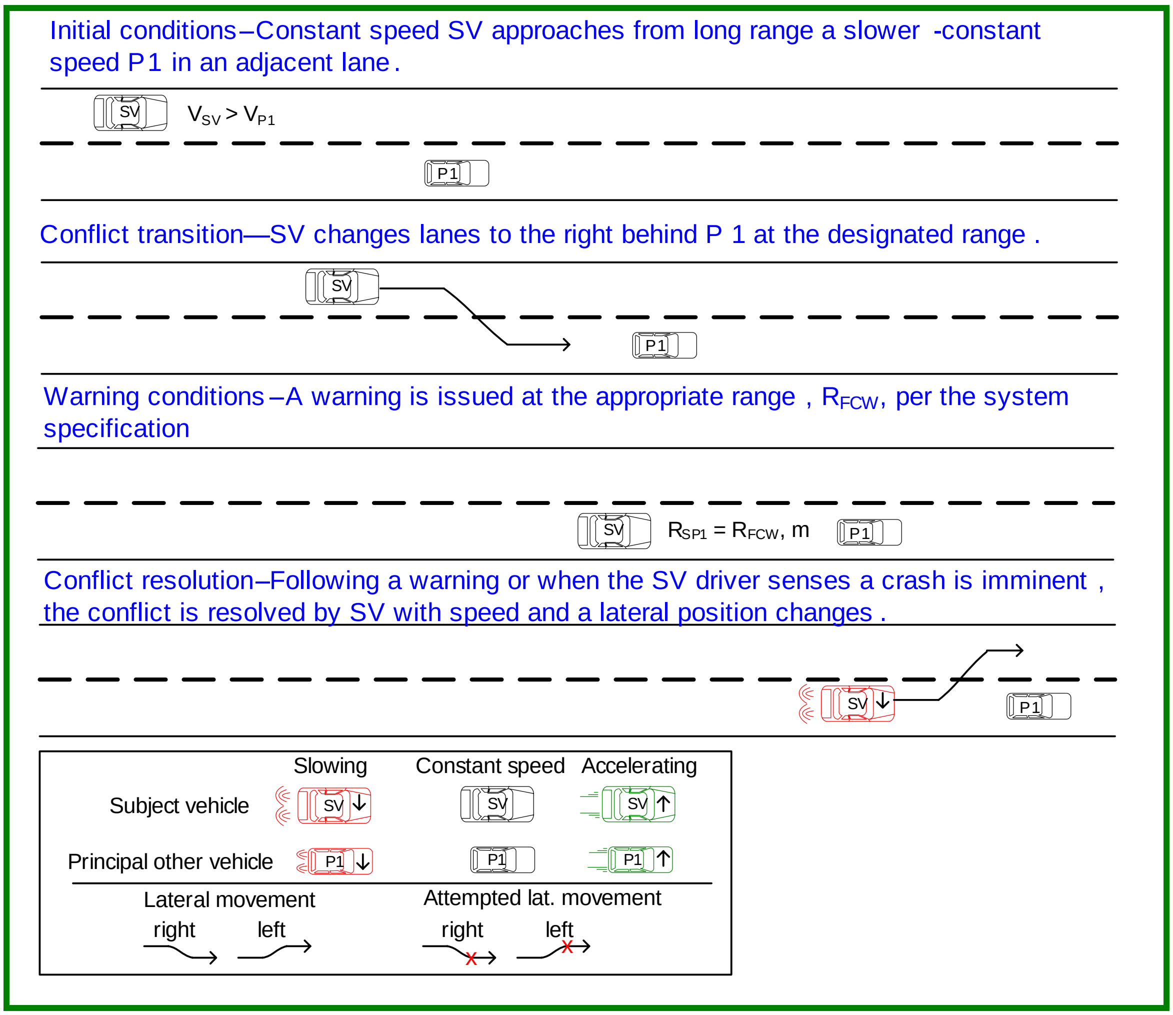

Figure 13: Initial and final conditions for rear-end conflict with slower P1 after a lane change by SV.

2.6.2. Performance measures and evaluation criteria

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 16.

Table 16. Run validity criteria for rear-end conflict with slower POV after a lane change by SV

Parameter, Unit	*Target Value*	*Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	15.7 (35 mph)	± .8 (1.75 mph)
$Rdot_{SP1}$, m/s	-4.5	± 1.8
$LatV_{SV}$, m/s	0.4	± .15
D1 ((Rsp1)ss), m	100 m	N/A
D2 (R_{SP1} at start of LC), m	50 m	± 5.0
D3 (R_{SP1} at LC completion), m	30 m	± 5.0

The purpose of running an Engineering test is to characterize system performance and determine system limitations. This also involves executing the test multiple times and ensuring that the system performance is repeatable and robust. Table 17 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 17. Pass/Fail Criteria for rear-end conflict with slower POV after a lane change by SV[8]

Alert Range	*R_{FCW}, m*
Maximum	
Nominal	
Minimum	

2.6.3. Track Setup and Driving Instructions

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 track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix.

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

Figure 14 below is the suggested track layout for conducting this test.

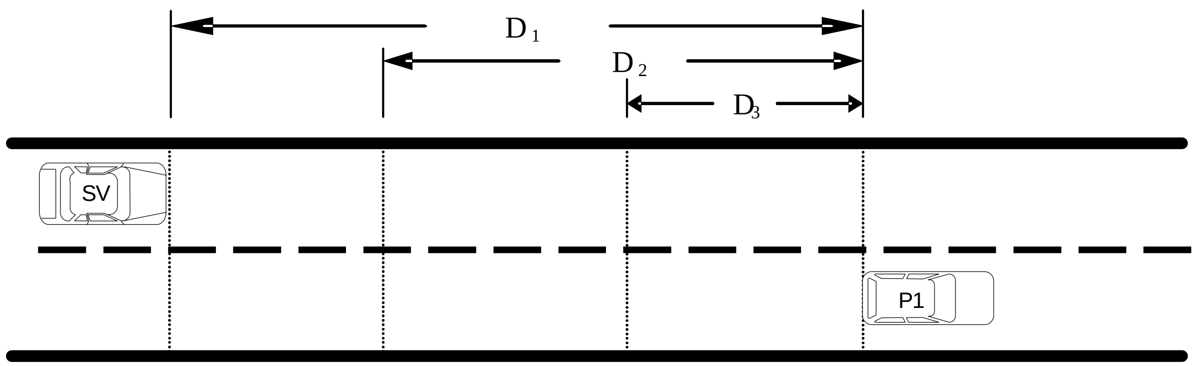

Figure 14: Track Layout for rear-end conflict with slower P1 after a lance change by SV

All specific speeds and initial conditions for this test are given in Table 16. Referring to Figure 14, both SV and P1 start in lane 6 and lane 5 respectively of the skid pad track with an initial gap of 150 m. Both SV and P1 should reach their respective steady state constant speed by the time the range between SV and P1 is D1 (100 m). The lane change by SV should be initiated when the range between SV and P1 is D2 (50 m).

SV Driving Instructions:

1. SV gives signal to P1 to start the test.
2. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
3. SV driver initiates a slow lane change move (low lateral velocity of 0.25 m/s to 0.55 m/s) to the right adjacent lane, when SV is about D2 (50 m) behind the P1. This lane change position is to be determined by the SV driver based on his own judgment, however, he may get some help from another IVBSS equipped vehicle or IMS system in determining this position. The range displayed after completion of lane change should be about D3 (30 m).
4. When the required crash alert occurs or when the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
5. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 15.7 m/s (35 mph) and engages the cruise control at 15.7 m/s (35 mph).
2. P1 maintains its lane and speed throughout the test.
3. At the completion of test P1 stops and gets ready for the next run.

2.6.4. Exceptions to the standard test conditions

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

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

The test determines whether the countermeasure's required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to issue timely warnings in response to a stopped vehicle in a curve to see if the system is able to determine the stopped vehicle to be in the same lane and therefore a threat.

2.7.1. Test Overview and Concept

This test begins with the SV traveling at 13.4 m/s (30 mph) on a straight, flat road in the right lane of a track approaching a curve. Ahead of the SV, in the same lane on the approaching curve ahead, is a stopped P1 vehicle in the constant radius section of the curve.

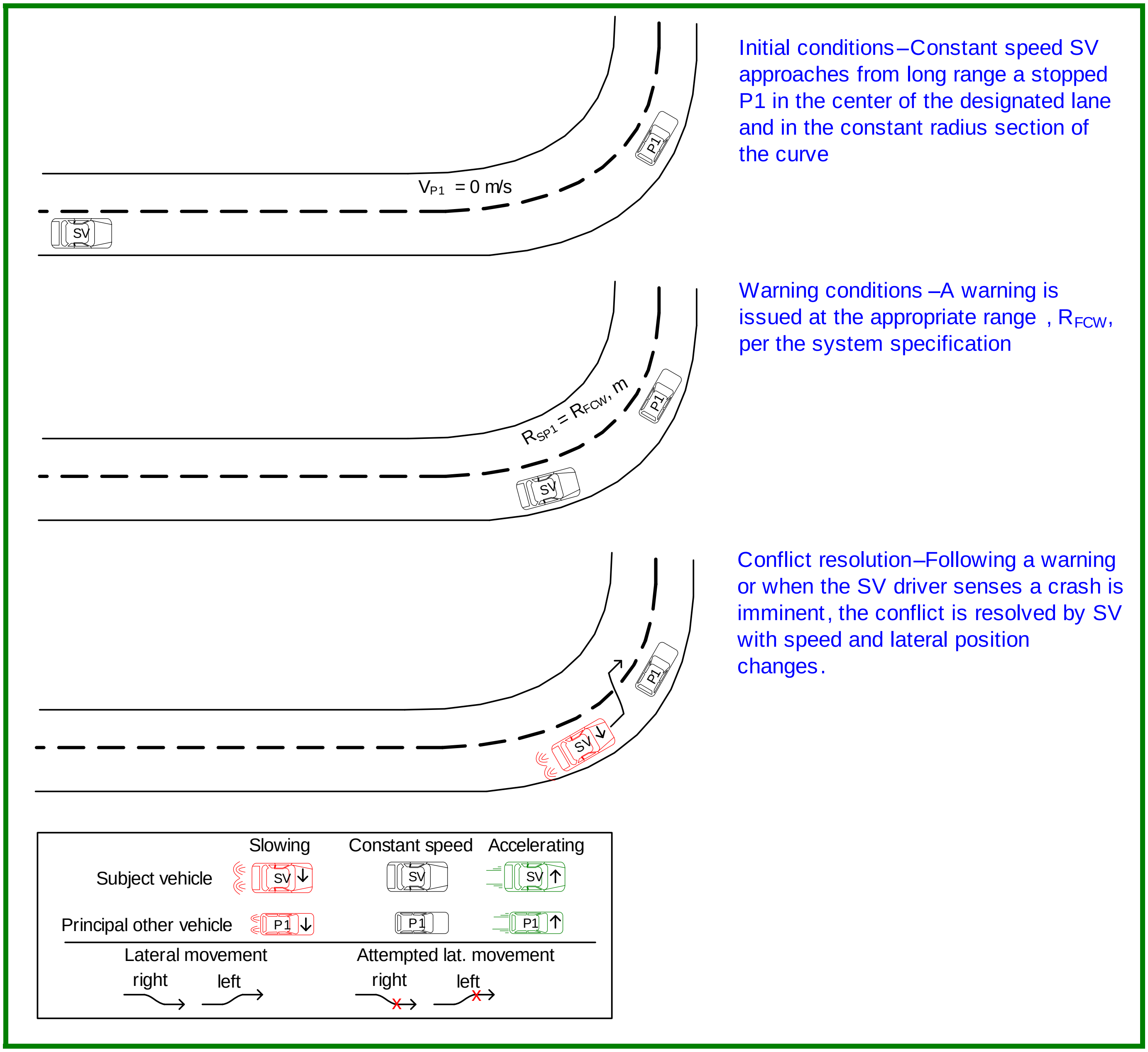

Figure 15: Initial and final conditions for rear-end conflict with stopped P1 in a curve.

2.7.2. Performance Measures and evaluation criteria

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 18.

Table 18. Run validity criteria for rear-end conflict with stopped POV in a curve

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	13.4 (30 mph)	± .7 (1.8 mph)
V_{P1}, m/s	0	N/A
$Rdot_{SP1}$, m/s	-13.4	± .7
Track Curve Radius (m)	300	± 30
D1 (Initial R_{SP1}), m	200	N/A
D2 ((Rsp1)ss), m	120	N/A

The purpose of running an Engineering test is to characterize system performance and determine system limitations. This also involves executing the test multiple times and ensuring that the system performance is repeatable and robust. Table 19 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 19. Pass/Fail Criteria for rear-end conflict with stopped POV in a curve[9]

Alert Range	*R_{FCW}, m*
Maximum	
Nominal	
Minimum	

2.7.3. Track Setup and Driving Instructions

The track to be used for this test is the Dana Track in Ottawa Lake, MI as shown in Figure A6 in Appendix.

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

Figure 16 below is the suggested track layout for conducting this test.

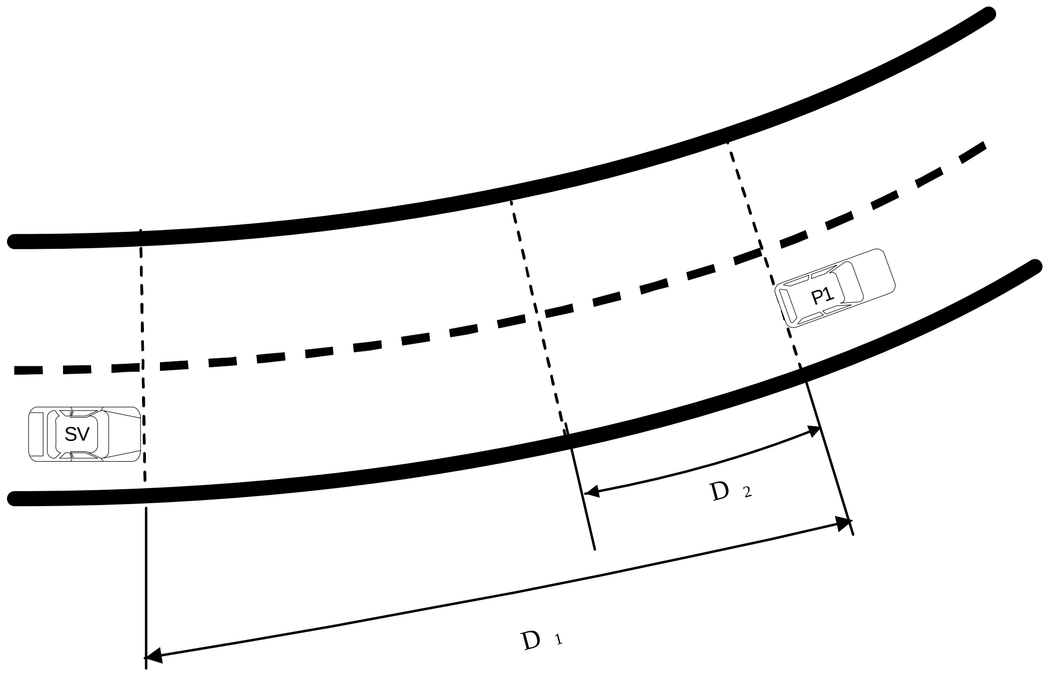

Figure 16: Track Layout for rear-end conflict with stopped P1 in a curve.

All specific speeds and initial conditions for this test are given in Table 18. Referring to Figure 16, P1 is stopped in the 1st lane of the curved section of the Dana Track and SV is stopped about D1 (200 m) behind this P1 vehicle in the same lane. SV should reach its steady state constant speed when the range between SV and P1 is D2 (120 m).

SV Driving Instructions:

1. SV accelerates to 13.4 m/s (30 mph) and engages the cruise control at 13.4 m/s (30 mph).
2. When the required crash alert occurs or when the SV driver senses a crash is imminent, SV steers and moves to the right adjacent lane to avoid striking P1.
3. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. P1 remains stopped in its designated lane.
2. The driver of P1 stays out of his vehicle during the entire test sequence for all the test runs.

2.7.4. 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. RE-8 Rear End conflict with slower POV in a Curve (Engineering Test)

The test determines whether the countermeasure's required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to issue timely warnings in response to a slower vehicle in a curve to see if the system is able to determine the slower vehicle to be in the same lane and therefore a threat.

2.8.1. Test Overview and Concept

This test as shown in Figure 17 begins with the SV traveling at 20.1 m/s (45 mph) on a straight, flat road in the right lane of a divided highway approaching a curve. Ahead of the SV, in the same lane on the curve ahead, is a slower moving P1 vehicle in the steady state portion of the curve.

Figure 17 shows the initial, transitional and final conditions for the rear-end conflict with a slower constant speed P1 in a curve. 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 P1 which is in the steady state portion of the curve, at a closing rate that exceeds 4.45 m/s (10 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 left to avoid a crash. If an FCW is not issued at the specified R_{FCW} then the test is aborted before the SV driver senses a crash is imminent.

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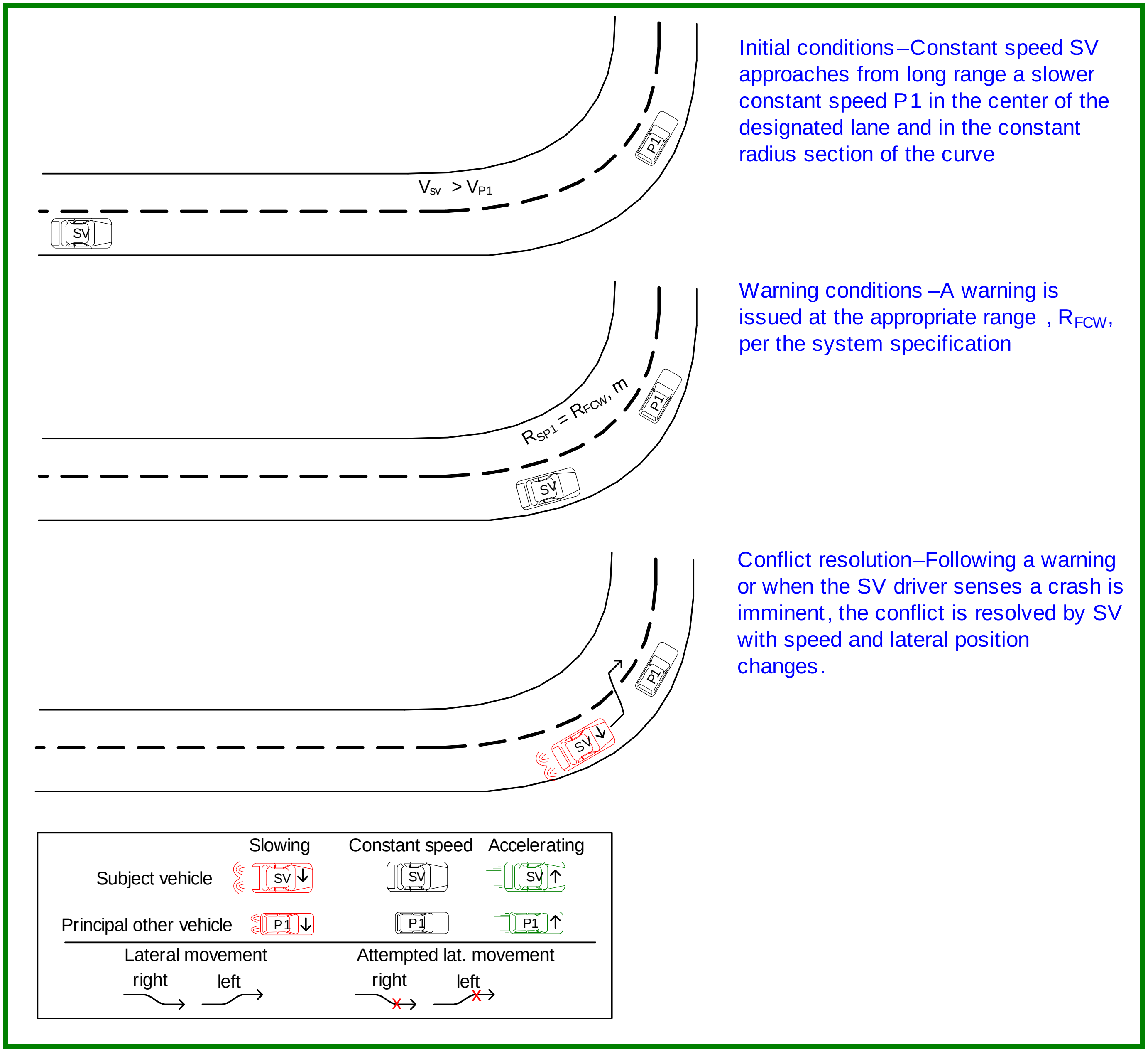

Figure 17: Initial and final conditions for rear-end conflict with a slower P1 in a curve.

2.8.2. Performance Measures and evaluation criteria

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.

Table 20. Run validity criteria for rear-end conflict with slower POV in a curve

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	15.7 (35 mph)	± 0.8 (1.8 mph)
$Rdot_{SP1}$, m/s	4.5 (10 mph)	± 1.8 (4.5 mph)
Track Curve Radius (m)	300	± 30
D1 (Initial R_{SP1}), m	150	N/A
D2 ((Rsp1)ss), m	100	N/A

The purpose of running an Engineering test is to characterize system performance and determine system limitations. This also involves executing the test multiple times and ensuring that the system performance is repeatable and robust. Table 21 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 21. Pass/Fail Criteria for rear-end conflict with slower POV in a curve[10]

Alert Range	*R_{FCW}, m*
Maximum	
Nominal	
Minimum	

2.8.3. Track Setup and Driving Instructions

The track to be used for this test is the Dana Track in Ottawa Lake, MI as shown in Figure A6 in Appendix.

Figure 18 below is the suggested track layout for conducting this test.

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

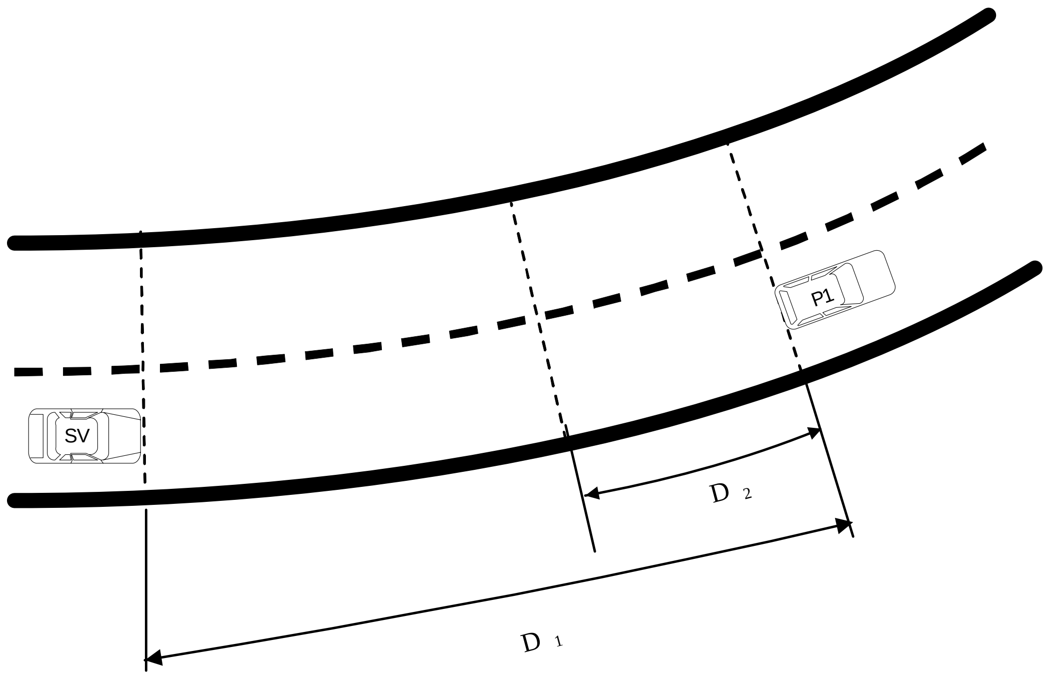

Figure 18: Track Layout for rear-end conflict with slower P1 in a curve.

All specific speeds and initial conditions for this test are given in Table 20.

Referring to Figure 18, both SV and P1 start in the middle lane of the Dana track with an initial gap of D1 (150 m). SV is placed in the middle of the straight section and P1 is placed D1 (150 m) ahead of SV. Both SV and P1 should reach their respective constant speeds by the time the range between SV and P1 is D2 (100 m). This steady state condition should be reached before SV enters the curved section of the track to ensure that the forward conflict with the slower POV occurs in the curved section of the track.

SV Driving Instruction:

1. SV gives signal to P1 to start the test.
2. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
3. When the required crash alert occurs or before the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1. The SV driver ensures that this conflict is occurring in the curved section of the track.
4. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 15.7 m/s (35 mph) and engages the cruise control at 15.7 m/s (35 mph).
2. P1 maintains its lane and speed throughout the test.
3. At the completion of test P1 stops and gets ready for the next run.

2.8.4. Exceptions to the standard test conditions

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

2.9. RE-9 Rear-end conflict with a slower constant speed motorcycle (P1) behind minivan (P2) (Engineering 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 larger vehicle (e.g. minivan). The test determines whether the countermeasure's required collision alert occurs at a range that is consistent with the collision alert onset timing requirements. This test especially explores the ability of the countermeasure to detect smaller in-path vehicle near larger vehicles and issue timely warnings.

2.9.1. Test Overview and Concept

This test begins with the SV traveling at 15.7 m/s (35 mph) on a straight, flat, two-lane road. Ahead of the SV in same lane is a motorcycle traveling at a slower speed. Figure 19 shows the initial, transitional and final conditions of the rear-end conflict with constant speed motorcycle behind a larger vehicle.

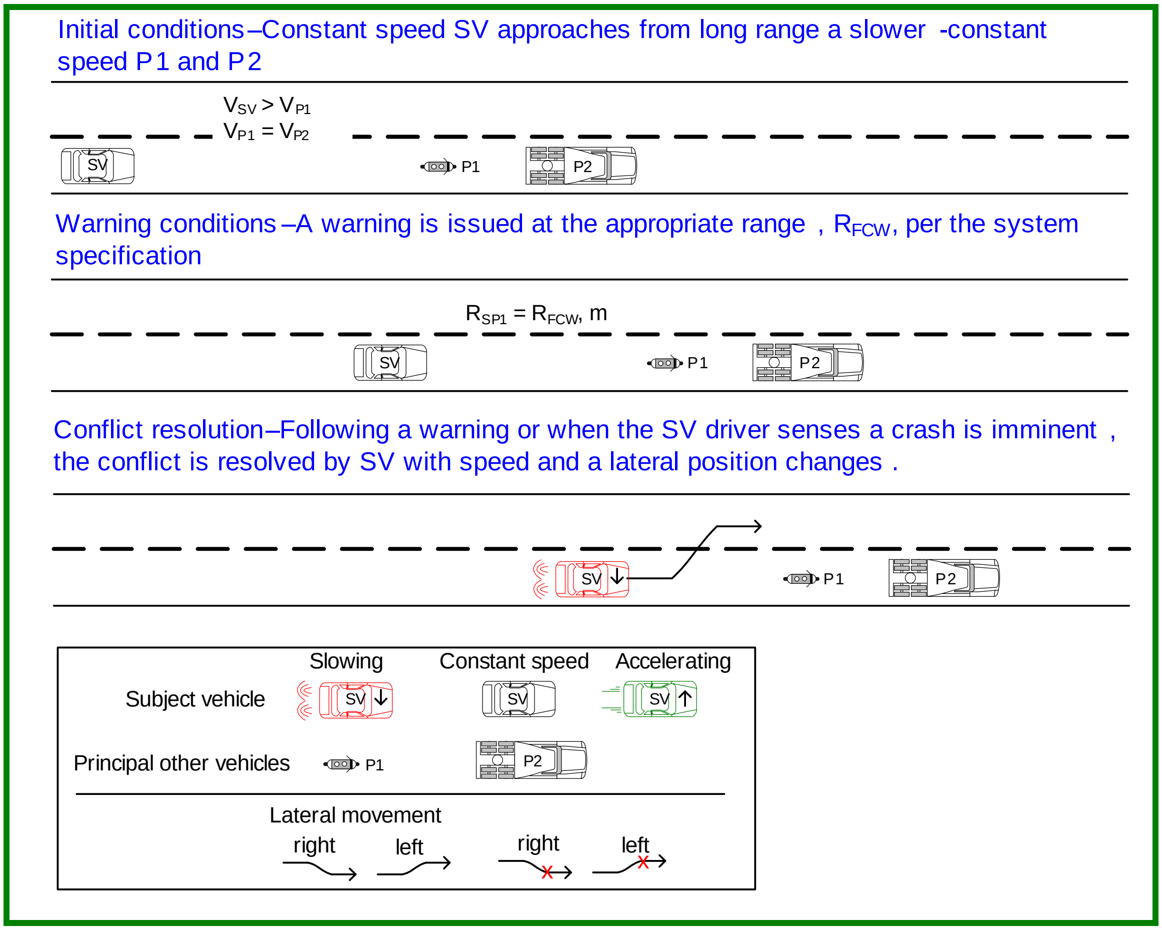

Figure 19: Initial and final conditions for rear-end conflict with constant speed motorcycle (P1) behind a minivan (P2).

2.9.2. Performance Measures and evaluation criteria

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

Table 22. Run validity criteria for rear-end conflict with constant speed motorcycle (P1) behind a minivan (P2).

Parameter, Unit	*Target Value*	*Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	11.2 (25 mph)	± 0.9 (2.0 mph)
V_{P2}, m/s	11.2 (25 mph)	± 0.6 (1.3 mph)
$Rdot_{SP1}$, m/s	-8.9	± 1.9
D1 (Initial R_{SP1}), m	200	N/A
D2 ((Rsp1)ss), m	150	N/A
D3 (Gap between P1 and P2), m	20	N/A

The purpose of running an Engineering test is to characterize system performance and determine system limitations. This also involves executing the test multiple times and ensuring that the system performance is repeatable and robust. Table 23 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 23. Pass/Fail Criteria for rear-end conflict with constant speed motorcycle (P1) behind a minivan (P2).[11]

Alert Range	*R_{FCW}, m*
Maximum	
Nominal	
Minimum	

2.9.3. Track Setup and Driving Instructions

The track to be used for this test is the Dana Track in Ottawa Lake, MI as shown in Figure A6 in Appendix.

Figure 20 below is the suggested track layout for conducting this test.

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

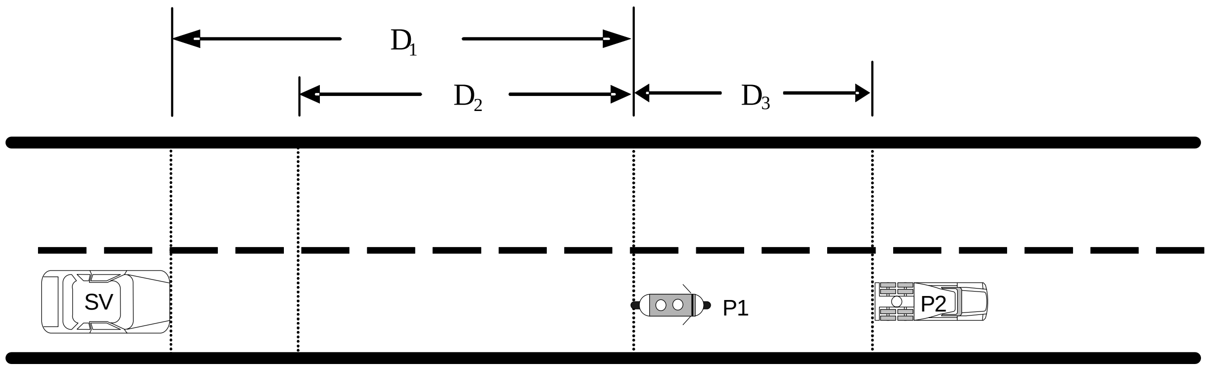

Figure 20: Track Layout for rear-end conflict with constant speed motorcycle (P1) behind a minivan (P2).

All specific speeds and initial conditions for this test are given in Table 20. Referring to Figure 20; SV, P1 and P2 start in the middle lane of the straight section of the Dana track such that the initial gap between SV and motorcycle P1 is about D1 (200 m) and the gap between motorcycle (P1) and minivan (P2) is about D3 (20 m). All three vehicles SV, P1 and P2 should reach their respective constant speeds by the time the range between SV and P1 is D2 (150 m). P1 maintains the gap of D3 (20 m) with the minivan during the entire duration of the test. P1 and P2 continue to drive around the track till all the runs are completed.

For this test, two telltales made from light retro-reflective plastic stripping will be cut to a predetermined length and tied to the rear bumper of the P2. These telltales will be used by the P1 driver to maintain a constant following distance behind the P2 rear bumper.

SV Driving Instruction:

1. SV gives signal to P1 and P2 to start the test.
2. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
3. When the required crash alert occurs or before the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
4. At the completion of test SV slows down and gets ready for the next test run.
5. In this test, since P1 and P2 are continuously driving around the track, SV comes back in the middle lane and accelerates to 20.1 m/s (45 mph) such that the gap between SV and P1 is about D2 (150) when SV reaches its steady state speed of 20.1 m/s.
6. Repeat steps 3 to 5 till all the runs are successfully completed.

P1 (Motorcycle) Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 11.2 m/s (25 mph).
2. P1 maintains its lane, speed and the gap with the minivan (P2) throughout the test.
3. P1 follows P2 at the desired range using telltales of a predetermined length as a guide to the specified following range for the test.
4. At the completion of one test run, P1 continues to drive around the track while maintaining its lane, speed and gap with the minivan (P2) till all the runs are successfully completed.

P2 (Minivan) Driving Instructions:

1. After receiving signal from SV, P2 accelerates to 11.2 m/s (25 mph).
2. P2 maintains its lane and speed throughout the test.
3. At the completion of one test run, P2 continues to drive around the track while maintaining its lane and speed till all the runs are successfully completed.

2.9.4. Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions, except that the POV1 (P1) is a motorcycle and POV2 (P2) is a minivan.

2.10. RE-10 Rear-end conflict with POV after a cut-in by the POV (Engineering 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 Overview and Concept

This test consists of an SV traveling on a straight, flat road at a speed of 15.7 m/s (35 mph) toward a vehicle (P1) that is moving in the left lane of travel at 11.2 m/s (25 mph). P1 cuts-in, in front of the faster moving SV at a distance such that cut-in lane change is completed at TTC of about 5-6 seconds.

Figure 21 shows the initial, transitional and final conditions for the rear-end conflict with a slower P1 after a lane change by the P1. The initial conditions are in the top of the figure and show a constant speed SV approaching a slower constant-speed P1 that is traveling in an adjacent lane to the left of the SV. Then, at a predetermined range, the driver of the P1 changes lanes to the right 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, the conflict is resolved by the SV slowing and moving laterally to the left while the P1 accelerates and moves to the right to avoid a crash.

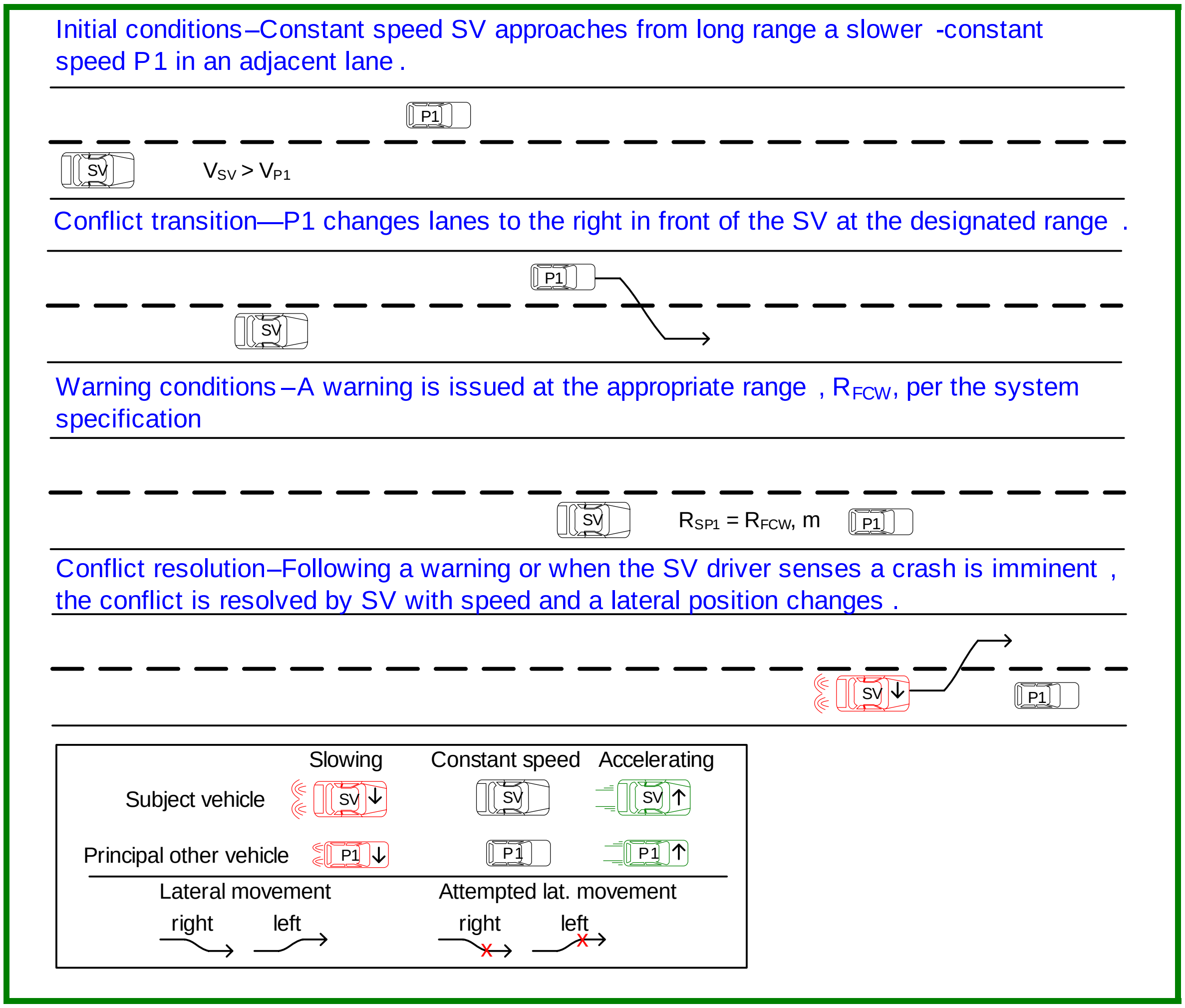

Figure 21: Initial and final conditions for rear-end conflict with P1 after cut-in by P1.

2.10.2. Performance measures and evaluation criteria

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 24.

Table 24. Run validity criteria for rear-end conflict with POV after a cut-in by the POV.

Parameter, Unit	*Target Value*	*Tolerance*
V_{SV}, m/s	15.7 (35 mph)	± 0.8 (1.8 mph)
V_{P1}, m/s	11.2 (25 mph)	± 0.6 (1.3 mph)
$Rdot_{SP1}$, m/s	-4.5	± 1.4
$LatV_{P1}$, m/s	0.4	± .15
D1 (Initial R_{SP1}), m	150	N/A
D2 ((Rsp1)ss), m	100	N/A
D3 (R_{SP1} at start of cut-in by P1), m	45	± 5.0
D4 (R_{SP1} at cut-in completion), m	25	± 5.0

The purpose of running an Engineering test is to characterize system performance and determine system limitations. This also involves executing the test multiple times and ensuring that the system performance is repeatable and robust. Table 25 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 25. Pass/Fail Criteria for rear-end conflict with POV after a cut-in by the POV.[12]

Alert Range	*R_{FCW}, m*
Maximum	
Nominal	
Minimum	

2.10.3. Track Setup and Driving Instructions

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 track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix.

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

Figure 22 below is the suggested track layout for conducting this test.

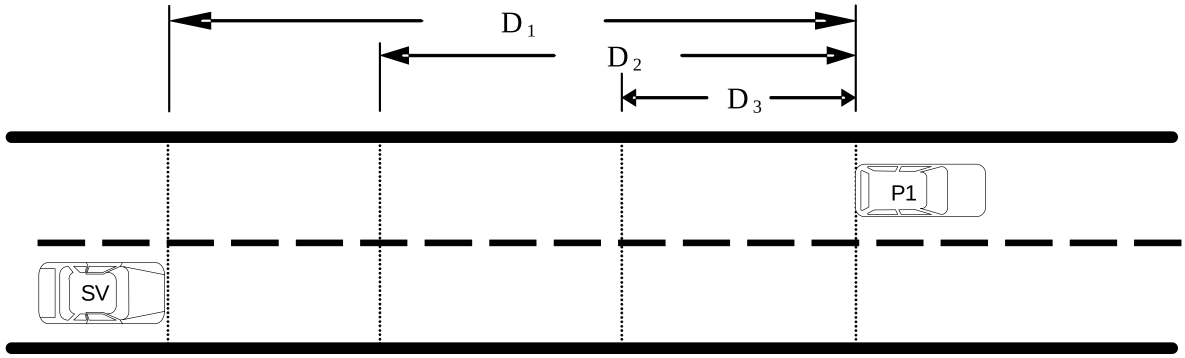

Figure 22: Track Layout for rear-end conflict with P1 after cut-in by P1.

All specific speeds and initial conditions for this test are given in Table 24. Referring to Figure 22, SV starts in lane 5 and P1 starts in lane 6 of the skid pad track with an initial gap of D1 (150 m). Both SV and P1 should reach their respective constant speeds by the time the range between SV and P1 is D2 (100 m). P1 should initiate the cut-in when the range between SV and P1 is D3 (45 m)

SV Driving Instructions:

1. SV gives signal to P1 to start the test.
2. SV accelerates to 15.7 m/s (35 mph) and engages the cruise control at 15.7 m/s (35 mph).
3. If SV is equipped (with IMS system) to measure the P1 distance, it gives signal to P1 vehicle to start the lane change at appropriate distance.
4. SV carefully monitors the slower P1 driving ahead on the left adjacent lane, which is going to cut-in at a close headway gap to be in front of faster moving SV.
5. When the required crash alert occurs or before the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
6. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 11.2 m/s (25 mph) and engages the cruise control at 11.2 m/s (25 mph).
2. P1 driver estimates the distance between the approaching SV and P1 and when the gap is D3 (45 m), P1 driver initiates a slow lane change move (low lateral velocity of 0.25 m/s to 0.55 m/s) to the right adjacent lane to be in front of the approaching SV. This lane change initiation is based on P1 driver’s estimate; however, he may get some help from the IMS equipped vehicle in determining this distance.
3. After changing lane to be in front of SV, P1 maintains its lane and speed throughout the test.
4. At the completion of test P1 stops and gets ready for the next run.

2.10.4. 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. RE-11 Rear-end conflict with a slower P1 after P2 cut-out (Engineering Test)

This test is intended to verify the timeliness detecting a new in-path vehicle and the appropriateness of an FCW when a slower POV is suddenly revealed after the cut-out of an intermediate vehicle.

2.11.1. Test Overview and Concept

This test consists of a SV traveling on a straight, flat road at a speed of 22.4 m/s (50 mph) behind a vehicle (P2) that is moving at the same speed in the same lane of travel. P2 cuts out into the left lane, abruptly revealing another POV (P1) that is traveling in the same lane at a slower speed of 11.2 m/s (25 mph).

Figure 23 shows the initial, transitional and final conditions for the rear-end conflict with a slower P1 after a P2 cuts-out. The initial conditions are in the top of the figure and show all three vehicles SV, P1 and P2 traveling at the same speed of 15.7 m/s (35 mph) in the same lane with a constant headway gap. Next, the figure shows that the lead P1 vehicle suddenly starts decelerating. This prompts the intermediate vehicle P2 to cut-out to the left lane thus exposing the slowing P1 to 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, the conflict is resolved by the SV slowing and moving laterally to the left.

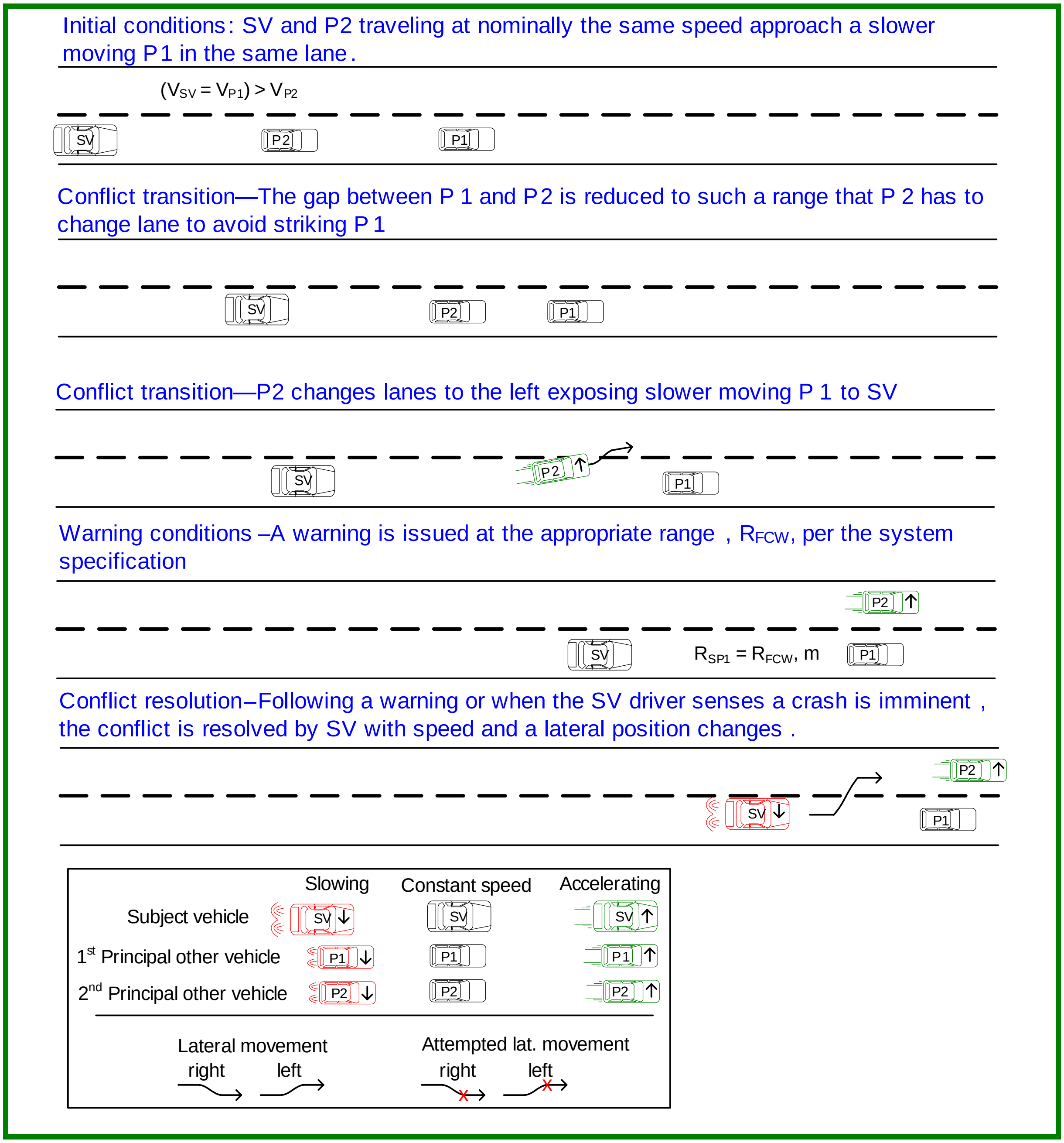

Figure 23: Initial and final conditions for rear-end conflict with a slower P1 after P2 cut-out.

2.11.2. Performance Measures and evaluation criteria

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 24.

Table 26: Run validity criteria for rear-end conflict with a slower P1 after P2 cut-out.

Parameter, Unit	*Target Value*	*Tolerance*
V_{SV}, m/s	22.4 (50 mph)	± 1.12 (2.5 mph)
V_{P2}, m/s	22.4 (50 mph)	± 1.12 (2.5 mph)
V_{P1}, m/s	11.2 (25 mph)	± 0.56 (1.3 mph)
$Rdot_{SP2}$, m/s	0	± 2.24
$Rdot_{SP1}$, (when P1 is revealed to SV), m/s	-11.2	± 1.68
$LatV_{P2}$ (when P2 cuts-out), m/s	0.7	± .1
D1 (Steady State Gap between SV and P2), m	34	± 4
D2 (Initial Gap between P2 and P1), m	250	N/A
D3 (Range between P2 and P1, when P2 cuts-out), m	45	± 5
D4 (Range between SV and P1 when P1 is initially revealed to SV), m	60	± 10

The purpose of running an Engineering test is to characterize system performance and determine system limitations. This also involves executing the test multiple times and ensuring that the system performance is repeatable and robust. Table 27 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 27: Pass/Fail Criteria for rear-end conflict with a slower P1 after P2 cut-out.[13]

Alert Range	*R_{FCW}, m*
Maximum	
Nominal	
Minimum	

2.11.3. Track Setup and Driving Instructions

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 track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in the Appendix.

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

Figure 24 below is the suggested track layout for conducting this test.

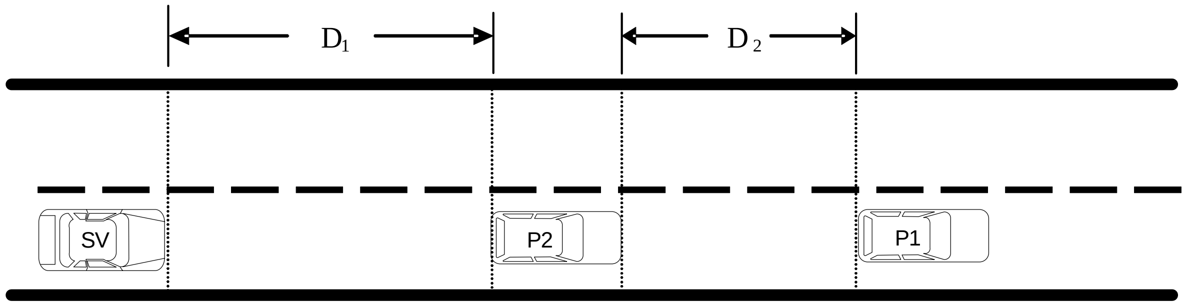

Figure 24: Track Layout for rear-end conflict with a slower P1 after P2 cut-out

All specific speeds and initial conditions for this test are given in Table 24.

Referring to Figure 22, all three vehicles SV, P1, P2 start in lane 5 of the skid pad track with a gap of D1 between SV and P2; and a gap of D2 between P2 and P1. SV and P2 should reach their respective constant speeds such that the gap between SV and P2 is D1 and remains constant till P2 cuts-out.

SV Driving Instructions:

1. SV gives signal to P1 and P2 to start the test.
2. SV accelerates to 22.4 m/s (50 mph) and engages the cruise control at 22.4 m/s (50 mph).
3. SV driver monitors the range displayed on the monitor and adjusts its speed such that a constant headway gap of about D1 (34 m) with the P2 vehicle is reached.
4. After reaching this steady state headway gap, SV maintains this gap with P2, till P2 cuts-out.
5. When P2 vehicle reaches within certain range of P1, it will cut-out to the left lane, revealing a slower moving P1 to SV. SV continues to drive in its lane towards this slower P1.
6. When the required crash alert occurs or when the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
7. At the completion of test SV stops and gets ready for the next test run.

P2 Driving Instructions:

1. After receiving signal from SV, P2 accelerates to 22.4 m/s (50 mph) and engages the cruise control at 22.4 m/s (50 mph).
2. When the range between P2 and P1 reaches D3 (45 m), P2 driver makes a quick lane change (lateral velocity of 0.6 m/s to 0.8 m/s) to the left to avoid striking P1. Determining this gap for lane change is based on P2 driver’s estimate only and no special instrumentation is required. However, if P2 vehicle also happens to be equipped with an IVBSS system, P2 driver could make use of the range displayed on the display monitor to determine this gap of D2.
3. After changing lane, P2 accelerates and continues to drive in its new lane till the test is completed.
4. At the completion of test or when all the other vehicles stop moving, P2 also stops and gets ready for the next run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 11.2 m/s (25 mph) and engages the cruise control at 11.2 m/s (25 mph).
2. P1 maintains its lane and speed throughout the test.
3. At the completion of test P1 stops and gets ready for the next run.

2.11.4. Exceptions to the standard test conditions

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

2.12. RE-12 Rear-end conflict with constant speed POV (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. This test especially explores the ability of the countermeasure to detect and issue timely warnings for smaller in-path vehicles.

2.12.1. Test Overview and Concept

This test begins with the SV traveling at 20.1 m/s (45 mph) on a straight, flat, two-lane road. Ahead of the SV in same lane is a motorcycle traveling at a slower speed.

Figure 25 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 defined 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 left to avoid a crash.

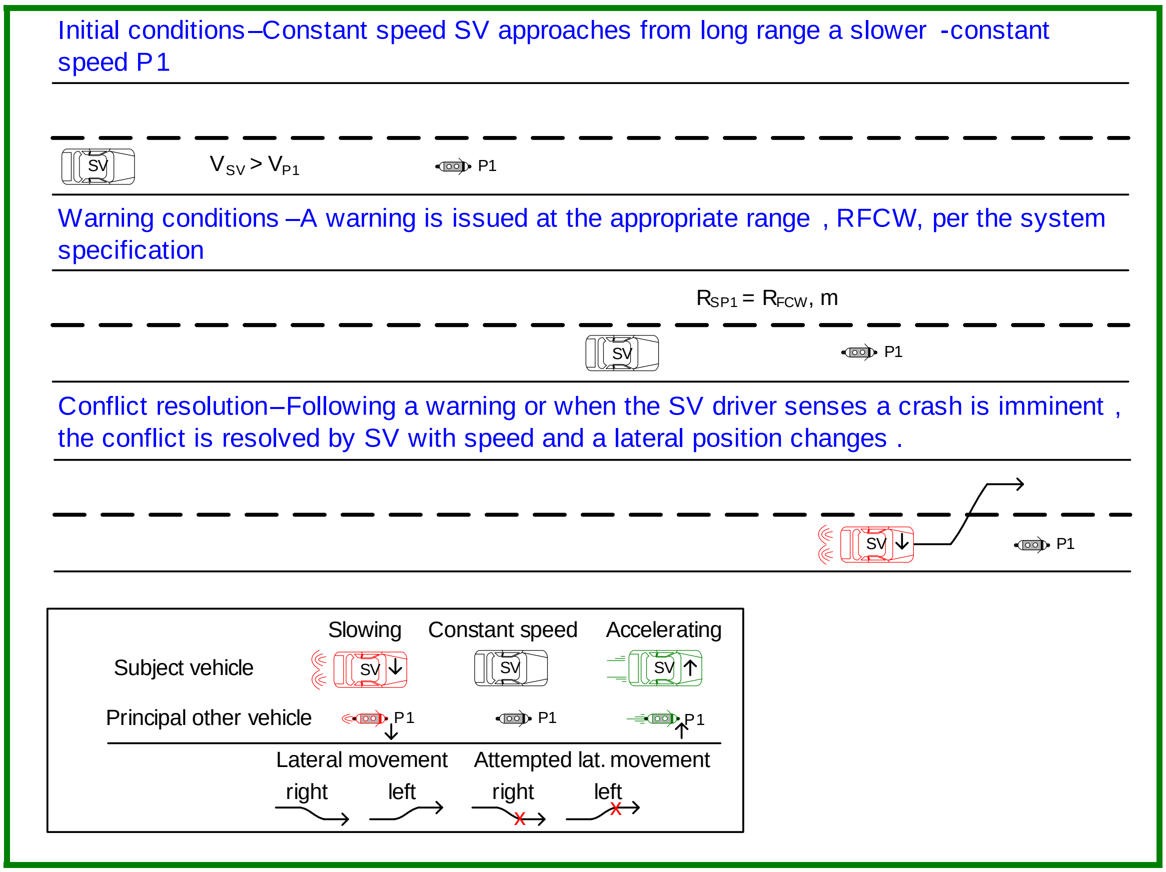

Figure 25: Initial and final conditions for rear-end conflict with a constant speed POV (motorcycle).

2.12.2. Performance measures and evaluation criteria

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.

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

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)

V_{P1}, m/s	11.2 (25 mph)	± .90 (2.0 mph)
$Rdot_{SP1}$, m/s	-8.9	± 1.90
D1 (Initial R_{SP1}), m	200	N/A
D2, m	150	N/A

Table 29 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 29: Pass/Fail Criteria for rear-end conflict with a constant speed POV (motorcycle).[14]

Alert Range	R_{FCW}, *m*
Maximum	
Nominal	
Minimum	

2.12.3. Track Setup and Driving Instructions

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 track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in the Appendix.

Figure 26 below is the suggested track layout for conducting this test.

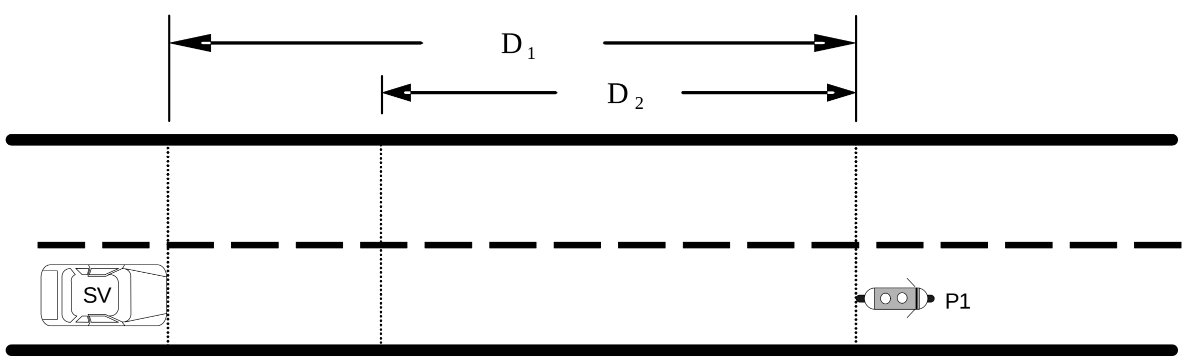

Figure 26: Track Layout for rear-end conflict with a constant speed POV (motorcycle).

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

All specific speeds and initial conditions for this test are given in Table 28. Referring to Figure 26, both SV and P1 start in lane 5 of the skid pad track with an initial gap of D1 (200 m). Both SV and P1 should reach their respective constant speeds by the time the range between SV and P1 is D2 (150 m)

SV Driving Instructions:

1. SV gives signal to P1 to start the test.
2. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
3. When the required crash alert occurs or before the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
4. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 8.9 m/s (20 mph).
2. P1 maintains its lane and speed throughout the test.
3. At the completion of test P1 stops and gets ready for the next run.

2.12.4. Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions, except that POV is a motorcycle in this test.

3. Lane Change Merge (LCM) Warning Tests

The procedures described in this section are designed to test the LCM subsystem. Each of the tests involves both longitudinal and lateral position changes. The LCM subsystem is primarily concerned with the vehicles in adjacent lanes within close proximity and vehicles in adjacent lanes that are entering the region of close proximity.

Most of the tests in this section require a certain lateral velocity range. Specific cone positions could be suggested to aid the driver in achieving appropriate lateral velocity, however, it is observed that professional drivers, based on their driving expertise, consistently run the tests and achieve the desired lateral velocity without any external aid.

3.1. LC-1 Lane Change conflict with POV in blind spot on right (Required Test)

This test is intended to verify the appropriateness of a warning when the right side blind zone is occupied by a vehicle. The SV driver gives a turn signal and begins to change lanes to the occupied right adjacent lane. Physically the POV is positioned with its front bumper behind the SV driver. Both vehicles are traveling at the same forward speed.

3.1.1. Test Overview and Concept

Figure 27 shows the initial, transitional, warning and conflict resolution conditions for a lane-change conflict. The test begins with the SV and POV traveling at the same speed in the center of their lanes, with the POV front bumper behind the SV driver. The conflict is initiated when SV driver signals and moves to the right with a lateral velocity, $LatV_{SV}$, between 0.5 and 0.8 m/s. The test ends when a LCM warning is issued or the

SV driver senses a crash is imminent. The conflict is resolved when, subsequent to the warning, the SV makes a lateral position change to the left and moves away from the POV.

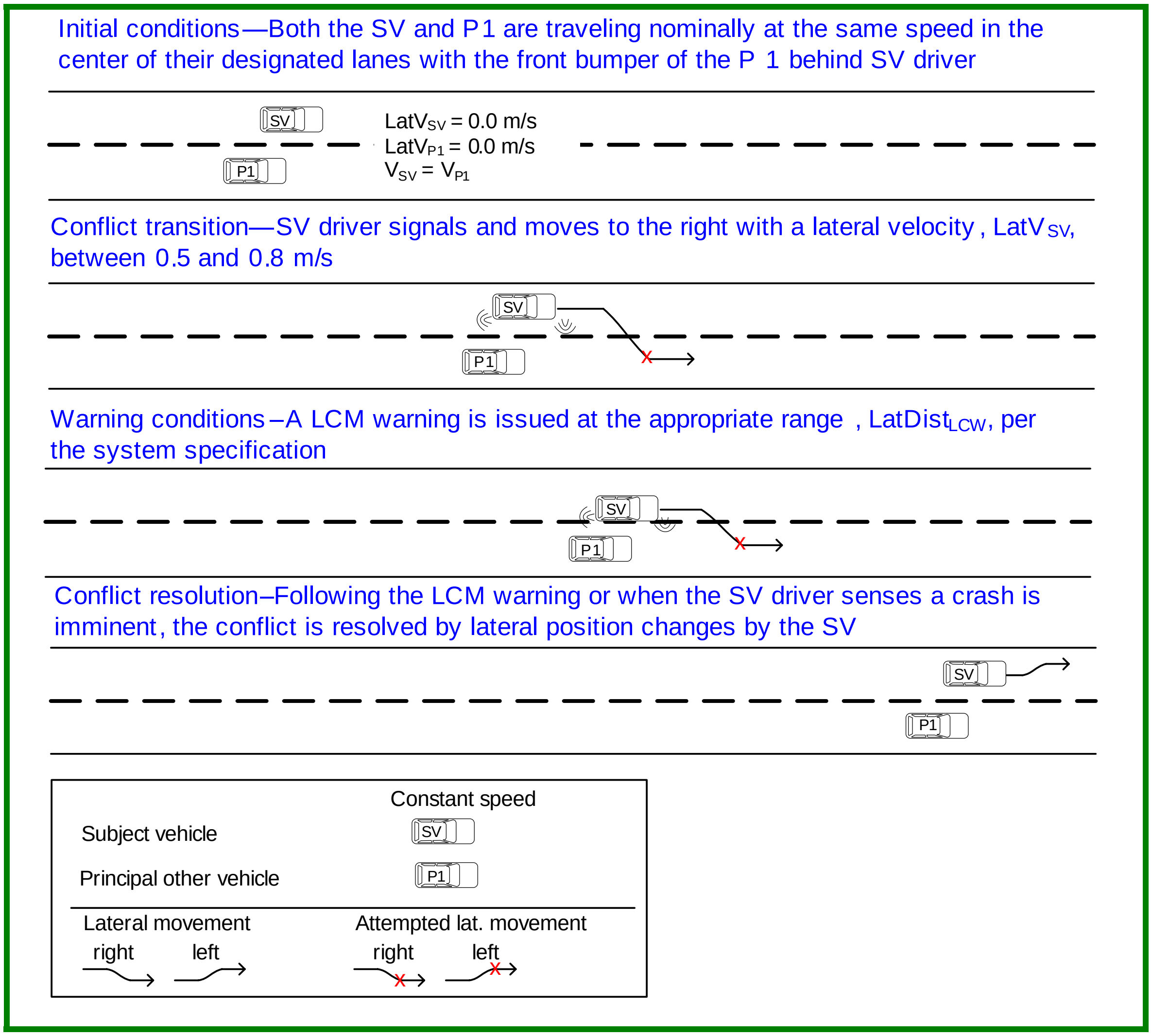

Figure 27: Initial and final conditions for lane-change conflict with POV in blind-spot on right.

3.1.2. Performance measures and evaluation criteria

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 30.

Table 30: Run validity criteria for lane-change conflict with POV in blind-spot on right.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
$LatV_{SV,}$ m/s	0.65	± 0.15
P1 Position	P1 front bumper behind SV driver	N/A
Turn Signal Status	On	N/A
D1, m	200	N/A
$LatDist_{ss}$	>0.9m	N/A

Table 31 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS system.

Table 31: Pass/Fail Criteria for lane-change conflict with POV in blind-spot on right.[15]

Alert Range	*$LatDist_{LCW}$, m*
Maximum	
Nominal	
Minimum	

3.1.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track.

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

Figure 28 below is the suggested track layout for conducting this test.

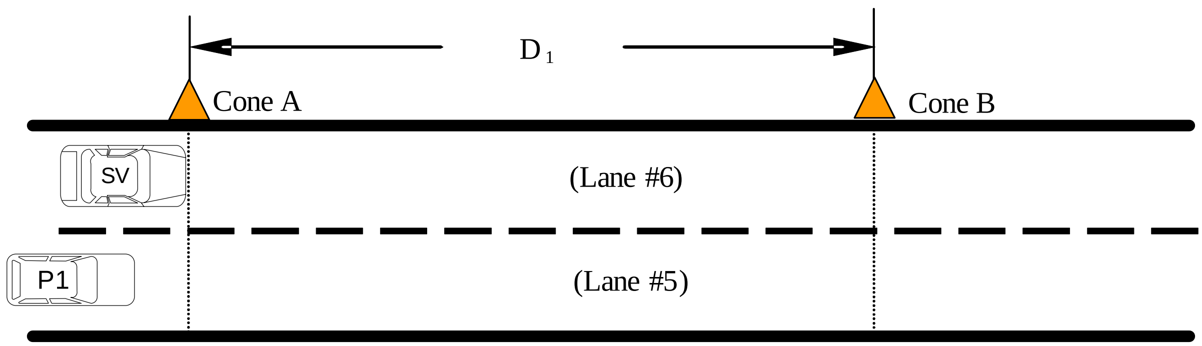

Figure 28: Track Layout for lane-change conflict with POV in blind-spot on right.

All specific speeds and initial conditions for this test are given in Table 30.

Referring to Figure 28, SV and P1 are placed in lane 6 and lane 5 of the skid pad track respectively such that P1's front bumper is behind SV driver. P1 should maintain its position relative to SV during the test until SV changes lane.

SV Driving Instructions:

7. SV signals P1 to start the test.
8. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
9. SV should reach this speed before reaching cone B.
10. At cone B, SV signals and initiates a right lane change move towards P1 at a moderate rate of lateral drift (0.5 to 0.8 m/s).
11. When the required lane change merge warning occurs or when the SV driver senses a crash with P1 is imminent, SV steers back in its original lane 6.
12. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 20.1 m/s (45 mph) and engages the cruise control.
2. During this period P1 maintains its relative position with respect to SV and matches its speed with SV.
3. P1 should carefully monitor the SV vehicle, which would be changing lane and moving to the lane 5 currently occupied by P1.
4. When SV is changing lane, P1 driver should maintain its designated lane to the best of their ability and judgment (in order to elicit a lane change merge warning); however, if P1 driver senses a crash is imminent with SV, it could move into the right adjacent lane 4.
5. At the completion of test P1 stops and gets ready for the next run.

3.1.4. Exceptions to the standard test conditions

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

3.2. LC-2 – This test has been changed to RD-8. Please refer RD-8

LC-3 Lane Change into adjacent POV on Curve (Engineering Test)

This test is intended to verify the appropriateness of a warning when the SV signals and begins to change lanes to the left while the adjacent lane is occupied by another vehicle such that the front bumper of the POV is behind SV driver. In this test both vehicles are traveling at the same forward speed and negotiating a large radius curve (~150 to 500 m).

3.2.1. Test Overview and Concept

Figure 29 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 a large radius curve and in the center of their designated lanes with the front bumper of the P1 behind SV driver. The conflict initiates when SV driver signals and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.5 and 0.8 m/s. The test ends when a LCM warning is issued or the SV driver senses a crash is imminent. The conflict is resolved by lateral position changes to the right by the SV.

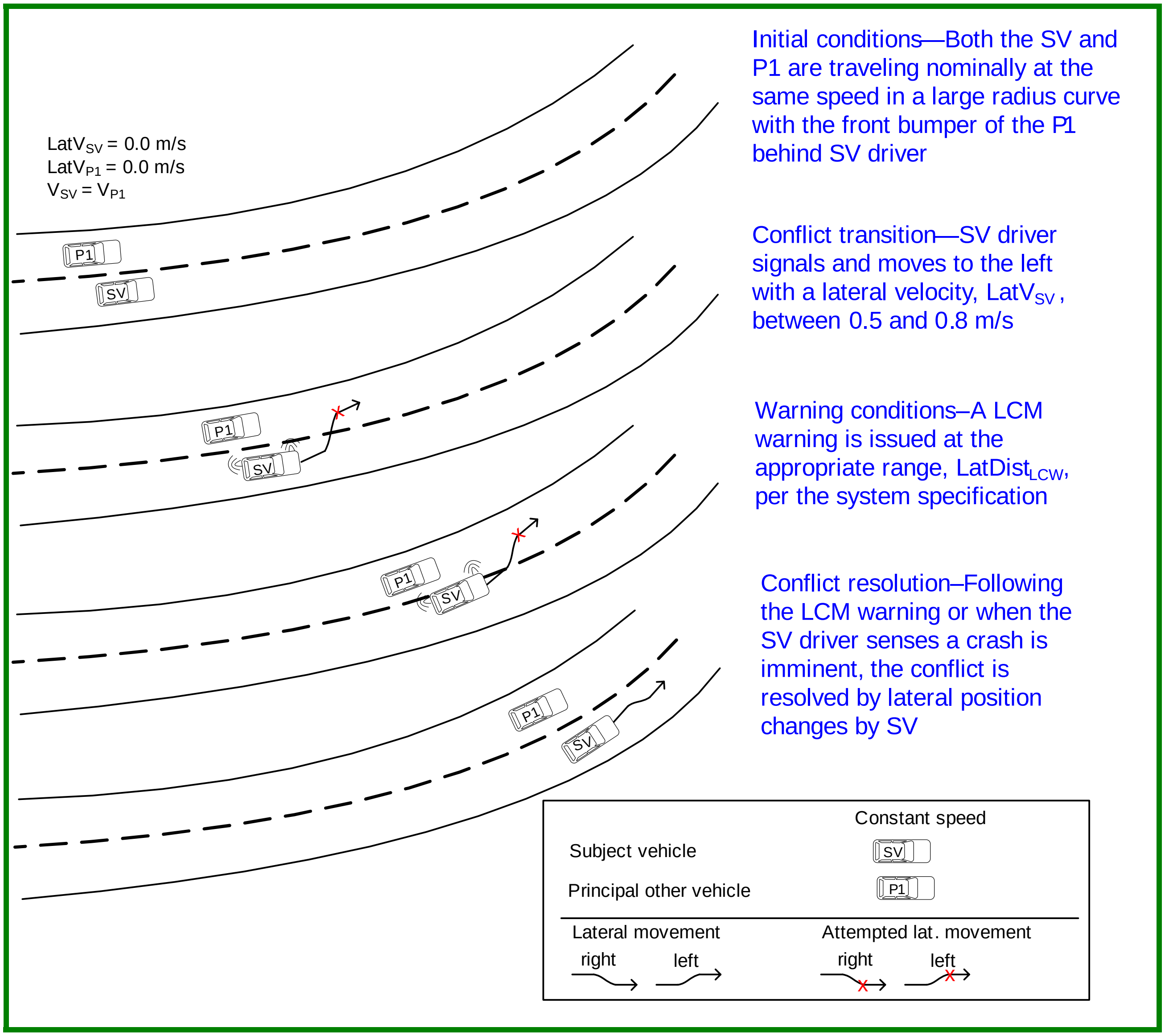

Figure 29: Initial and final conditions for lane change into adjacent POV on curve.

3.2.2. Performance measures and evaluation criteria

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 32.

Table 32: Run validity criteria for lane change into adjacent POV on curve.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	± .8 (1.8 mph)
V_{P1}, m/s	15.7 (35 mph)	± .8 (1.8 mph)
$LatV_{SV}$, m/s	0.65	± 0.15
Curve Radius, m	150 – 500 m	N/A
P1 Position	P1 front bumper behind SV driver	N/A
Turn Signal Status	On	N/A
D1, m	200	N/A
$LatDist_{ss}$	>0.9 m	N/A

Table 33 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS system.

Table 33: Pass/Fail Criteria for lane change into adjacent POV on curve.[16]

Alert Range	*$LatDist_{LCW}$, m*
Maximum	
Nominal	
Minimum	

3.2.3. Track Setup and Driving Instructions

The track to be used for this test is either the Winding Road Course or the Vehicle Dynamics Area at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figures A2 and A3 in Appendix. It is to be ensured that there are good lane markings on the track.

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

Figure 30 below is the suggested track layout for conducting this test.

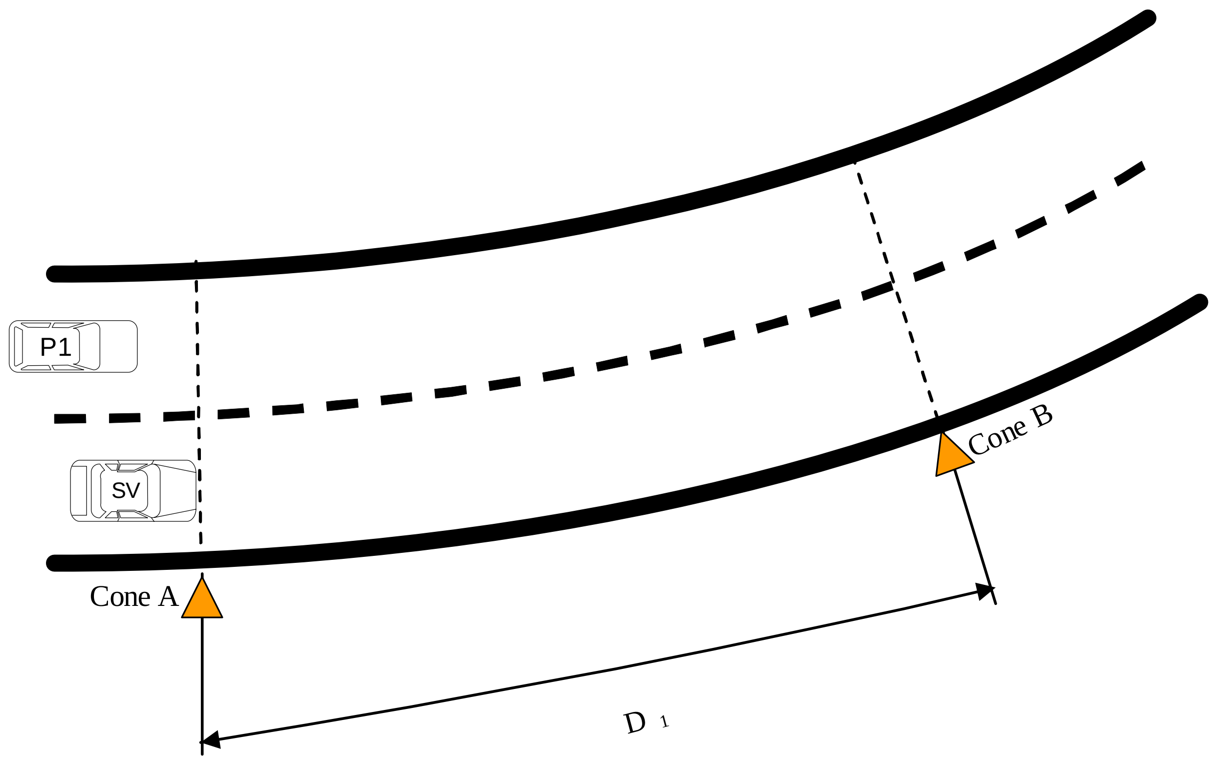

Figure 30: Track Layout for lane change into adjacent POV on curve.

All specific speeds and initial conditions for this test are given in Table 32.

Referring to Figure A3, both SV and P1 start from point H and travel clockwise (H-I-J).

Referring to Figure 30, SV is placed in the outside lane and P1 is placed in the adjacent left lane such that P1's front bumper is behind SV driver. P1 should maintain its position relative to SV during the test until SV changes lane.

SV Driving Instructions:

1. SV signals P1 to start the test.
2. SV accelerates to 15.6 m/s (35 mph) and engages the cruise control.
3. SV should reach this speed before reaching cone B.
4. At cone B, SV signals and initiates a left lane change move towards P1 at a moderate rate of lateral drift (0.5 to 0.8 m/s).
5. When the required lane change merge warning occurs or when the SV driver senses a crash with P1 is imminent, SV steers back in its original lane.
6. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 15.6 m/s (35 mph) and engages the cruise control.
2. During this period P1 maintains its relative position with respect to SV and matches its speed with SV.
3. P1 should carefully monitor the SV vehicle, which would be changing lane and moving to the left lane currently occupied by P1.
4. When SV is changing lane, P1 driver should maintain its designated lane to the best of their ability and judgment (in order to elicit a lane change merge warning); however, if P1 driver senses a crash is imminent with SV, it could move away from SV.
5. At the completion of test P1 stops and gets ready for the next run.

3.2.4. Exceptions to the standard test conditions

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

3.3. LC-4 Lane Change into adjacent POV on merge (Required Test)

This test is intended to verify the appropriateness of a warning when the SV signals and begins to merge into a lane that is occupied by another vehicle located in the blind spot of the SV driver. In this test both vehicles are traveling at the same forward speed. The test determines whether the IVBSS system's required lane change merge warning is consistent with the warning requirements when the lane marker is not available.

3.3.1. Test Overview and Concept

Figure 31 shows the initial, transitional, warning and conflict resolution conditions for a lane-change conflict into adjacent POV on merge. The test begins with the SV and POV traveling at the same speed in the center of their lanes, with the POV front bumper behind the SV driver. The conflict is initiated when SV driver signals and moves to the right with a lateral velocity, $LatV_{SV}$, between 0.5 and 0.8 m/s. The test ends when a LCM warning is issued or the SV driver senses a crash is imminent. The conflict is resolved when, subsequent to the warning, the SV makes a lateral position change to the left and moves away from the POV.

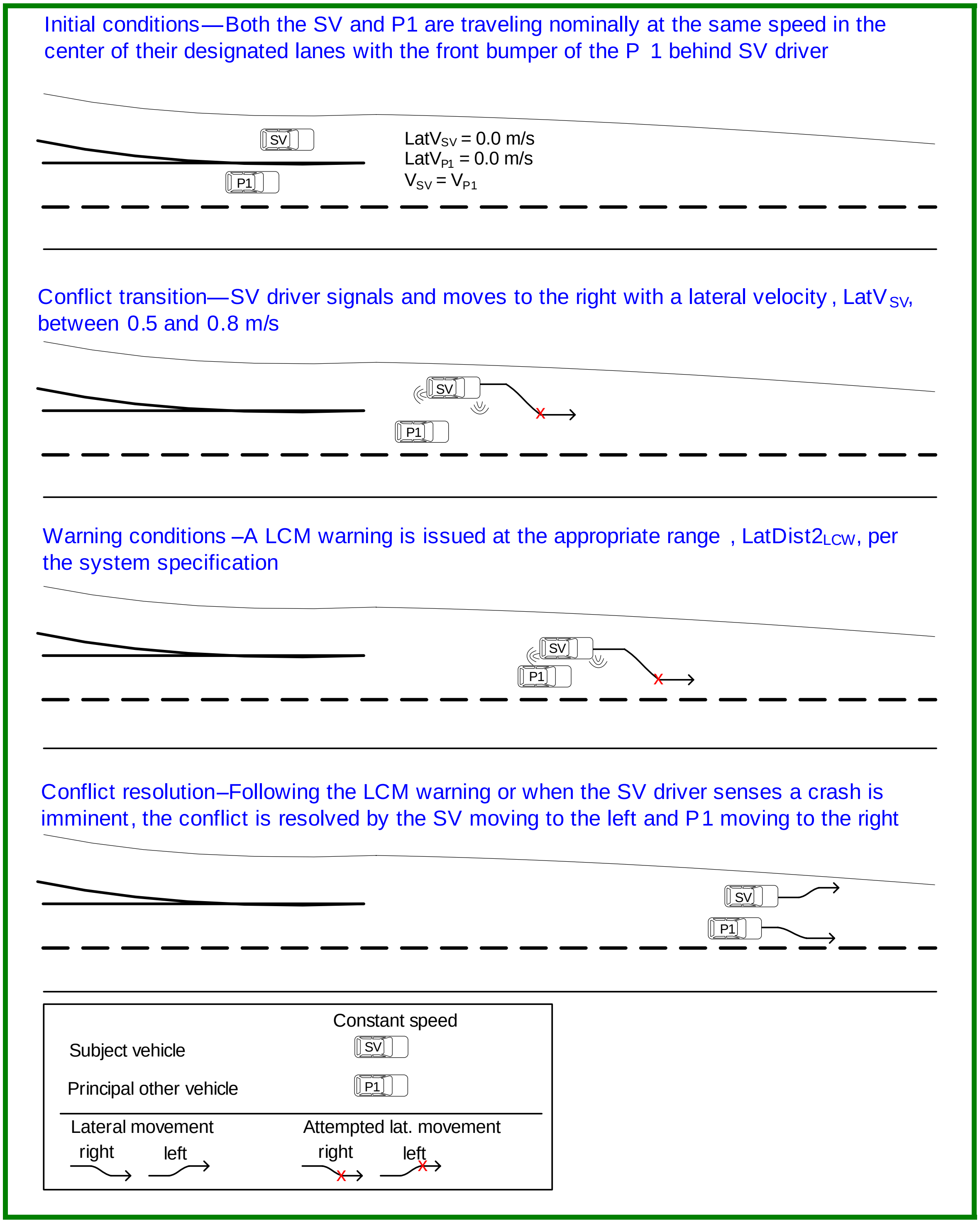

Figure 31: Initial and final conditions for lane change into adjacent POV on merge.

3.3.2. Performance measures and evaluation criteria

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 34.

Table 34: Run validity criteria for lane change into adjacent POV on merge.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	± .8 (1.8 mph)
V_{P1}, m/s	15.7 (35 mph)	± .8 (1.8 mph)
$LatV_{SV}$, m/s	0.65	± 0.15
P1 Position	P1 front bumper behind SV driver	N/A
Turn Signal Status	On	N/A
$LatDist2_{ss}$	>2.0 m	N/A

Table 35 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS system.

Table 35: Pass/Fail Criteria for lane change into adjacent POV on merge.[17]

Alert Range	$LatDist2_{ss} - LatDist2_{LCW}$, *m*
Maximum	
Minimum	

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

3.3.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track for the merge section where lane 6 is ending and merging into lane 5 as shown in the Figure 32 below.

Figure 32 below is the suggested track layout for conducting this test.

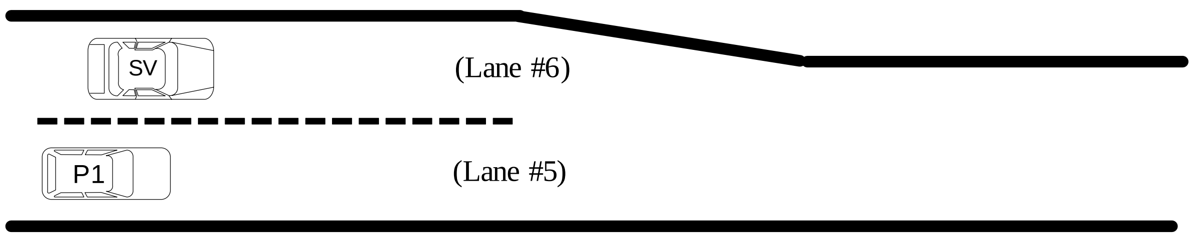

Figure 32: Track Layout for lane change into adjacent POV on merge.

All specific speeds and initial conditions for this test are given in Table 34.

Referring to Figure 32, SV and P1 are placed in lane 6 and lane 5 of the skid pad track respectively such that P1's front bumper is behind SV driver. P1 should maintain its position relative to SV during the test until SV changes lane.

SV Driving Instructions:

1. SV signals P1 to start the test.
2. SV accelerates to 15.6 m/s (35 mph) and engages the cruise control.
3. At the end of lane 6, where lane 6 starts merging into lane 5, SV signals and initiates a right lane change move towards P1 at a moderate rate of lateral drift (0.5 to 0.8 m/s). SV should initiate a lane change at the end of lane markings.
4. When the required lane change merge warning occurs or when the SV driver senses a crash with P1 is imminent, SV steers back to the left in the available shoulder lane.
5. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 15.6 m/s (35 mph) and engages the cruise control.
2. During this period P1 maintains its relative position with respect to SV and matches its speed with SV.
3. P1 should carefully monitor the SV vehicle, which would be changing lane and moving to the lane 5 currently occupied by P1.

4. When SV is changing lane, P1 driver should maintain its designated lane to the best of their ability and judgment (in order to elicit a lane change merge warning); however, if P1 driver senses a crash is imminent with SV, it could move into the right adjacent lane 4.
5. At the completion of test P1 stops and gets ready for the next run.

3.3.4. Exceptions to the standard test conditions

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

3.4. LC-5 Lane Change into adjacent POV after passing (Engineering Test)

This test is intended to verify the appropriateness of a warning when the SV signals and begins to change lanes too soon after passing the vehicle in the left lane. In this test SV vehicle is traveling a little faster than the POV.

3.4.1. Test Overview and Concept

Figure 33 shows the initial, transitional, warning and conflict resolution conditions for a lane-change into adjacent POV after passing. The test begins with the SV and P1 traveling in the center of their designated lanes, such that SV is traveling at slightly higher speed and is passing the P1 vehicle in the adjacent left lane. The conflict initiates when SV driver signals and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.5 and 0.8 m/s. The test ends when a LCM warning is issued or the SV driver senses a crash is imminent. The conflict is resolved by lateral position changes to the right by the SV.

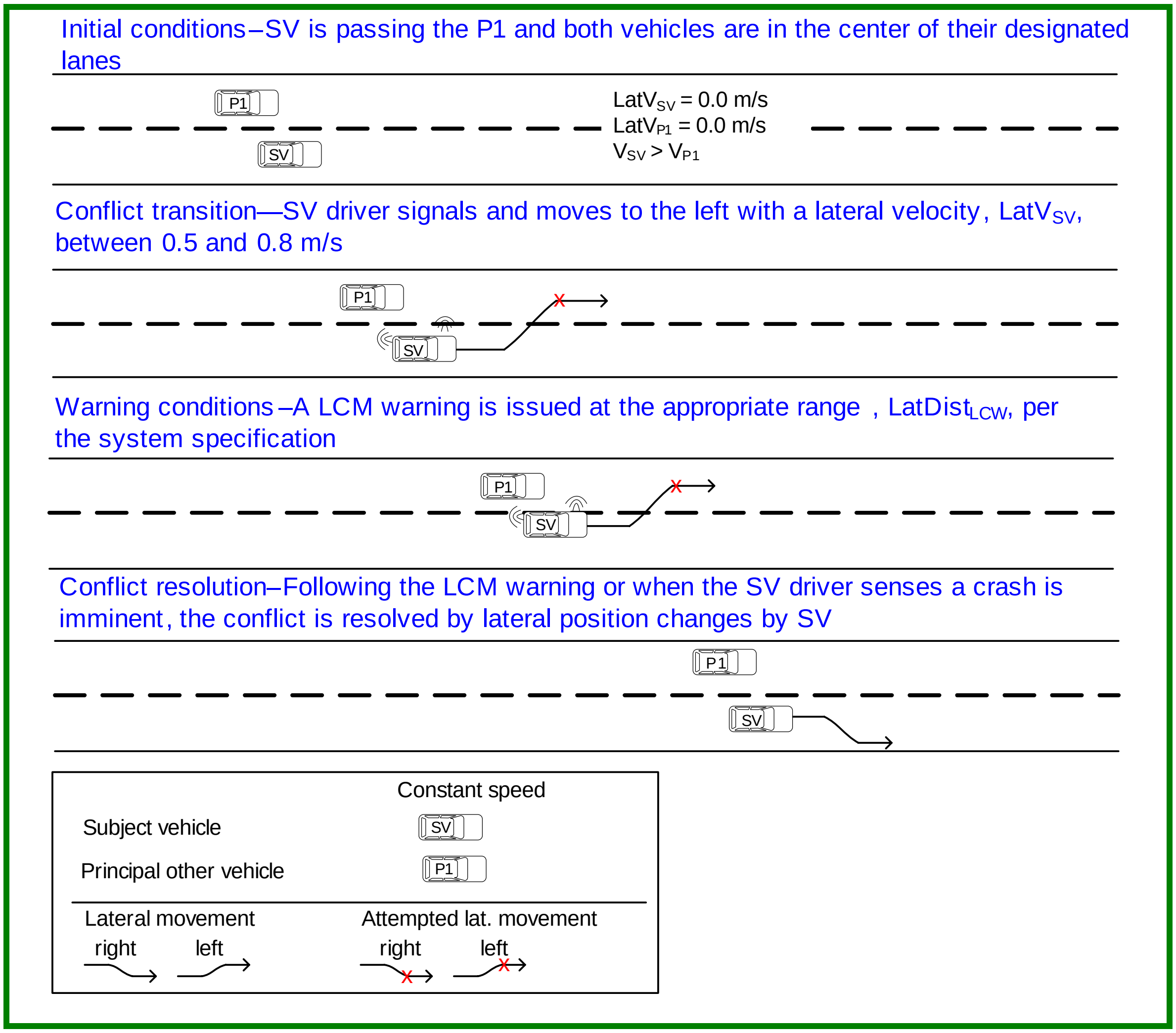

Figure 33: Initial and final conditions for lane change into adjacent POV after passing.

3.4.2. Performance measures and evaluation criteria

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 34.

Table 36: Run validity criteria for lane change into adjacent POV after passing.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	16.5 (37 mph)	± .8 (1.8 mph)
V_{P1}, m/s	15.7 (35 mph)	± .8 (1.8 mph)
$LatV_{SV,}$ m/s	0.65	± 0.15
Turn Signal Status	On	N/A
SV Lane Change Location	When SV driver passes the front bumper of P1	N/A
D1, m	20	N/A
$LatDist_{ss}$	>0.9 m	N/A

Table 37 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS system.

Table 37: Pass/Fail Criteria for lane change into adjacent POV after passing.[18]

Alert Range	*$LatDist_{LCW}$, m*
Maximum	
Nominal	
Minimum	

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

3.4.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track.

Figure 34 below is the suggested track layout for conducting this test.

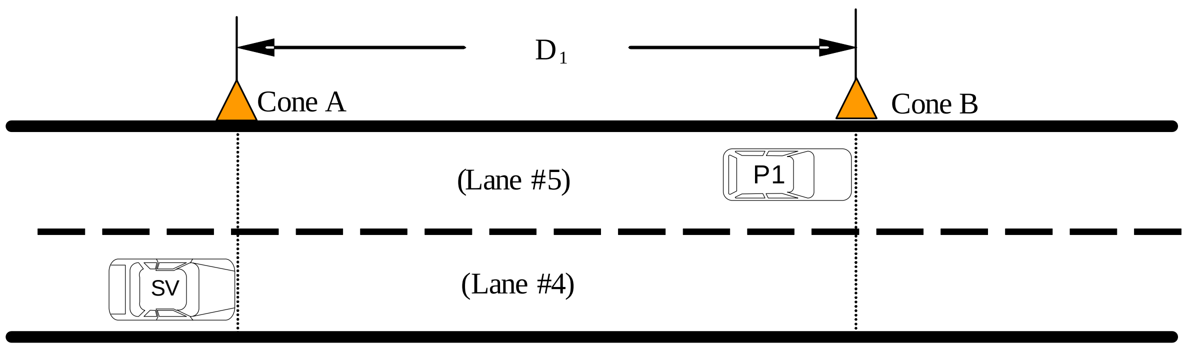

Figure 34: Track Layout for lane change into adjacent POV after passing.

All specific speeds and initial conditions for this test are given in Table 34.

Referring to Figure 34, SV and P1 are placed in lane 4 and lane 5 of the skid pad track respectively such that SV is about D1, m behind P1.

SV Driving Instructions:

1. SV signals P1 to start the test.
2. SV accelerates to 16.5 m/s (37 mph) and engages the cruise control.
3. SV driver signals and initiates a fast lane change move (high lateral velocity of 0.5 m/s to 0.8 m/s) to the left lane, immediately after SV driver (not the whole vehicle) passes the front bumper of the P1 vehicle.
4. If a LCM warning occurs or when the SV driver senses a crash with P1 is imminent, SV steers back in its original lane, lane 4.
5. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 15.6 m/s (35 mph) and engages the cruise control.
2. P1 should carefully monitor the SV vehicle slowly approaching from behind, which would be changing lane and moving to the lane 5 currently occupied by P1.
3. When SV is changing lane, P1 driver should maintain its designated lane to the best of their ability and judgment (in order to elicit a lane change merge warning); however, if P1 driver senses a crash is imminent with SV, it could move into the left adjacent lane 6.

4. At the completion of test P1 stops and gets ready for the next run.

3.4.4. Exceptions to the standard test conditions

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

3.5. LC-6 Lane Change into approaching POV (Required Test)

This test is intended to verify the appropriateness of a warning when the SV changes lane and encounters an approaching POV.

3.5.1. Test Overview and Concept

This test evaluates the warning system's ability to warn 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 is approaching from behind.

Figure 35 shows the initial, transitional, warning and conflict resolution conditions for a lane-change into approaching POV. The test begins with the SV and P1 traveling in the center of their designated lanes, such that P1 is traveling at slightly higher speed and is going to pass the SV vehicle, which is in the adjacent right lane. The conflict initiates when the SV driver signals and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.5 and 0.8 m/s, while the P1 vehicle is in the SV proximity zone behind SV vehicle and closing. The test ends when a LCM warning is issued or the SV driver senses a crash is imminent. The conflict is resolved by lateral position changes to the right by the SV.

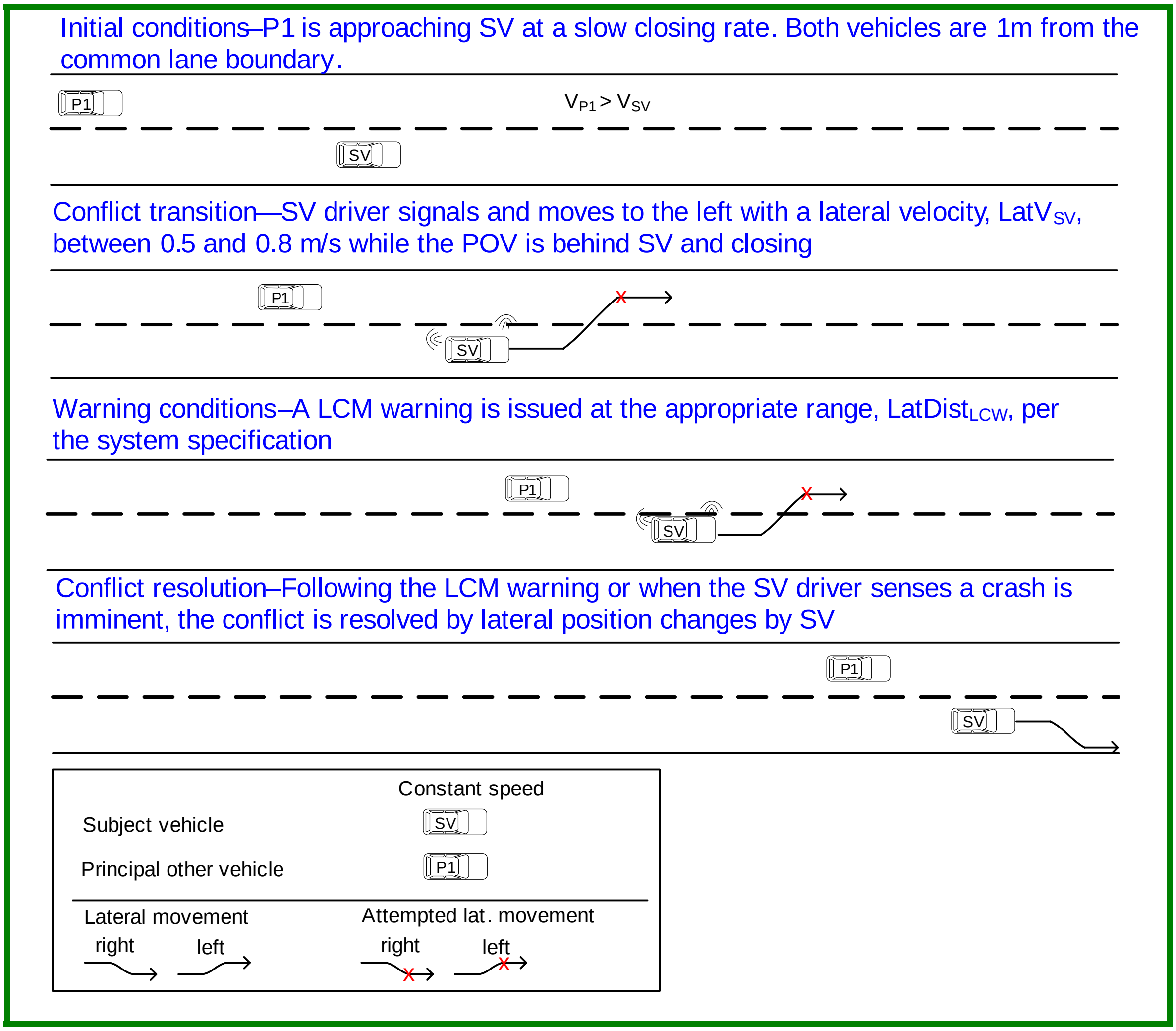

Figure 35: Initial and final conditions for lane change into approaching POV.

3.5.2. Performance measures and evaluation criteria

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 38.

Table 38: Run validity criteria for lane change into approaching POV.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	22.4 (50 mph)	± 1.1 (2.5 mph)
V_{P1}, m/s	26.8 (60 mph)	± 1.3 (3.0 mph)
$LatV_{SV}$, m/s	0.65	± 0.15
Turn Signal Status	On	N/A
D1, m	60	N/A
D2, m	25	± 5
$LatDist_{ss}$	>0.9 m	N/A

Table 39 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS system.

Table 39: Pass/Fail Criteria for lane change into approaching POV.[19]

Alert Range	*$LatDist_{LCW}$, m*
Maximum	
Nominal	
Minimum	

3.5.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in the Appendix. It is to be ensured that there are good lane markings on the track.

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

Figure 36 below is the suggested track layout for conducting this test.

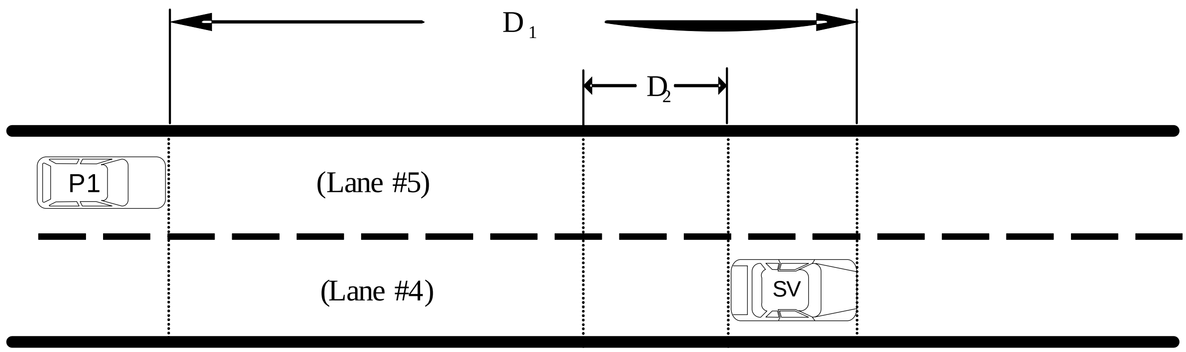

Figure 36: Track Layout for lane change into approaching POV.

All specific speeds and initial conditions for this test are given in Table 38.

Referring to Figure 36, SV and P1 are placed in lane 4 and lane 5 of the skid pad track respectively such that P1 is about D1 m behind SV. Both P1 and SV start and maintain a 1 m distance from the common lane boundary.

SV Driving Instructions:

1. SV signals P1 to start the test.
2. SV accelerates to 22.4 m/s (50 mph) and engages the cruise control.
3. SV driver signals and initiates a slow lane change move (low lateral velocity of 0.25 m/s to 0.55 m/s) to the left lane, when P1 vehicle, approaching from behind, is approximately D2, m behind SV rear bumper. This lane change position is to be determined by the SV drivers based on their own judgment. The SV driver could use the blind side detection light (turning yellow), which indicates that the P1 vehicle is entering into the proximity zone.
4. When the required lane change merge warning occurs or when the SV driver senses a crash with P1 is imminent, SV steers back in its original lane 4.
5. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 26.8 m/s (60 mph) and engages the cruise control.
2. P1 should carefully monitor the SV vehicle ahead in lane 4, which would be changing lane and moving to the lane 5 currently occupied by P1.
3. When SV is changing lane, P1 driver should maintain its designated lane to the best of their ability and judgment (in order to elicit a lane change merge warning); however, if P1 driver senses a crash is imminent with SV, it could move into the left adjacent lane 6.
4. At the completion of test P1 stops and gets ready for the next run.

3.5.4. Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions, except ensuring that wiper is turned off during the test.

4. Road Departure Verification Test Procedures

The tests in this section involve the SV unintentionally departing its designated lane of travel.

All tests in this section must be run only when the Lateral Drift Warning (LDW) system availability icon is on, if present on the SV.

Some of the tests in this section require a certain lateral velocity range. Specific cone positions are suggested to aid the driver in achieving appropriate lateral velocity, however, it is very possible and in fact recommended that, professional drivers, based on their driving expertise, could consistently run the tests and achieve the desired lateral velocity without the aid of the suggested cone locations.

4.1. RD-1 Road departure toward opposing traffic lane with 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 a solid lane boundary. The lateral velocity of the SV relative to the boundary markers should be between 0.2 and 0.4 m/s.

4.1.1. Test Overview and Concept

Figure 37 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 left with a low lateral velocity between 0.2 and 0.4 m/s. This is followed by a lateral drift warning at the appropriate distance from the boundary line per the LDW system specification. The conflict is resolved by the SV returning to the center of the original lane.

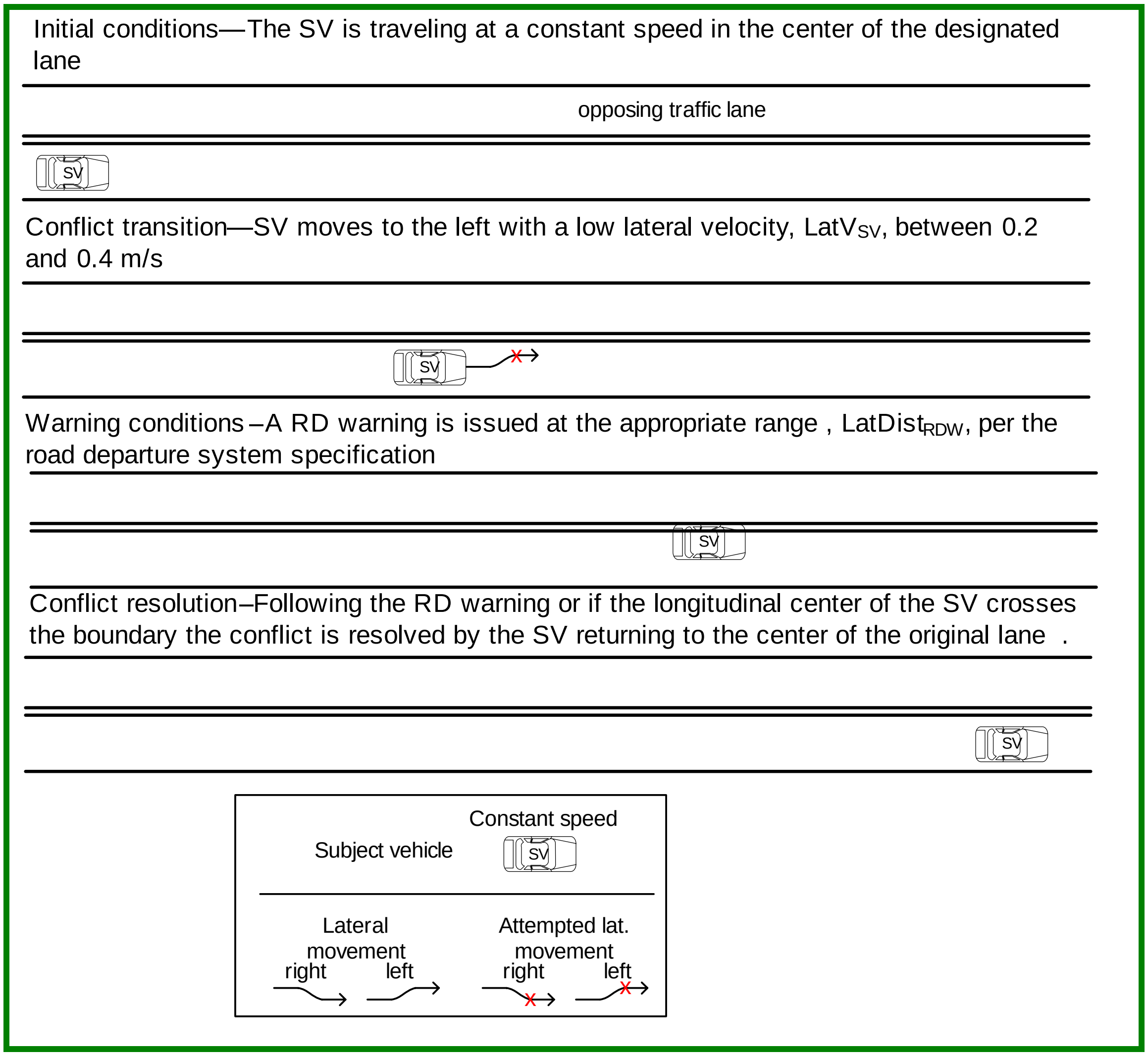

Figure 37: Initial and final conditions for road departure toward opposing traffic lane with low lateral speed.

4.1.2. Performance measures and evaluation criteria

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.

Table 40: Run validity criteria for road departure toward opposing traffic lane with low lateral speed.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
$LatV_{SV,}$ m/s	0.3	± 0.1
Lane Width, m	4.3	N/A
Turn Signal Status	Off	N/A
D1, m	400	N/A
D2, m	143	± 1.0

Table 41 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem. Negative values are outside the lane.

Table 41: Pass/Fail Criteria for road departure toward opposing traffic lane with low lateral speed.[20]

Alert Range	$LatDist_{RDW}$, *m*
Maximum	
Nominal	
Minimum	

4.1.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track, with a solid lane boundary on the side of the lane where road departure is taking place.

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

Figure 38 below is the suggested track layout for conducting this test.

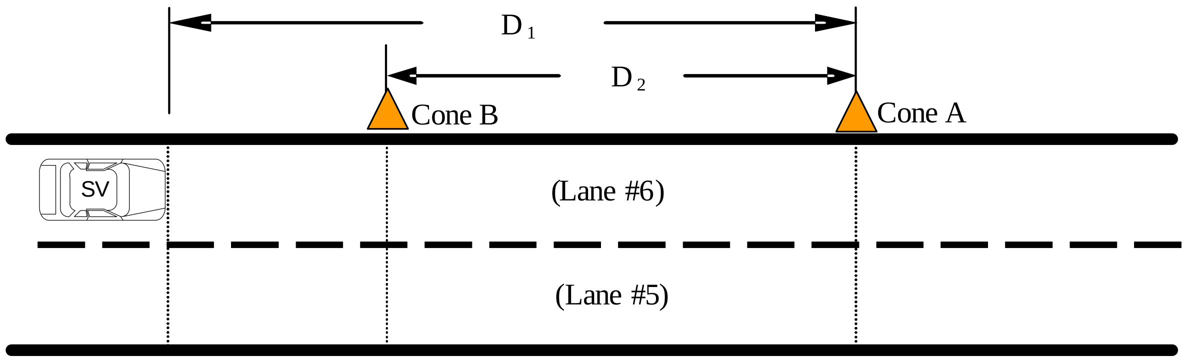

Figure 38: Track Layout for RD toward opposing traffic lane with low lateral speed.

All specific speeds and initial conditions for this test are given in Table 40.

Referring to Figure 38, Cones A and B are placed at the outer edge of lane 6 of the skid pad track, with a gap of D2. SV starts in lane 6 of the skid pad track with a gap of D1 from Cone A. SV should reach its steady state constant speed before reaching cone B. SV should initiate lane drift at cone B.

It is to be noted that lanes 5 and 6 at skid pad tracks are approximately 4.3 m (14 ft) wide. Cones A and B are placed about 0.5 lane width (2.1 m) away from the SV centerline. D2 is calculated based on this 0.5 lane width of 2.1 m to generate appropriate drift rate.

SV Driving Instructions:

13. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
14. SV should reach this speed before reaching cone B.
15. At cone B, SV will begin to drift from the center of lane 6, aiming towards cone A, with a lateral drift rate of about .3 m/s.
16. Following the LDW or if the longitudinal center of the SV crosses the lane boundary, SV returns to the center of its original lane.
17. At the completion of test SV stops and gets ready for the next test run.

4.1.4. 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. RD-2 Road departure toward a clear shoulder with 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 lane boundary. The lateral velocity of the SV relative to the boundary markers should be between 0.6 and 0.8 m/s.

4.2.1. Test Overview and Concept

Figure 39 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a clear shoulder with a high 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 high lateral velocity between 0.6 and 0.8 m/s. This is followed by a lateral drift warning at the appropriate distance from the boundary line per the LDW system specification. The conflict is resolved by the SV returning to the center of the original lane.

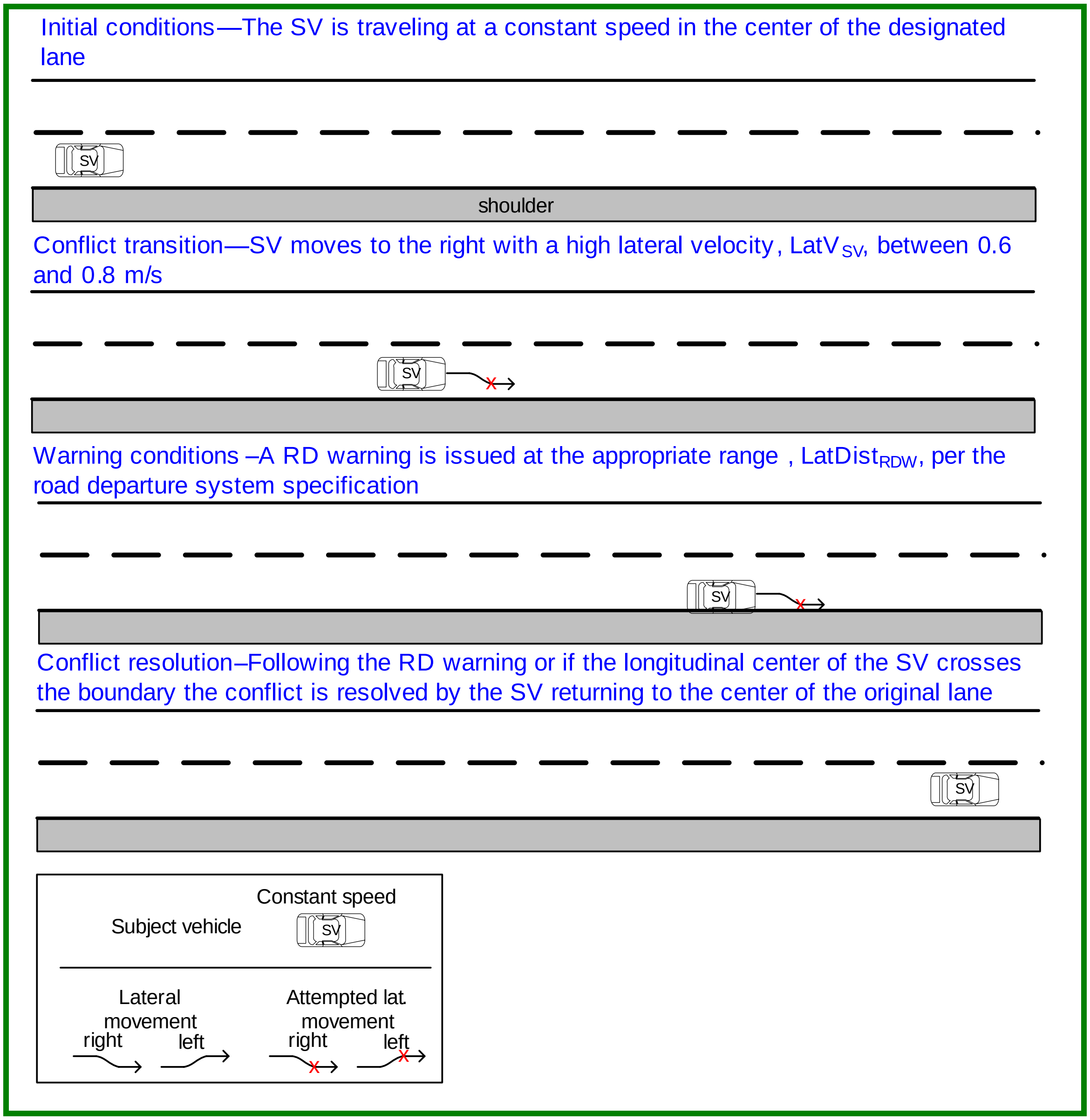

Figure 39: Initial and final conditions for road departure toward a clear shoulder with high lateral speed.

4.2.2. Performance measures and evaluation criteria

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.

Table 42: Run validity criteria for road departure toward a clear shoulder with high lateral speed.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
$LatV_{SV,}$ m/s	0.7	± 0.1
Lane Width, m	4.3	N/A
Turn Signal Status	Off	N/A
D1, m	300	N/A
D2, m	61	± 1.0

Table 43 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem. Negative values are outside the lane.

Table 43: Pass/Fail Criteria for road departure toward a clear shoulder with high lateral speed.[21]

Alert Range	*$LatDist_{RDW}$, m*
Maximum	
Nominal	
Minimum	

4.2.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track, with a solid lane boundary on the side of the lane where road departure is taking place.

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

Figure 40 below is the suggested track layout for conducting this test.

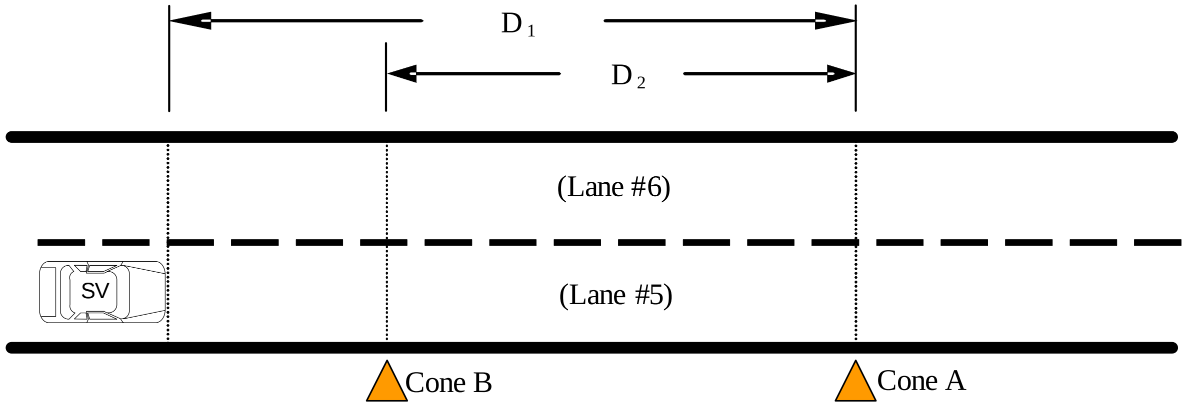

Figure 40: Track Layout for RD toward a clear shoulder with high lateral speed.

All specific speeds and initial conditions for this test are given in Table 42.

Referring to Figure 40, Cone A and Cone B are placed at the outer edge of lane 5 of the skid pad track, with a gap of D2. SV starts in lane 5 of the skid pad track with a gap of D1 from Cone A. SV should reach its steady state constant speed before reaching cone B. SV should initiate lane drift at cone B.

It is to be noted that lanes 5 and 6 at skid pad tracks are approximately 4.3 m (14 ft) wide. Cones A and B are placed about 0.5 lane width (2.1 m) away from the SV centerline. D2 is calculated based on this 0.5 lane width of 2.1 m to generate appropriate drift rate of .7 m/s.

SV Driving Instructions:

1. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
2. SV should reach this speed before reaching cone B.
3. At cone B, SV will begin to drift from the center of lane 5, aiming towards cone A, with a lateral drift rate of about .7 m/s.
4. Following the lateral drift warning or if the longitudinal center of the SV crosses the lane boundary, SV returns to the center of its original lane.
5. At the completion of test SV stops and gets ready for the next test run.

4.2.4. 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. RD-3 Road departure toward a clear shoulder on a curve with a small radii and low vehicle speed (Required Test)

This test is intended to verify the appropriateness of an LDW when the SV, driving at a low speed, drifts at a low lateral speed toward a clear shoulder (designated by a solid lane boundary) on a curve with a small radius (~200 m). The lateral velocity of the SV relative to the solid white boundary marker should be between 0.2 to 0.4 m/s.

4.3.1. Test Overview and Concept

This test evaluates the warning system's ability to detect whether the vehicle is drifting off the road when approaching a curve and to warn the driver in time to ensure that the driver does not exit the road. The speeds and curve radii are to be consistent with a rural road.

Figure 41 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a clear shoulder on a small radius curve, 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 clear shoulder while on a small radius curve. This is followed by a lateral drift warning at the appropriate distance from the boundary line per the LDW system specification. The conflict is resolved by the SV returning to the center of the original lane.

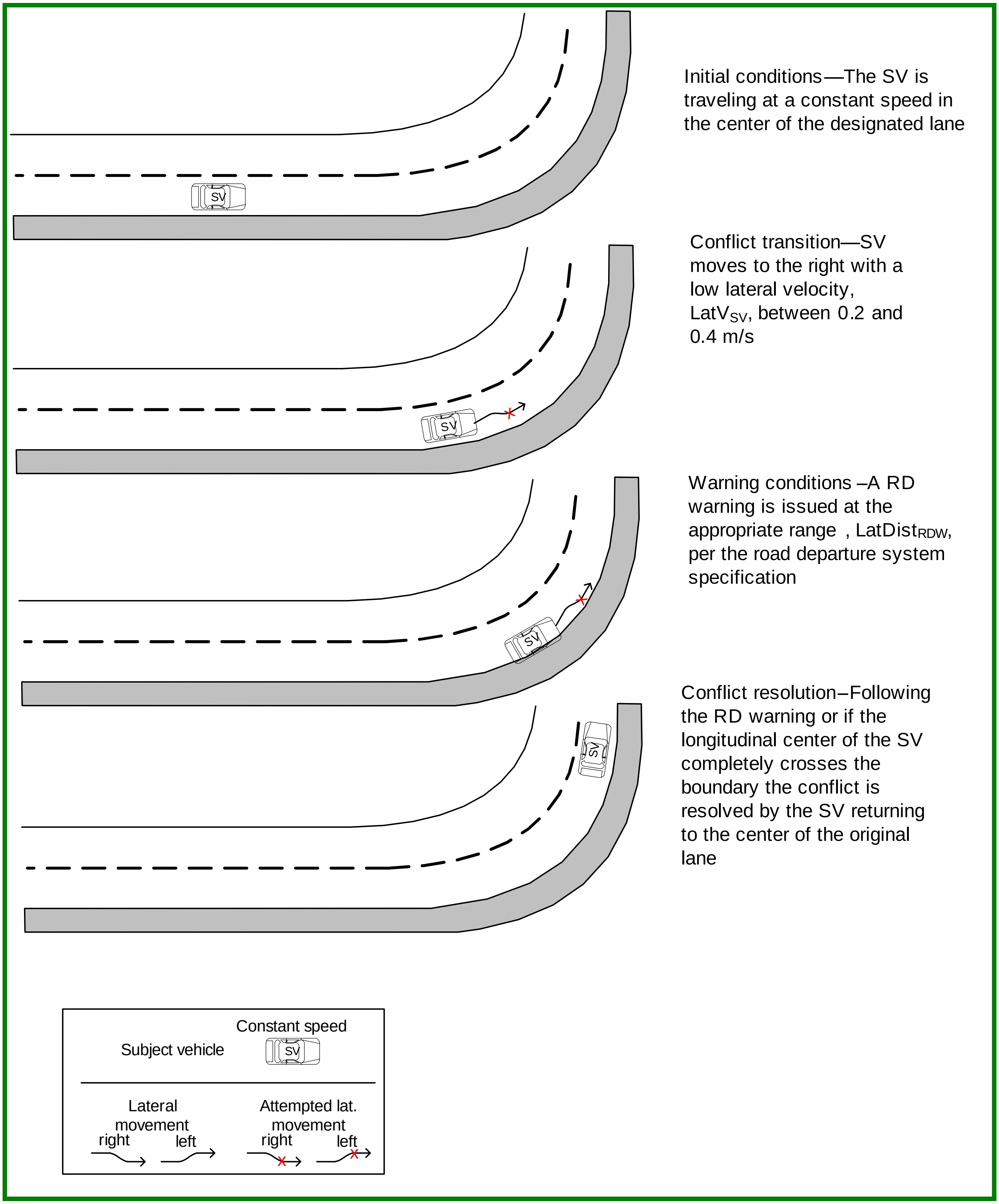
SV
Initial conditions—The SV is traveling at a constant speed in the center of the designated lane
Conflict transition—SV moves to the right with a low lateral velocity, $LatV_{SV}$, between 0.2 and 0.4 m/s
Warning conditions –A RD warning is issued at the appropriate range , $LatDist_{RDW}$, per the road departure system specification
Conflict resolution–Following the RD warning or if the longitudinal center of the SV completely crosses the boundary the conflict is resolved by the SV returning to the center of the original lane
Constant speed
Subject vehicle
Lateral movement
right
left
Attempted lat. movement
right
left

Figure 41: Initial and final conditions for road departure toward a clear shoulder on a curve with small radii

4.3.2. Performance measures and evaluation criteria

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.

Table 44: Run validity criteria for road departure toward a clear shoulder on a curve with a small radius.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	± .8 (1.8 mph)
$LatV_{SV,}$ m/s	0.3	± 0.1
Curve Radius, m	200	± 20
Lane Width, m	3.7	N/A
Turn Signal Status	Off	N/A
D1, m	200	N/A
D2, m	95	± 1.0

Table 45 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem. Negative values are outside the lane.

Table 45: Pass/Fail Criteria for road departure toward a clear shoulder on a curve with a small radius.[22]

Alert Range	*$LatDist_{RDW}$, m*
Maximum	
Nominal	
Minimum	

4.3.3. Track Setup and Driving Instructions

The track to be used for this test is the Winding Road Course (WRC) at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A3 in Appendix. It is to be ensured that there are good lane markings on the track, with a solid lane boundary on the side of the lane where road departure is taking place.

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

Figure 42 below is the suggested track layout for conducting this test.

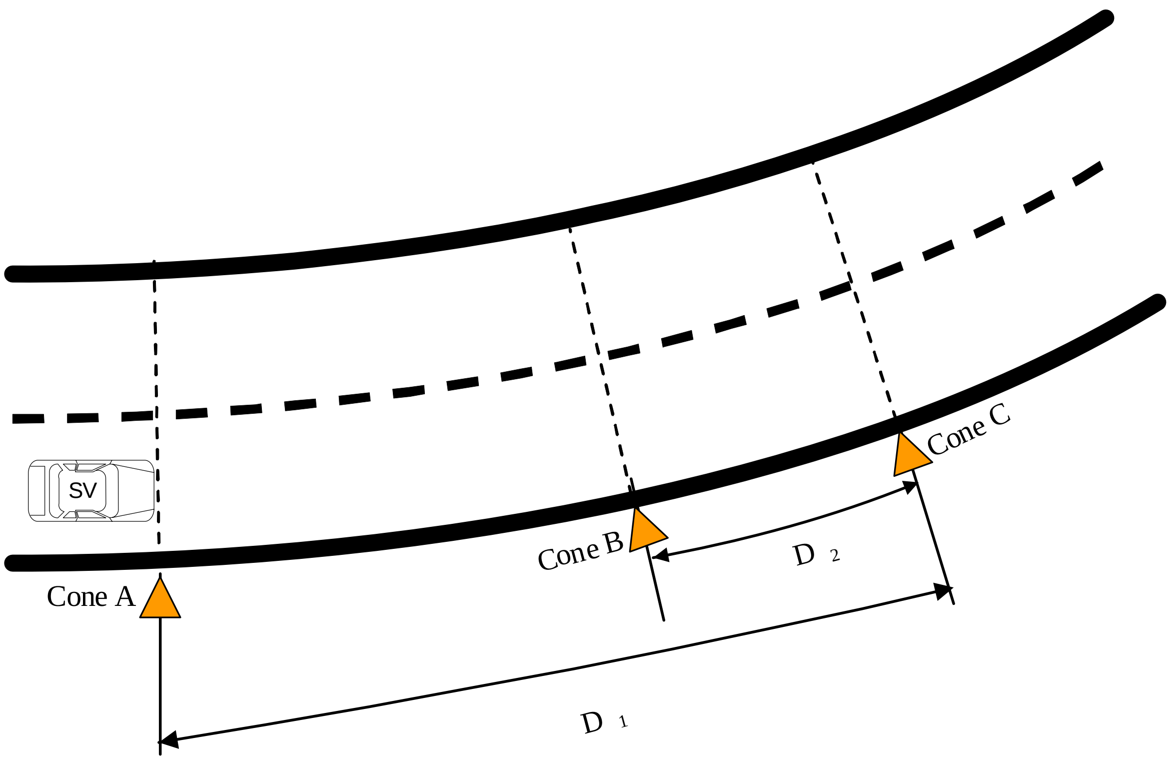

Figure 42: Track layout for RD toward a clear shoulder on a curve with a small radius.

All specific speeds and initial conditions for this test are given in Table 44.

Referring to Figure 42, Cones A, B and C are placed at the outer edge of the outer lane boundary in the curved section H-I of Winding Road Course (Figure A3 in appendix). The SV, traveling clockwise A-B-C-D-G-H-I-J, should reach its steady state constant speed before reaching cone A. SV should initiate lane drift at cone B towards cone C to generate appropriate drift rate.

The lane markings in the curved section shall be placed to get a lane width of 3.66 m (12 ft). Cones A, B and C are placed about 0.5 lane width (1.83 m) away from the SV centerline. D2 is calculated based on this 0.5 lane width of 1.83 m to generate appropriate drift rate when SV starts drifting at Cone B towards cone C.

SV Driving Instructions:

1. SV starts from Point A on the WRC and drives in a counter-clockwise direction (A-B-C-D-G-H-I-J).
2. SV accelerates to 15.7 m/s (35 mph) and engages the cruise control at 15.7 m/s (35 mph).
3. SV should reach this speed before reaching cone A placed on the curved section H-I.
4. At cone B, SV begins to drift towards right from the center of its lane, aiming towards cone C, with a lateral drift rate of about .3 m/s.
5. When LDW is issued or when the longitudinal center of the SV crosses the lane boundary, SV returns to the center of its original lane.
6. At the completion of test SV stops and gets ready for the next test run.

4.3.4. 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. RD-4 Road departure toward a clear shoulder on a curve with a large radii and high vehicle speed (Required Test)

This test is intended to verify the appropriateness of an LDW when the SV, driving at a high speed, drifts at a low lateral speed toward a clear shoulder (designated by a solid lane boundary) on a curve with a large radius (~ 300 m). The lateral velocity of the SV relative to the solid white boundary marker should be between 0.2 to 0.4 m/s.

4.4.1. Test Overview and Concept

This test evaluates the warning system's ability to detect whether the vehicle is drifting off the road when approaching a curve and to warn the driver in time to ensure that the driver does not exit the road. The speeds and curve radii are to be consistent with highway road.

Figure 43 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a clear shoulder on a large radius curve, 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 clear shoulder while on a large radius curve. This is followed by a lateral drift warning at the appropriate distance from the boundary line per the LDW system specification. The conflict is resolved by the SV returning to the center of the original lane.

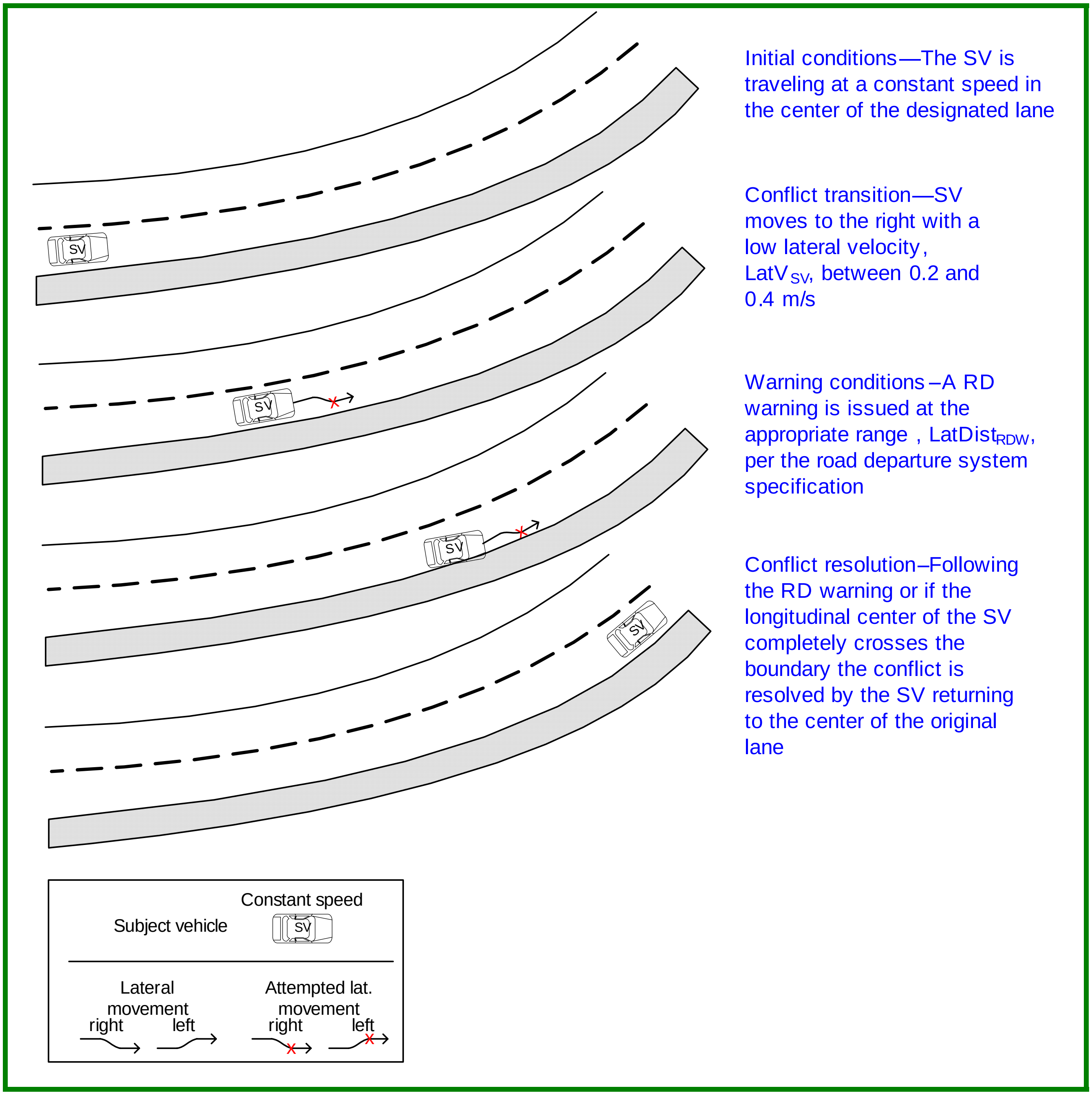

Figure 43: Initial and final conditions for road departure toward a clear shoulder on a curve with a large radius.

4.4.2. Performance measures and evaluation criteria

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 46.

Table 46: Run validity criteria for road departure toward a clear shoulder on a curve with a large radius.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
$LatV_{SV}$, m/s	0.3	± 0.1
Curve Radius, m	300	± 30
Lane Width, m	4.36	N/A
Turn Signal Status	Off	N/A
D1, m	250	N/A
D2, m	146	± 2.0

Table 47 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem. Negative values are outside the lane.

Table 47: Pass/Fail Criteria for road departure toward a clear shoulder on a curve with a large radius.[23]

Alert Range	*$LatDist_{RDW}$, m*
Maximum	
Nominal	
Minimum	

4.4.3. Track Setup and Driving Instructions

The track to be used for this test is the Dana Track in Ottawa Lake, Michigan as shown in Figure A6 in Appendix. It is to be ensured that there are good lane markings on the track, with a solid (or dashed) lane boundary on the side of the lane where road departure is taking place.

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

Figure 44 below is the suggested track layout for conducting this test.

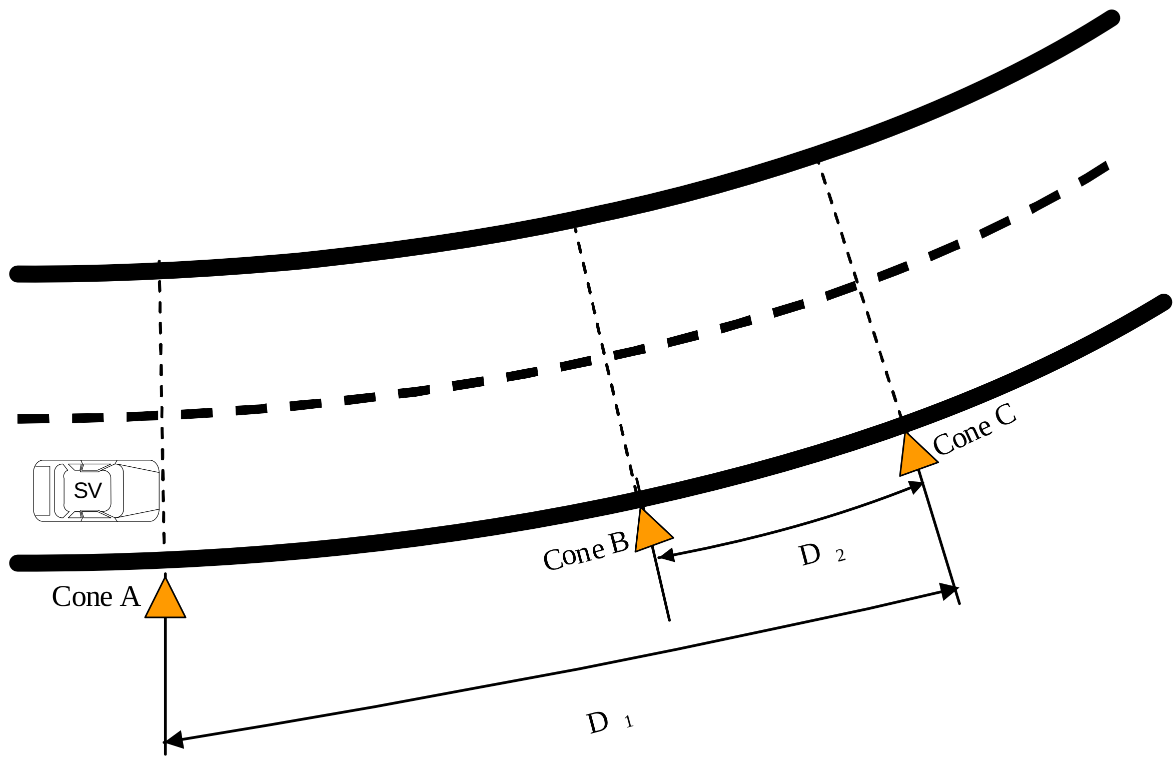

Figure 44: Track Layout for RD toward a clear shoulder on a curve with a large radius.

All specific speeds and initial conditions for this test are given in Table 46.

Referring to Figure 44, Cones A, B and C are placed on the outer edge of the outer lane boundary in the curved section of Dana Track (2.18 m away from the center of the innermost 1st lane).

The lane markings in the curved section are such that we get a lane width of 4.36 m. Cones A, B and C are placed about 0.5 lane width (2.18 m) away from the SV centerline. D2 is calculated based on this 2.18 m to generate appropriate drift rate when SV starts drifting at Cone B towards cone C.

SV should reach its steady state constant speed before reaching cone A. SV should initiate lane drift at cone B towards cone C to generate appropriate drift rate.

SV Driving Instructions:

1. SV starts in the straight section of the inner most 1st lane of the Dana track and accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
2. SV should reach this speed before reaching cone A, placed on the curved section of Dana track.
3. At cone B, SV begins to drift towards right from the center of its lane, aiming towards cone C, with a lateral drift rate of about .3 m/s.
4. When LDW issued or when the longitudinal center of the SV crosses the lane boundary, SV returns to the center of its original lane.
5. At the completion of test SV stops and gets ready for the next test run.

4.4.4. 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. RD-5 Road departure toward a barrier with good lane marker (Engineering Test)

This test is intended to verify the appropriateness of an LDW when the SV drifts at a low lateral speed toward an adjacent jersey barrier with good lane marker. The lateral velocity of the SV relative to the barrier should be between 0.2 to 0.4 m/s.

4.5.1. Test Overview and Concept

This test evaluates the IVBSS system's ability to detect a side collision and warn appropriately.

Figure 45 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a barrier, 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 left with a low lateral velocity between 0.2 and 0.4 m/s toward a barrier. This is followed by a lateral drift warning at the appropriate distance from the LDW system specification. The conflict is resolved by the SV returning to the center of the original lane.

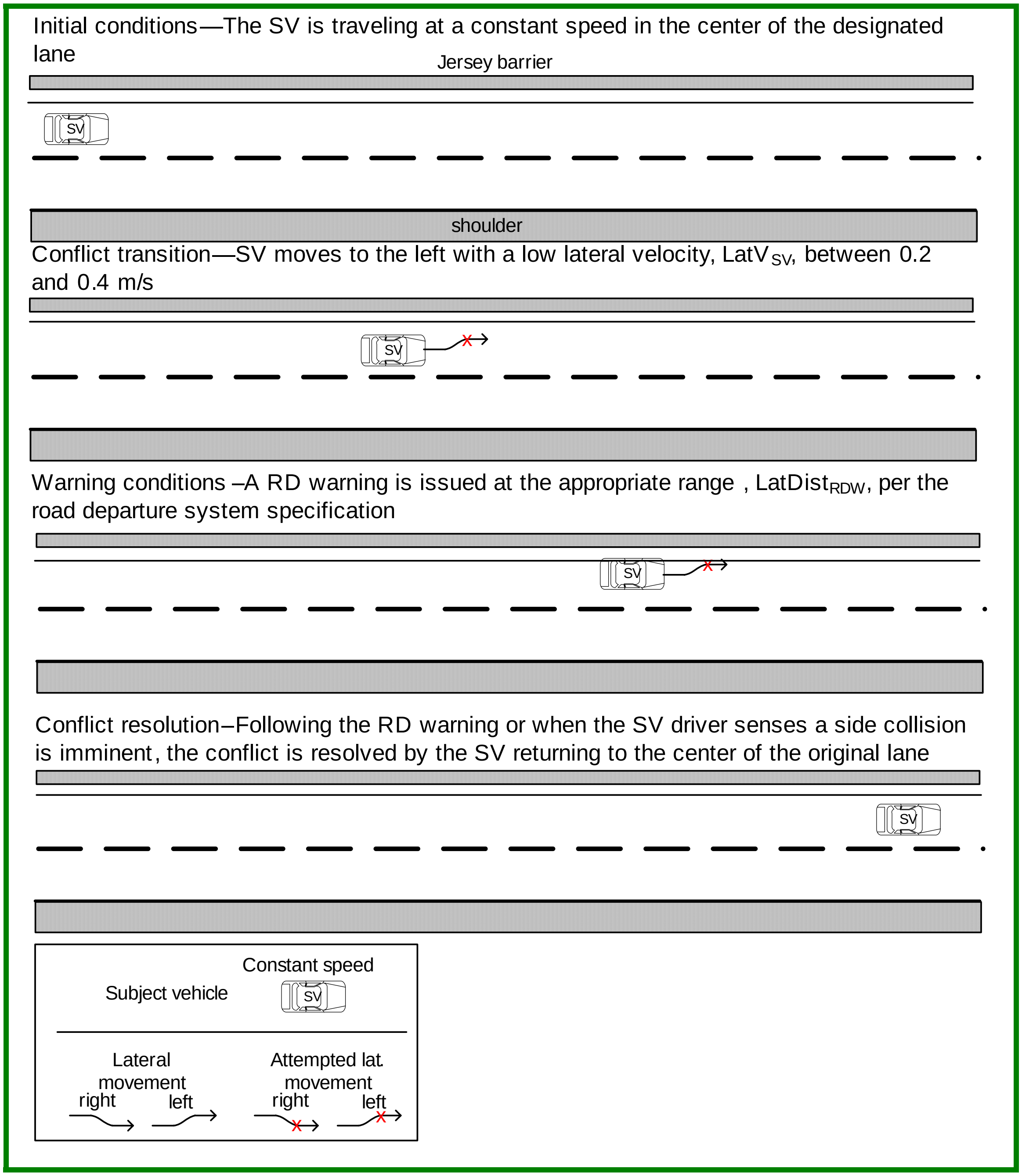

Figure 45: Initial and final conditions for road departure toward a barrier with no lane marker,

4.5.2. Performance measures and evaluation criteria

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.

Table 48: Run validity criteria for road departure toward a barrier with good lane marker.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	± .8 (1.8 mph)
$LatV_{SV,}$ m/s	0.3	± 0.1
Lane Width, m	4.36	N/A
Turn Signal Status	Off	N/A
D1, m	300	N/A
D2, m	114	± 1.0

Table 49 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem. Negative values are outside the lane.

Table 49: Pass/Fail Criteria for road departure toward a barrier with good lane marker.[24]

Alert Range	*$LatDist_{RDW}$, m*
Maximum	
Nominal	
Minimum	

4.5.3. Track Setup and Driving Instructions

The track to be used for this test is the Dana Track in Ottawa Lake, Michigan as shown in Figure A6 in Appendix.

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

Figure 46 below is the suggested track layout for conducting this test.

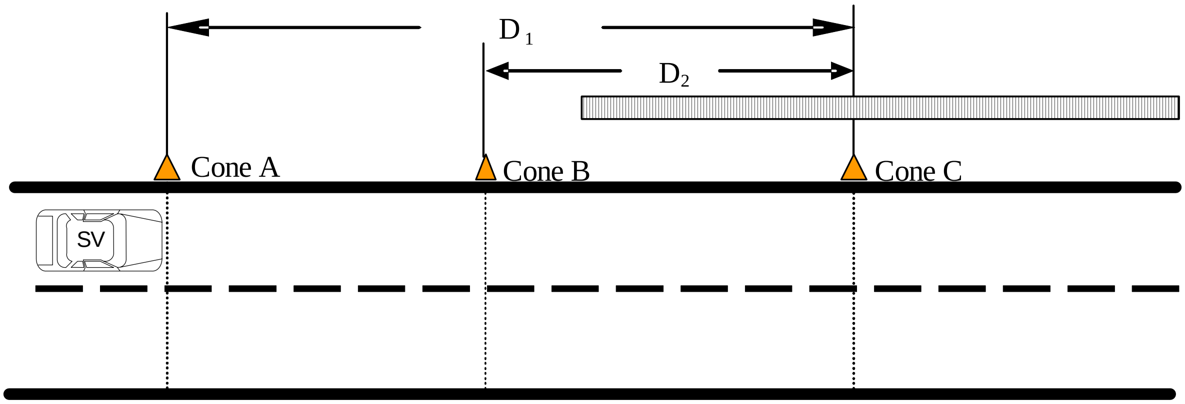

Figure 46: Track Layout for RD toward a barrier with no lane marker.

All specific speeds and initial conditions for this test are given in Table 48.

Referring to Figure 46, a continuous barrier shall be setup along the outside lane boundary of the inner most lane of Dana Track straight section. The continuous barrier shall be 1-meter outside of the inner lane boundary of Lane 1 (from the boundary on the left side of the SV). The continuous barrier shall be comprised of 76 m (250 ft) of plastic water-filled jersey barriers.

The track needs to be prepared such that there is good lane marking on both sides of the vehicle.

The lane width of 4.36 m is assumed to calculate the location of Cones A, B and C. Cones A, B and C are placed, about 0.5 lane width (2.18 m) away from the SV centerline. Cone C is placed near the midpoint of the Jersey barrier. Cones A and B are at specific distance from Cone C based on the values given in Table 48. D2 is calculated based on this 2.18 m value to generate appropriate drift rate when SV starts drifting at Cone B towards cone C.

SV should reach its steady state constant speed before reaching cone B. SV should initiate lane drift at cone B towards cone C to generate appropriate drift rate.

SV Driving Instructions:

1. SV starts at the beginning of the straight section of the Dana track from Cone A and accelerates to 15.7 m/s (35 mph) and engages the cruise control at 15.7 m/s (35 mph).
2. SV should reach this speed before reaching cone B.
3. At cone B, SV begins to drift towards left from the center of its lane, aiming towards cone C, with a lateral drift rate of about .3 m/s.
4. When LDW is issued or before the driver senses that side collision with the barrier is imminent, SV returns to the center of its original lane.
5. At the completion of test SV stops and gets ready for the next test run.

4.5.4. Exceptions to the standard test conditions

This test calls for placing a jersey barrier 1 m outside the lane boundary. Besides this, there are no other exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

4.6. RD-6 Road departure toward a curve with excessive speed in warm/dry condition (Required Test)

This test is intended to verify the appropriateness of a curve speed warning (CSW), when the SV driving at excessive speed encounters a small radius curve in warm/dry condition.

4.6.1. Test Overview and Concept

This test evaluates the warning system's ability to detect whether the vehicle is traveling too fast for an approaching curve and to warn the driver in time to slow the vehicle to a safe speed for warm/dry condition. The speeds and curve radii are to be consistent with a rural road scenario where this type of crash most often occurs.

This test consists of a SV traveling at 22.4 m/s (50 mph) on a straight, flat road toward a curve. The test is performed on the winding road course (WRC) at TRC traveling in the counter clockwise direction. The section between F and B are to be used and the radius of the curve at point C is 91 m (300 ft). Refer to Figure A3 in the appendix for WRC.

Figure 47 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a curve with excessive speed in warm/dry condition. The top of the figure shows that the SV is traveling at a constant high speed in the center of the designated lane. Next, the SV approaches the small radius curve at excessive speed. This is followed by a curve speed warning at the appropriate distance from the curve per the CSW system specification. The conflict is resolved by the SV slowing down to negotiate the curve at safe speed.

NOTICE

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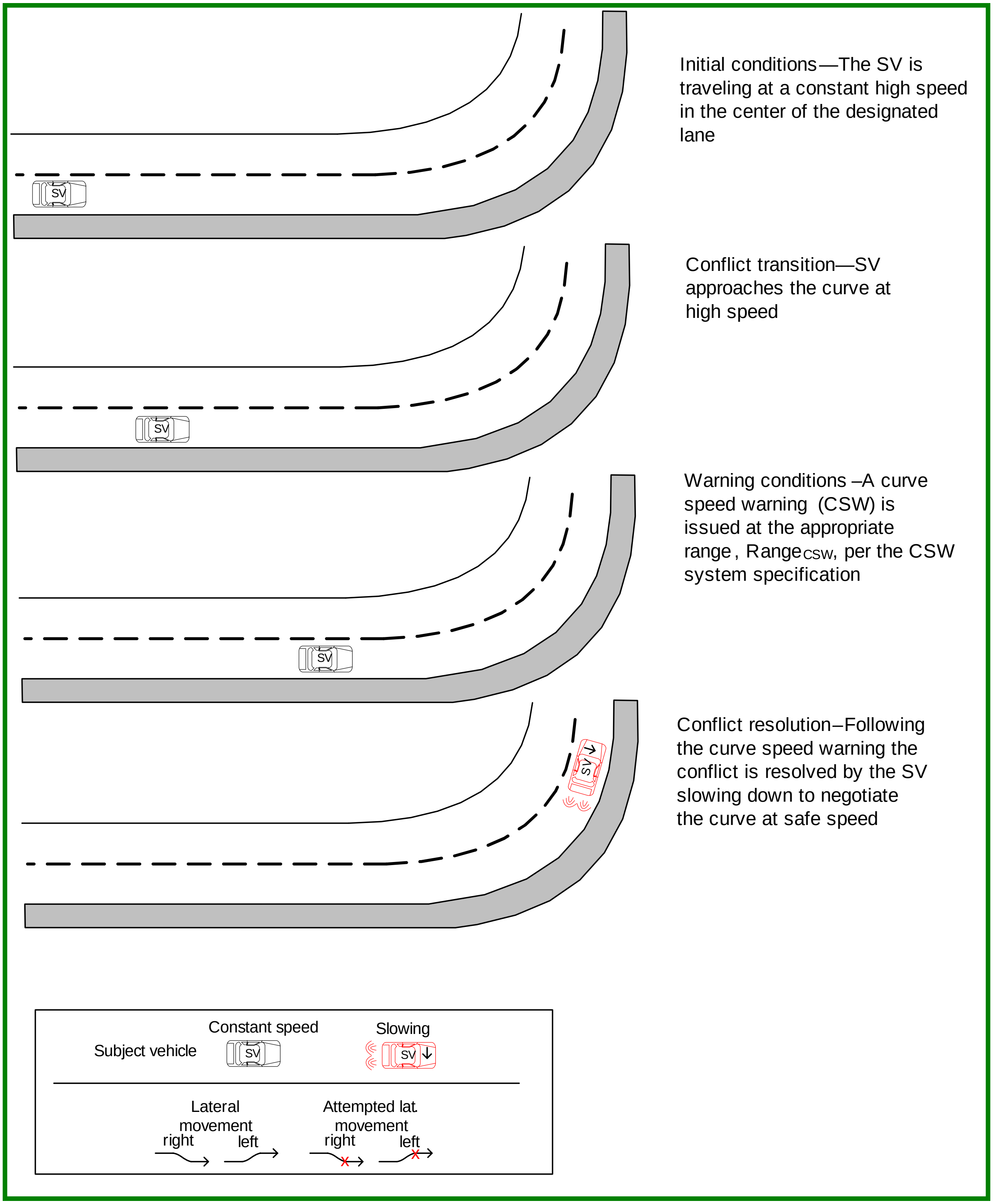


Figure 47: Initial and final conditions for road departure toward a curve with excessive speed in warm/dry condition.

4.6.2. Performance measures and evaluation criteria

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.

Table 50: Run validity criteria for road departure toward a curve with excessive speed in warm/dry condition.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	22.4 (50 mph)	± 1.1 (2.5 mph)
Curve Radius, m	100	± 10
Lane Width, m	3.7	N/A
Wiper Status	Off	N/A
D1, m[25]		N/A
D2, m[25]		± 1.0

Table 51 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 51: Pass/Fail Criteria for road departure toward a curve with excessive speed in warm/dry condition.[25]

Alert Range	*R_{CSW}, m*
Maximum	
Nominal	
Minimum	

4.6.3. Track Setup and Driving Instructions

The track to be used for this test is the Winding Road Course at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure 48.

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

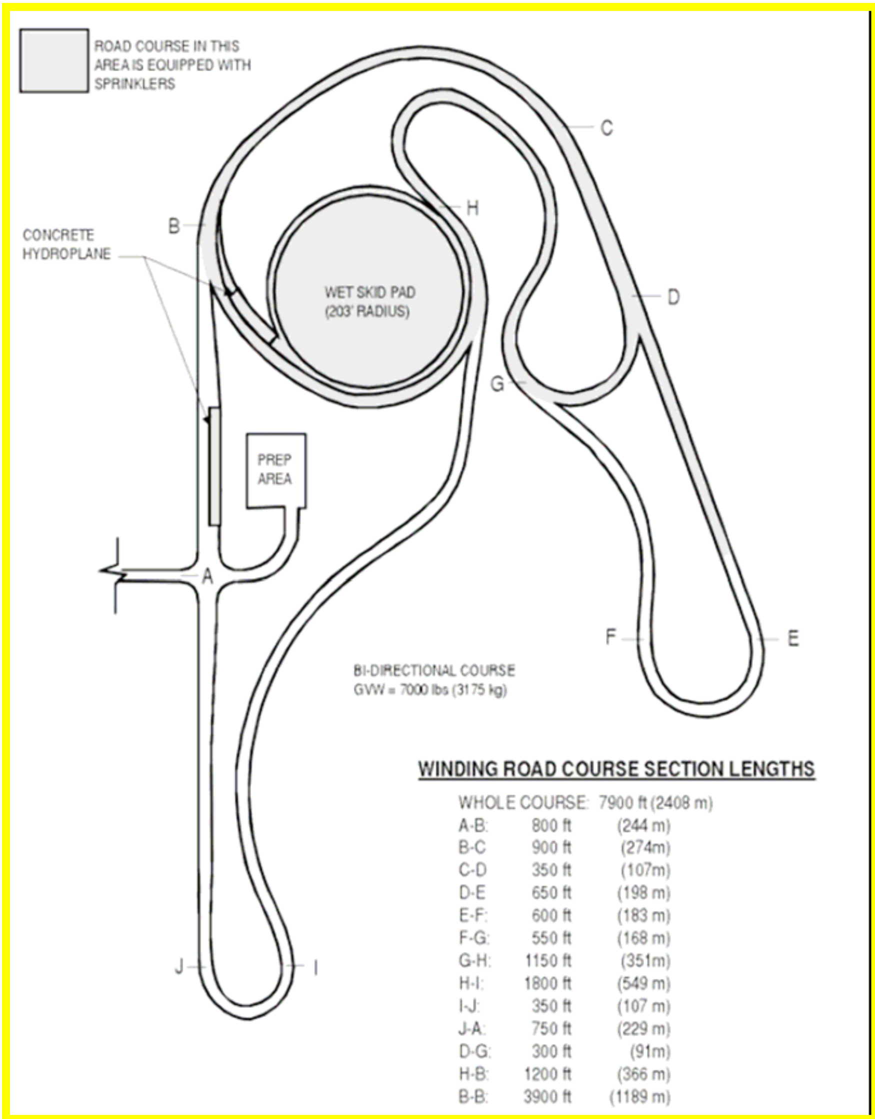


Figure 48: Track for RD toward a curve with excessive speed in warm/dry condition.

Figure 49 below is the suggested track layout for conducting this test.

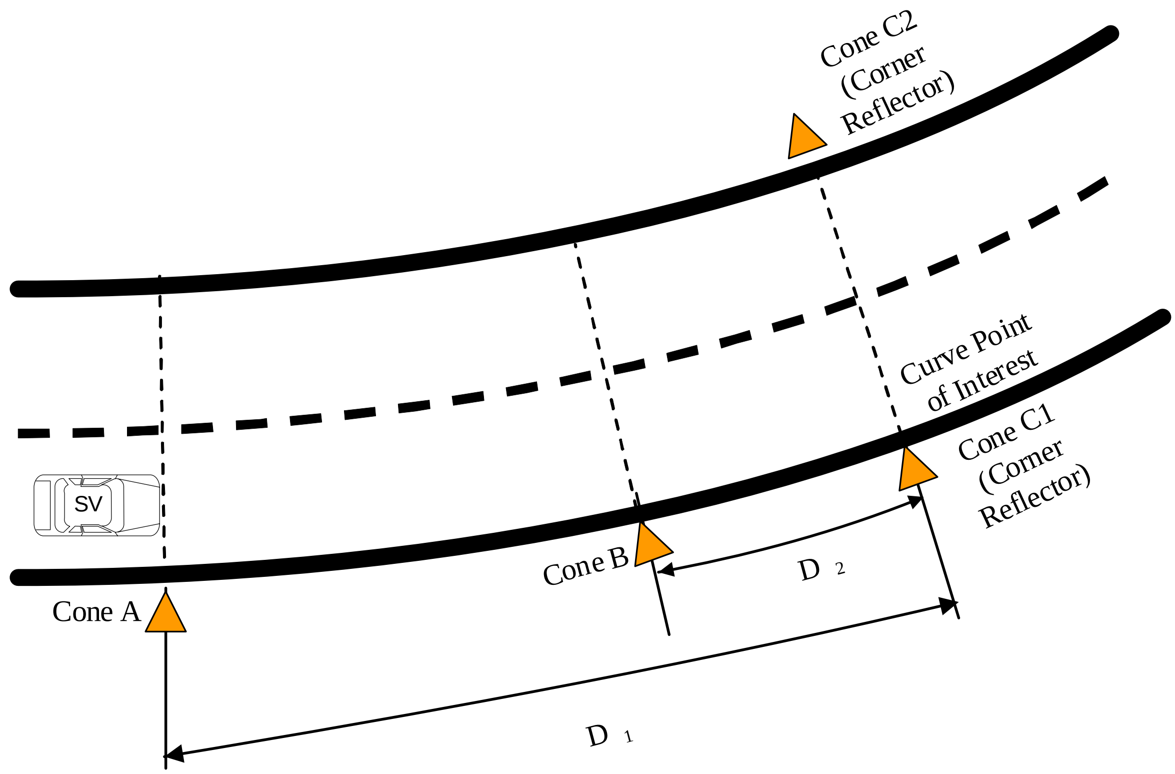


Figure 49: Track Layout for RD toward a curve with excessive speed in warm/dry condition.

For this test, standard 3.66 m wide lane boundaries shall be established 150 m prior to and after the transition point into the curve to assist the driver to maintain the same trajectory for each test.

Referring to Figure 49, Cones A, B and C1 are placed at the outer edge of the outer lane boundary in the curved section D-C-B of Winding Road Course (traveling counter clockwise E-D-C-B). Cone C2 is placed at the outer edge of the inner lane boundary of this same curved section D-C-B.

Cones C1 and C2 are corner reflectors, placed at the curve point of interest (CPI) to capture the vehicle's entrance to the curve as well as provide range data to be associated with curve speed warning. The inside corner reflector (C2) shall be a 20 dBsm triangle facing parallel to the road boundary. The other corner reflector (C1) shall be of the same magnitude but shall be placed perpendicular to the roadway to allow it to be seen by the forward looking radar.

This curve point of interest (CPI) location is calculated from simulation. It is the curvature point that triggers the curve speed warning at a given test speed for the test road segment. To locate it, we need to monitor the first curvature point (several points are displayed) using the serial bus from the CSW sub-system. When it becomes equal to the CPI used in the simulation, that position on the road segment is marked as the CPI for this specific test speed.

All specific speeds and initial conditions for this test are given in Table 50.

SV Driving Instructions:

1. SV starts from Point E on the WRC and drives in a counter-clockwise direction (E-D-C-B).
2. SV accelerates to 22.4 m/s (50 mph) and engages the cruise control at 22.4 m/s (50 mph).
3. SV should reach this speed before reaching cone A and should drive through the curve without applying the brakes.
4. CSW alert should be sounded before reaching cone B. SV should continue negotiating the curve even if alert is not issued.
5. When the CSW alert is sounded, SV driver must apply the brake to indicate to the IVBSS system that it was a valid alert.
6. At the completion of test SV stops and gets ready for the next test run.

4.6.4. Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions, except ensuring that wiper is turned off during the test.

4.7. RD-7 Road departure toward a curve with excessive speed in cold/wet condition (Required Test)

This test is intended to verify the appropriateness of a curve speed warning (CSW), when the SV driving at excessive speed encounters a small radius curve in cold/wet condition.

4.7.1. Test Overview and Concept

This test evaluates the warning system’s ability to detect whether the vehicle is traveling too fast for an approaching curve and to warn the driver in time to slow the vehicle to a safe speed for cold/wet condition. The speeds and curve radii are to be consistent with a rural road scenario where this type of crash most often occurs.

This test consists of a SV traveling at 22.4 m/s (50 mph) on a straight, flat road toward a curve. The test is performed on the Winding Road Course (WRC) at TRC traveling in the counter clockwise direction. The section between F and B are to be used and the radius of the curve at point C is approximately 91 m (300 ft). Refer to Figure A3 in the appendix for WRC.

Figure 50 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a curve with excessive speed in cold/wet condition. The top of the figure shows that the SV is traveling at a constant high speed in the center of the designated lane. Next, the SV approaches the small radius curve at excessive speed. This is followed by a curve speed warning at the appropriate distance from the curve per the CSW system specification. The conflict is resolved by the SV slowing down to negotiate the curve at safe speed.

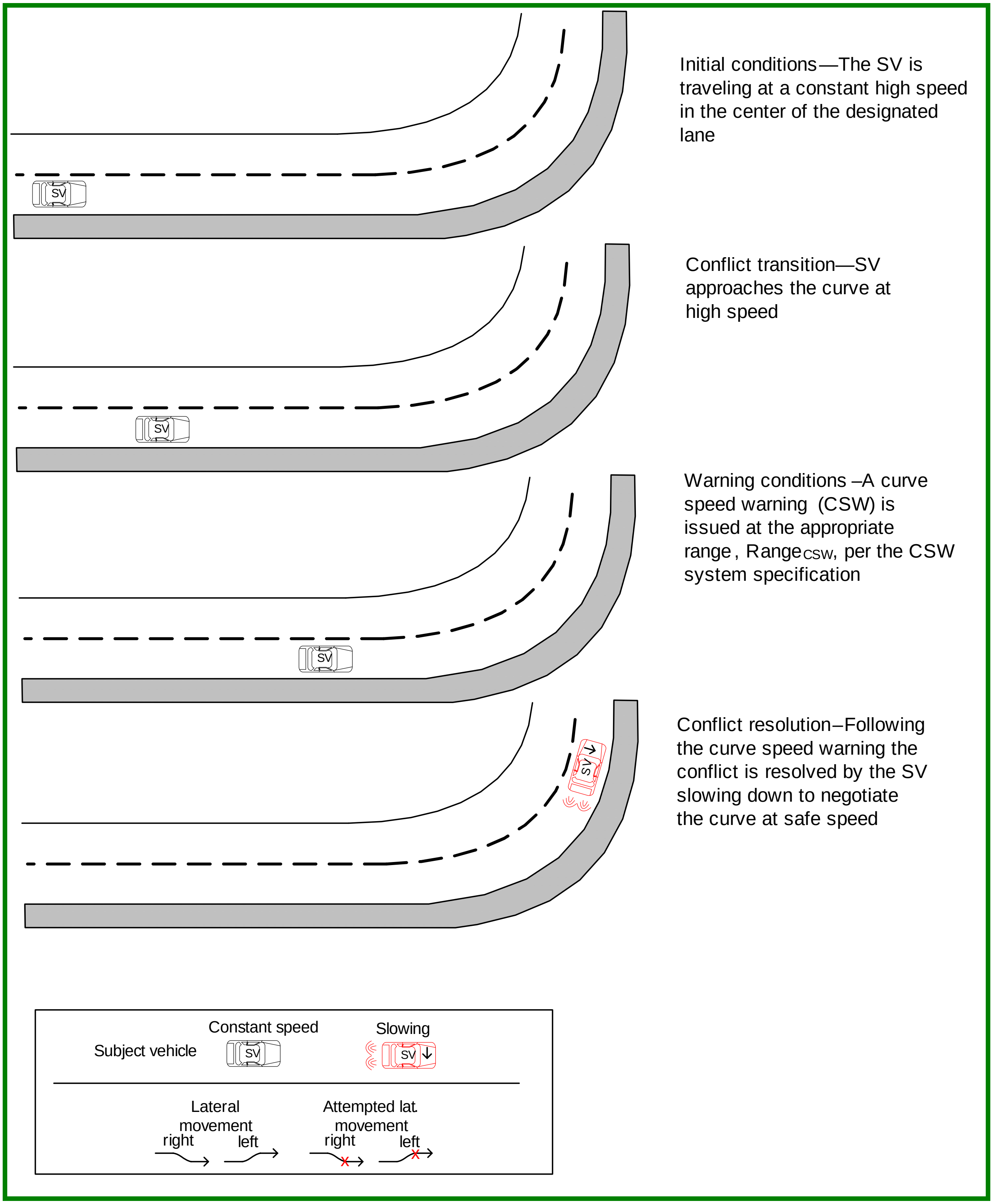


Figure 50: Initial and final conditions for road departure toward a curve with excessive speed in cold/wet condition.

4.7.2. Performance measures and evaluation criteria

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.

Table 52: Run validity criteria for road departure toward a curve with excessive speed in cold/wet condition.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	22.4 (50 mph)	± 1.1 (2.5 mph)
Curve Radius, m	100	± 10
Lane Width, m	3.7	N/A
Wiper Status	On	N/A
D1, m[26]		N/A
D2, m[26]		± 1.0

Table 53 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS subsystem.

Table 53: Pass/Fail Criteria for road departure toward a curve with excessive speed in cold/wet condition.[26]

Alert Range	*R_{CSW}, m*
Maximum	
Nominal	
Minimum	

4.7.3. Track Setup and Driving Instructions

The track to be used for this test is the Winding Road Course at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure 49.

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

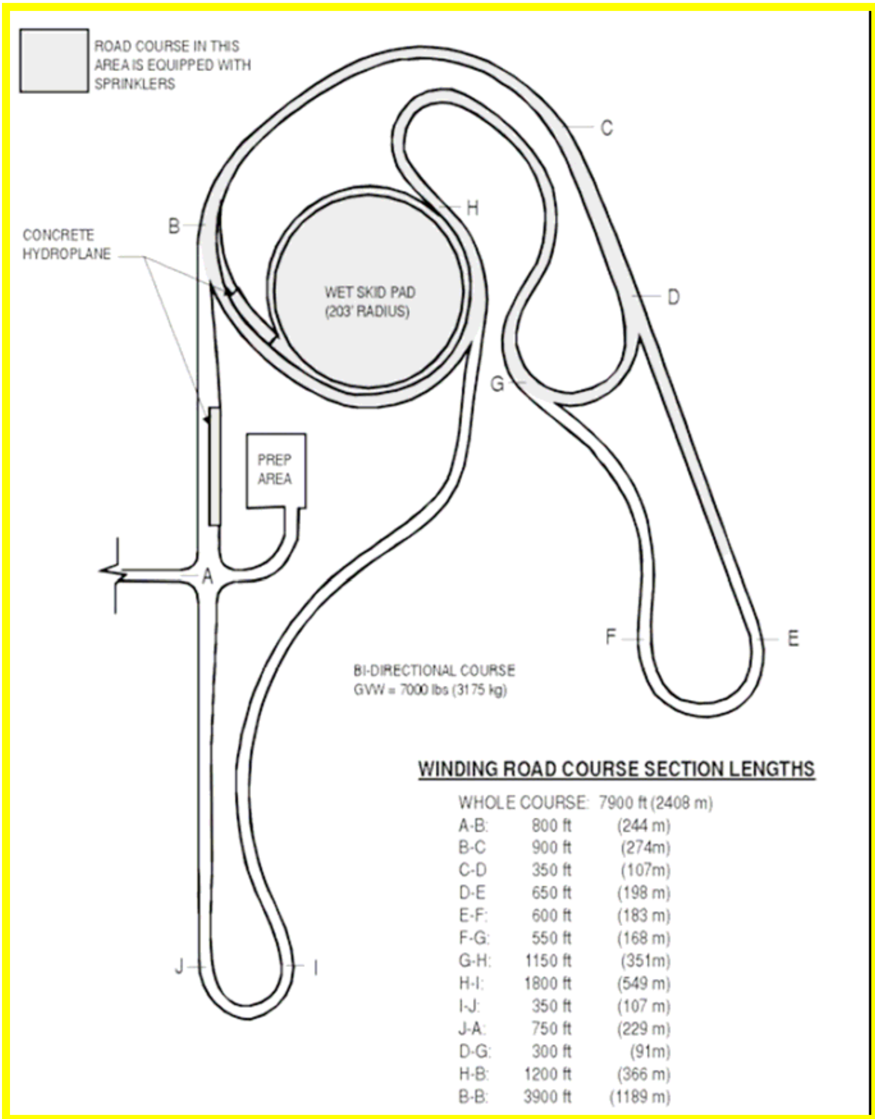


Figure 51: Track for RD toward a curve with excessive speed in cold/wet condition.

Figure 52 below is the suggested track layout for conducting this test.

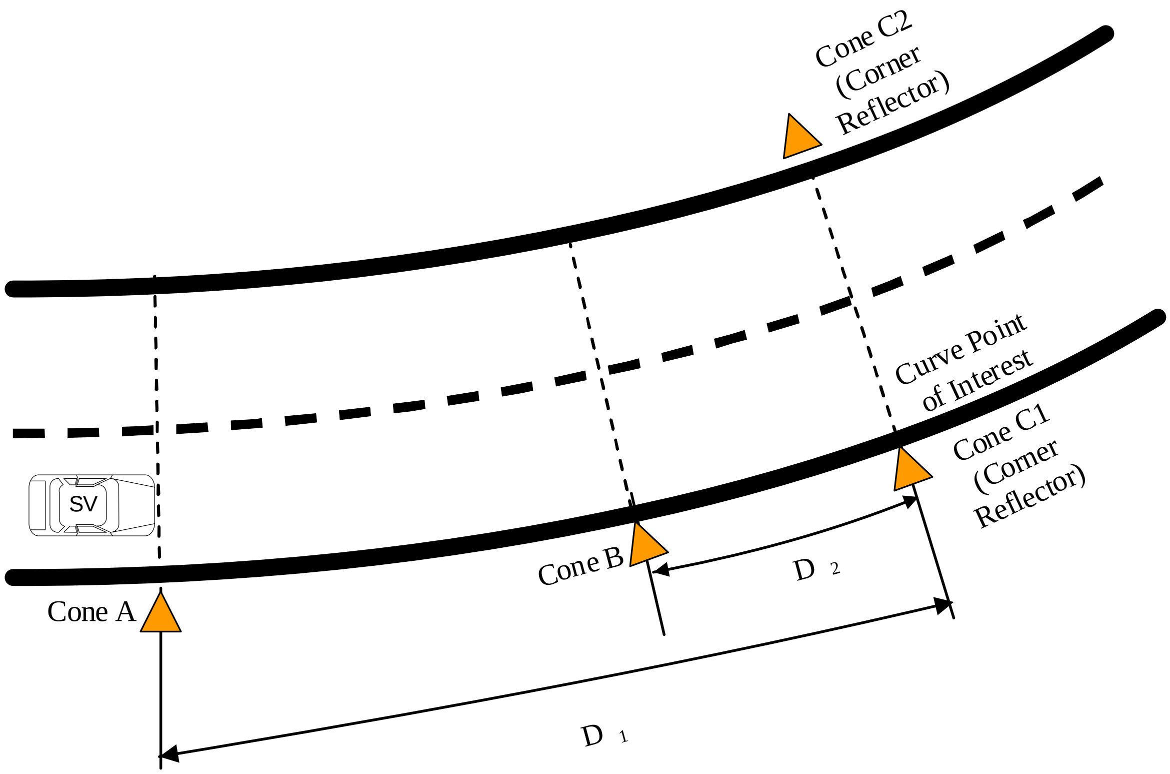


Figure 52: Track Layout for RD toward a curve with excessive speed in cold/wet condition.

For this test, standard 3.66 m wide lane boundaries shall be established 150 m prior to and after the transition point into the curve to assist the driver to maintain the same trajectory for each test.

Referring to Figure 52, Cones A, B and C1 are placed at the outer edge of the outer lane boundary in the curved section D-C-B of Winding Road Course (traveling counter clockwise E-D-C-B). Cone C2 is placed at the outer edge of the inner lane boundary of this same curved section D-C-B.

Cones C1 and C2 are corner reflectors, placed at the curve point of interest (CPI) to capture the vehicle's entrance to the curve as well as provide range data to be associated with curve speed warning. The inside corner reflector (C2) shall be a 20 dBsm triangle facing parallel to the road boundary. The other corner reflector (C1) shall be of the same magnitude but shall be placed perpendicular to the roadway to allow it to be seen by the forward looking radar.

This curve point of interest (CPI) location is calculated from simulation. It is the curvature point that triggers the curve speed warning at a given test speed for the test road segment. To locate it, we need to monitor the first curvature point (several points are displayed) using the serial bus from the CSW sub-system. When it becomes equal to the CPI used in the simulation, that position on the road segment is marked as the CPI for this specific test speed.

All specific speeds and initial conditions for this test are given in Table 52.

SV Driving Instructions:

1. SV starts from Point E on the WRC and drives in a counter-clockwise direction (E-D-C-B).
2. SV accelerates to 22.4 m/s (50 mph) and engages the cruise control at 22.4 m/s (50 mph).
3. SV should reach this speed before reaching cone A and should drive through the curve without applying the brakes.
4. CSW alert should be sounded before reaching cone B. SV should continue negotiating the curve even if alert is not issued.
5. When the CSW alert is sounded, SV driver must apply the brake to indicate to the IVBSS system that it was a valid alert.
6. At the completion of test SV stops and gets ready for the next test run.

4.7.4. Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions, except ensuring that wiper is turned on during the test.

4.8. RD-8 Road Departure toward an occupied lane with POV forward on left (Required Test) –

This test is intended to verify the appropriateness of a road departure warning when the SV begins to change lanes to the left without using the turn signal while the adjacent lane is occupied by another vehicle that is located such that the POV rear bumper is aligned with front bumper of SV. In this test both vehicles are traveling at the same forward speed.

4.8.1. Test Overview and Concept

Figure 53 shows the initial, transitional, warning and conflict resolution conditions for a lane departure conflict. The test begins with the SV and POV traveling nominally at the same speed in the center of their designated lanes with the rear bumper of the POV aligned laterally with front bumper of SV. The conflict initiates when SV driver without signaling, moves to the left with a lateral velocity, $LatV_{SV}$, between 0.25 and 0.55 m/s. The test ends when LDW warning is issued or the SV driver senses a crash is imminent. The conflict is resolved by lateral position changes to the right by the SV.

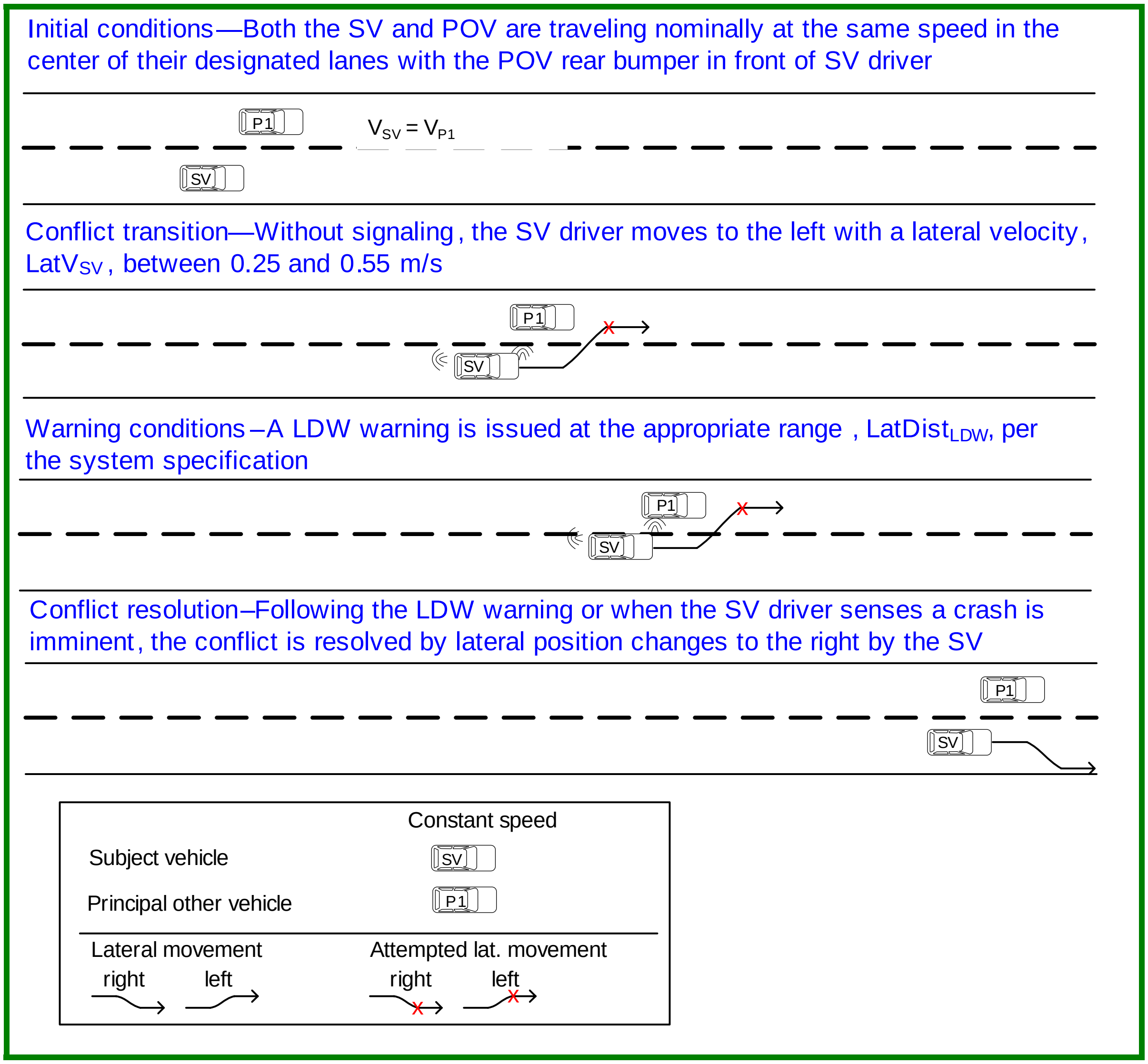


Figure 53: Initial and final conditions for road departure toward an occupied lane with POV forward on left.

4.8.2. Performance measures and evaluation criteria

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 54.

Table 54: Run validity criteria for road departure toward an occupied lane with POV forward on left.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
$LatV_{SV}$, m/s	0.40	± 0.15
P1 Position	P1 rear bumper in front of SV driver	N/A
Turn Signal Status	Off	N/A
D1, m	200	N/A

Table 55 below gives the alert range for evaluating if the warning was issued per the design intent of the IVBSS system.

Table 55: Pass/Fail Criteria for road departure toward an occupied lane with POV forward on left.[27]

Alert Range	*$LatDist_{RDW}$, m*
Maximum	
Nominal	
Minimum	

4.8.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track.

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

Figure 54 below is the suggested track layout for conducting this test.

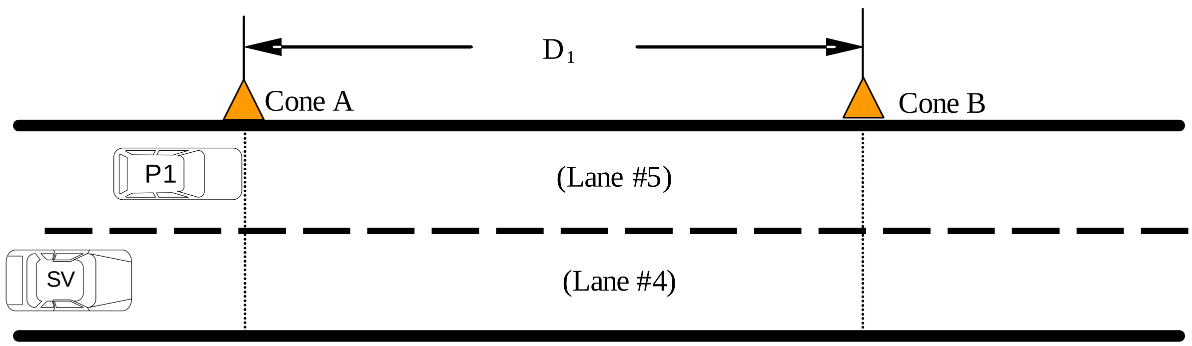


Figure 54: Track Layout for road departure toward an occupied lane with POV forward on left.

All specific speeds and initial conditions for this test are given in Table 54.

Referring to Figure 54, SV and P1 are placed in lane 4 and lane 5 of the skid pad track respectively such that P1's rear bumper is in front of SV driver. SV should maintain its position relative to P1 during the test until it changes lane.

SV Driving Instructions:

1. SV signals P1 to start the test.
2. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
3. SV should reach this speed before reaching cone B. During this period SV maintains its relative position with respect to P1 and matches its speed with P1.
4. At cone B, SV initiates a left lane change move (without using the turn signal) towards P1 at a low rate of lateral drift (0.25 to 0.55 m/s).
5. When the required road departure warning occurs or when the SV driver senses a crash with P1 is imminent, SV steers back in its original lane, lane 4.
6. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 20.1 m/s (45 mph) and engages the cruise control.
2. P1 should carefully monitor the SV vehicle, which would be changing lane and moving to the lane 5 currently occupied by P1.
3. When SV is changing lane, P1 driver should maintain its designated lane to the best of their ability and judgment (in order to elicit a road departure warning); however, if P1 driver senses a crash is imminent with SV, it could move into the left adjacent lane 6.
4. At the completion of test P1 stops and gets ready for the next run.

4.8.4. Exceptions to the standard test conditions

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

5. Multiple Threat (MT) Tests

There are two required multiple-threat crash-imminent tests. Each of the tests is intended to simulate conflict scenarios that consist of combinations of two or three individual warning functions. The intent of these tests is to verify that the system arbitration algorithm presents the driver with appropriate warnings that are inherently intuitive and do not confuse the driver.

5.1. MT-1 Avoid RE with slower P1 and encounter LC with adjacent P2 (FCW followed by LCW) (Required Test)

This test is intended to verify the appropriateness of an FCW and LCW when the SV approaches a slower P1 while there is an adjacent P2 that prevents the SV from changing lanes to maneuver around P1. In this test the SV and P2 are traveling at the same forward speed.

The test determines whether the IVBSS system provides appropriate warning or series of warnings to the SV in this multiple threat scenario. It will also show that the IVBSS Warning System will not suppress critical warnings due to multiple threats occurring.

5.1.1. Test Overview and Concept

Figure 55 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 P2 traveling at the same speed in the center of their designated lanes with the front bumper of P2 aligned with SV rear window (C-pillar). P1 is traveling at a slower speed in the center of the SV lane. The center of the figure shows that an FCW warning should occur when the SV reaches the R_{FCW} as specified by the designers of the FCW system. Following the FCW, the SV driver signals and moves to the right with a moderate lateral velocity. An LCW is issued at the appropriate range, $LatDist_{LCW}$. To resolve the conflict, P2 brakes and moves to the right, allowing SV to slow and maneuver around P1.

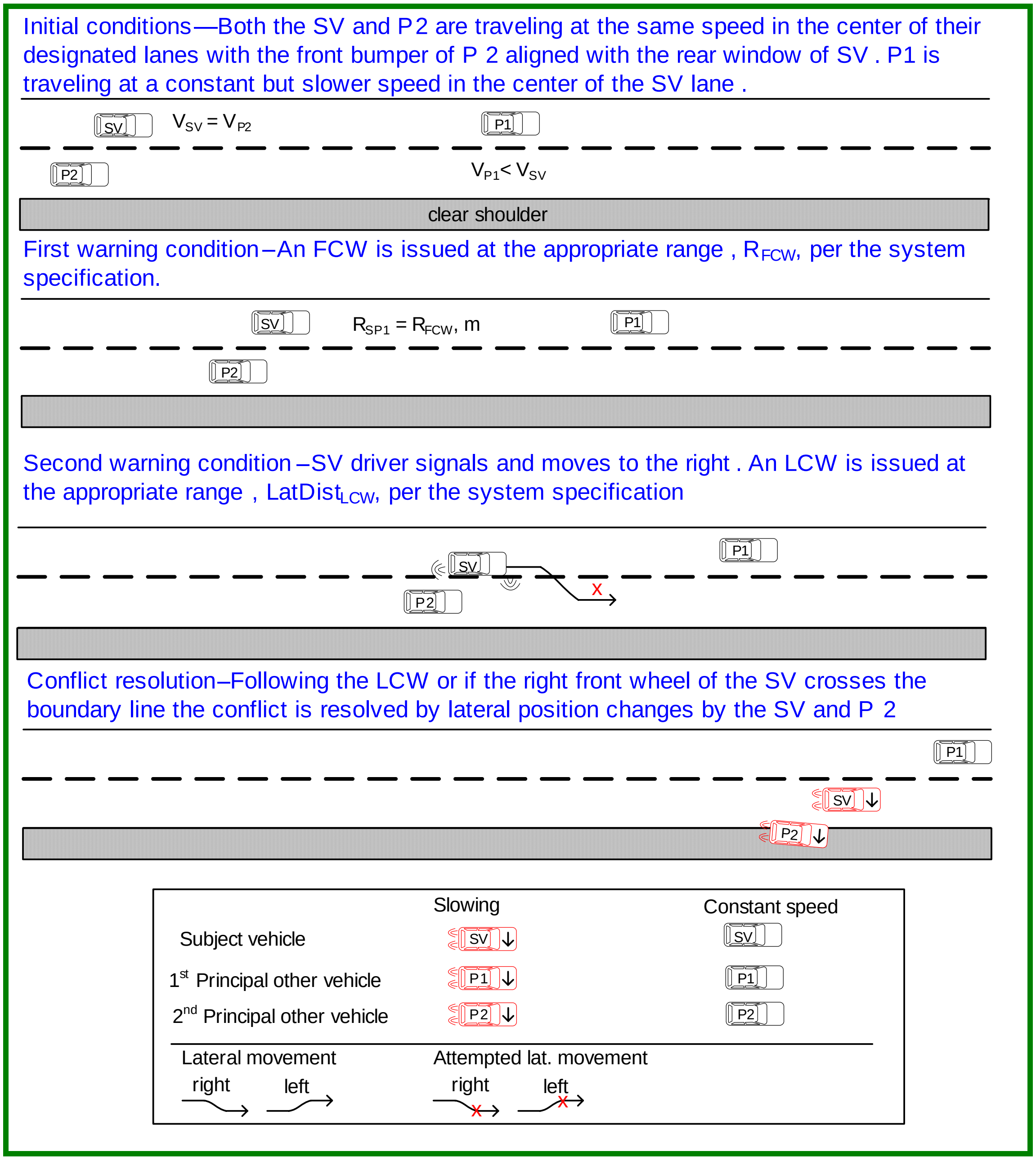


Figure 55: Initial and final conditions for MT1 (FCW followed by LCW)

5.1.2. Performance measures and evaluation criteria

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 56.

Table 56. Run validity criteria for MT1 (FCW followed by LCW)

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	22.4 (50 mph)	± 1.12 (2.5 mph)
V_{P1}, m/s	11.2 (25 mph)	± 0.56 (1.3 mph)
V_{P2}, m/s	22.4 (50 mph)	± 1.12 (2.5 mph)
$Rdot_{SP1}$, m/s	-11.2	± 1.68
P2 Position	P2 front bumper aligned with SV rear window (C-pillar)	N/A
$LatV_{SV}$, m/s	0.65	N/A
Turn Signal Status (after FCW)	On	N/A
D1 (Initial R_{SP1}), m	200	N/A
D2, m	100	N/A
$LatDist_{ss}$	>0.9 m	N/A

Table 57 below gives the alert ranges for evaluating if the warnings were issued per the design intent of the IVBSS subsystem.

Table 57. Pass/Fail Criteria for MT1 (FCW followed by LCW)[28]

Alert Range	*R_{FCW}, m*	*$LatDist_{LCW}$, m*
Maximum		
Nominal		
Minimum		

5.1.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix.

Figure 56 below is the suggested track layout for conducting this test.

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

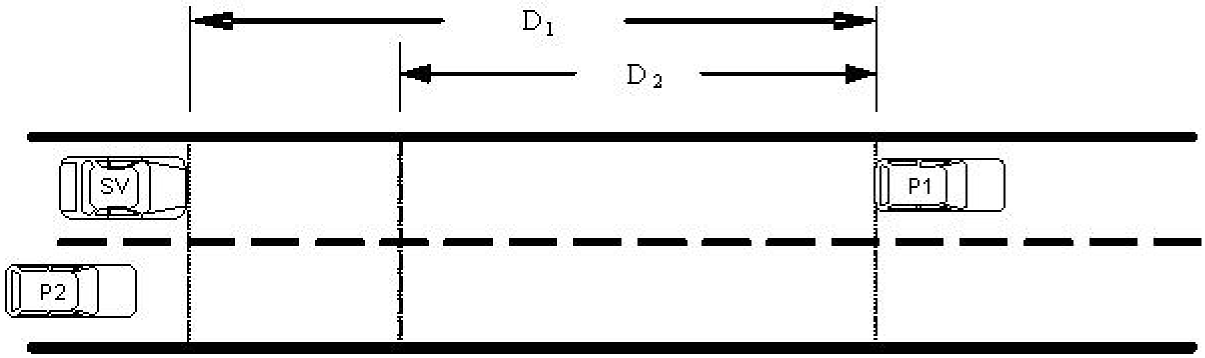


Figure 56: Track Layout for MT1 (FCW followed by LCW)

All specific speeds and initial conditions for this test are given in Table 56. Referring to Figure 56, both SV and P1 start in the lane 6 of the skid pad track with an initial gap of D1 (200 m). P2 starts in the right adjacent lane 5 and is placed such that its front bumper is aligned with the C-pillar (rear window) of the SV. Both SV and P1 should reach their respective steady state constant speeds when the range between SV and P1 is D2 (100 m). P2 will maintain its position relative to SV during the test until SV changes lane.

SV Driving Instructions:

5. SV gives signal to P1 and P2 to start the test.
6. SV accelerates to 22.4 m/s (50 mph) and engages the cruise control at 22.4 m/s (50 mph).
7. When the required forward crash alert occurs or when the SV driver senses a crash with P1 is imminent, SV signals and moves to the right adjacent lane towards P2 to avoid striking P1.
8. Lane change merge alert should be issued at appropriate range when SV is moving to the right adjacent lane towards P2.
9. When SV is moving to the right adjacent lane towards P2, it should carefully monitor the P2 vehicle, which should be moving to its right adjacent lane 4 to avoid the crash.
10. SV should complete the lane change and be in lane 5. At this time P2 vehicle should be in lane 4.
11. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

4. After receiving signal from SV, P1 accelerates to 11.2 m/s (25 mph) and engages the cruise control.
5. P1 maintains its designated lane and speed throughout the test.
6. At the completion of test P1 stops and gets ready for the next run.

P2 Driving Instructions:

1. After receiving signal from SV, P2 accelerates to 22.4 m/s (50 mph) and engages the cruise control at 22.4 m/s (50 mph).
2. During this period P2 maintains its relative position with respect to SV and matches its speed with SV.
3. P2 should carefully monitor the SV vehicle, which would be changing lane (to avoid RE with P1) and moving to the lane 5 currently occupied by P2.
4. When SV is changing lane, P2 driver should maintain its lane to the best of his ability and judgment (in order to elicit a lane change merge warning), however, before a crash is imminent with SV, P2 should move into the right adjacent lane 4 so that SV could occupy lane 5.
5. At the completion of test P2 stops and gets ready for the next run.

5.1.4. Exceptions to the standard test conditions

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

5.2. MT-2 Aborted Lane Change, Followed by Rear-End, Followed by Road Departure (Required Test)

This test is intended to verify the appropriateness of a LDW followed by a possible FCW when SV encounters a slowing P1 after an aborted un-signaled lane change (an adjacent P2 prevents the SV from changing lanes).

The test determines whether the IVBSS system provides appropriate warning or series of warnings to the SV in this multiple threat scenario. It will also show that the IVBSS Warning System will not suppress critical warnings due to multiple threats occurring.

5.2.1. Test Overview and Concept

The purpose of this test is to check that the IVBSS Warning system gives warnings as required when the SV changes lane without using the turn signal and encounters a vehicle (P2) in the left lane going at the same speed as the SV. After receiving the LDW it aborts the lane change attempt and receives a possible FCW for RE with a slowing P1.

Figure 57 shows the initial, transitional and final conditions for the multiple threat conflict involving an LDW followed by a possible FCW. The initial conditions are in the top of the figure and show both the SV and P2 traveling at the same speed in the center of their designated lanes with the front bumper of P2 aligned with the rear window (C- pillar) of SV. P1 is traveling at a slower speed in the center of the same lane as SV. An LDW occurs when the SV driver attempts an un-signaled lane change to the left toward P2 with a lateral speed, $LatV_{SV}$, between 0.4 and 0.6 m/s. Following the LDW, the SV driver returns to its original lane and an

FCW is issued with P1 when SV reaches the 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 P1.

(Note: There should not be a second LDW as the driver is intentionally maneuvering around P1 while possibly engaging the brake.)

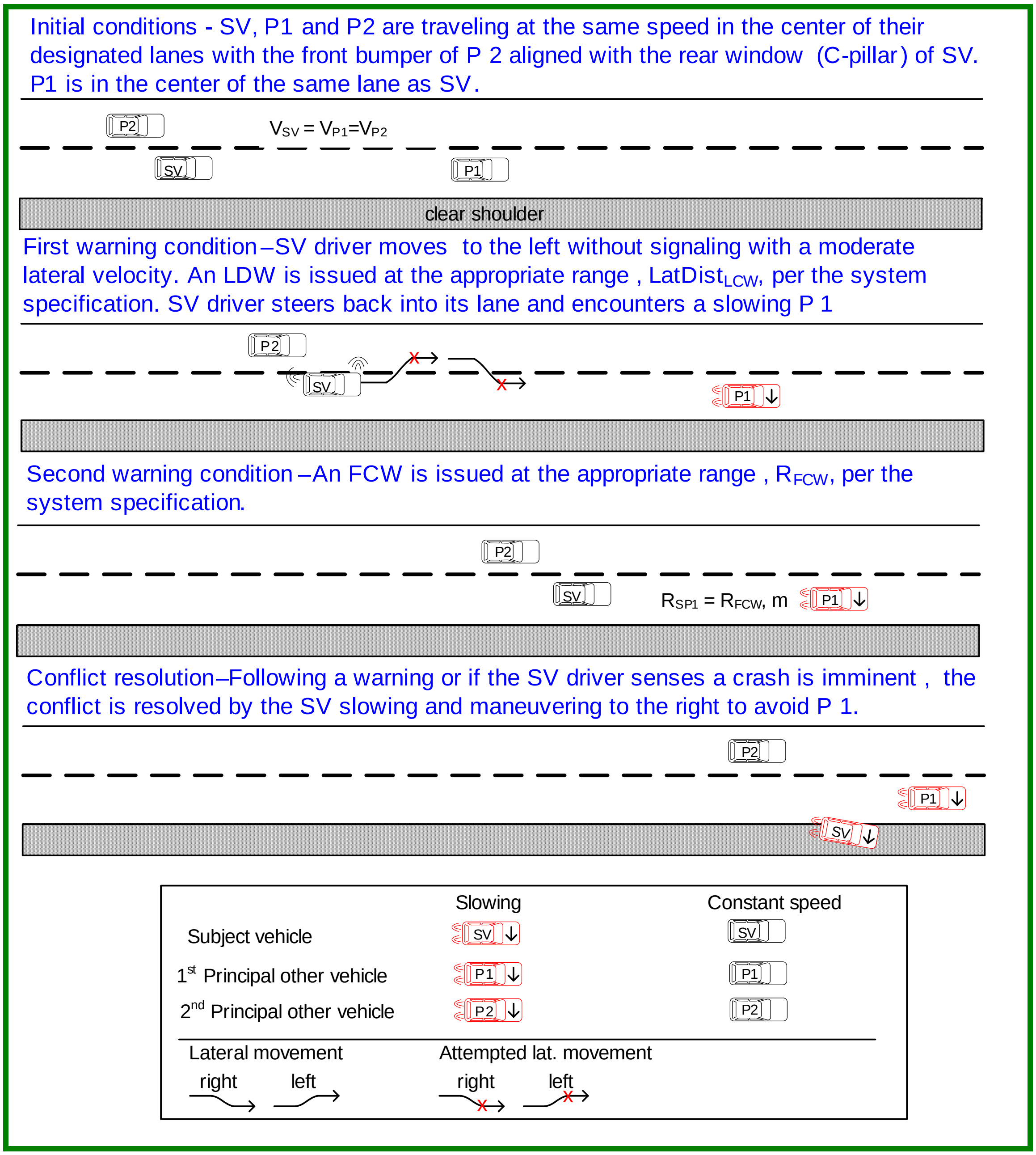


Figure 57: Initial and final conditions for MT2 (LDW followed by FCW)

5.2.2. Performance measures and evaluation criteria

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.

Table 58. Run validity criteria for MT2 (LDW followed by FCW)

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	± 0.8 (1.8 mph)
V_{P1}, m/s	15.7 (35 mph)	± 0.8 (1.8 mph)
V_{P2}, m/s	15.7 (35 mph)	± 0.8 (1.8 mph)
$Rdot_{SP1}$, m/s	0	± 1.6
P2 Position	P2 front bumper aligned with SV rear window (C-pillar)	N/A
$LatV_{SV}$, m/s (during LC)	0.5	N/A
Turn Signal Status	Off	N/A
D1 (Initial R_{SP1}), m	40	N/A
D2 ($(R_{SP1})_{SS}$), m	30	± 3.0
A_{xP1}, m/sec^2	- 2.0 (.2g)	± 0.5

Table 59 below gives the alert ranges for evaluating if the warnings were issued per the design intent of the IVBSS subsystem.

Table 59. Pass/Fail Criteria for MT2 (LDW followed by FCW)[29]

Alert Range	*$LatDist_{LDW}$, m*	*R_{FCW}, m*
Maximum		
Nominal		
Minimum		

5.2.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix.

Figure 58 below is the suggested track layout for conducting this test.

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

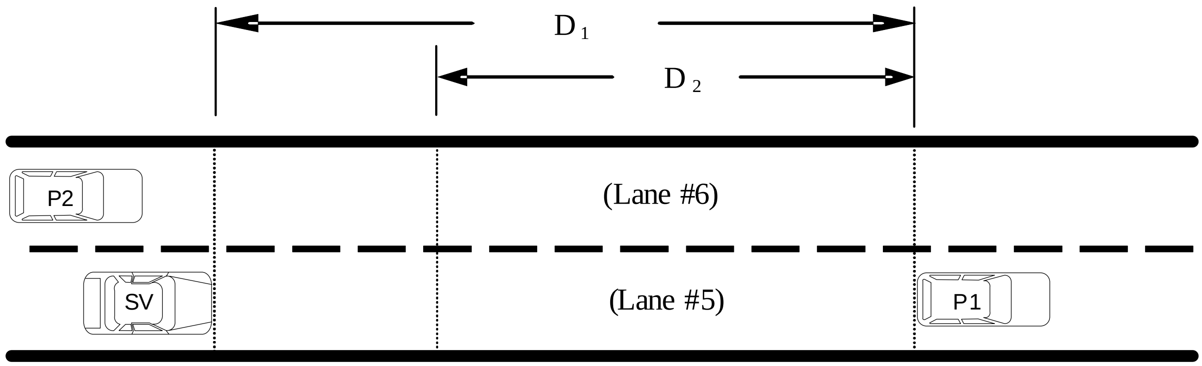


Figure 58: Track Layout for MT2 (LDW followed by FCW)

All specific speeds and initial conditions for this test are given in Table 58. Referring to Figure 58, both SV and P1 are stopped in the lane 5 of the skid pad track with an initial gap of D1 (40 m). P2 occupies the left adjacent lane 6 and is placed such that its front bumper is aligned with the C-pillar (rear window) of the SV. SV, P1 and P2 should reach their steady state constant speeds when the range between SV and P1 is D2 (30 m). P2 will maintain its position and speed relative to SV during the test until SV initiates a lane change.

SV Driving Instructions:

1. SV gives signal to P1 and P2 to start the test.
2. SV accelerates to 15.7 m/s (35 mph) and engages the cruise control.
3. SV driver monitors the range displayed on the monitor and slowly creeps upon the P1 vehicle till he reaches a headway gap of 30 m.
4. After reaching this steady state headway gap of 30 m, and maintaining this gap for about 2 seconds, SV driver initiates a left lane change move towards P2 (without using the turn signal) at a moderate rate of lateral drift (0.4 to 0.6 m/s).
5. When the required LDW alert occurs or when the SV driver senses a crash with P2 is imminent, SV steers back in its original lane 5.
6. SV continues to drive at 15.7 m/s (35 mph) in its original lane 5 and encounters a slowing P1.
7. When the required forward crash alert occurs or when the SV driver senses a crash with slowing P1 is imminent, SV steers and moves to the right adjacent lane 4 to avoid striking P1.
8. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 15.7 m/s (35 mph) and engages the cruise control.
2. When P1 driver notices that SV has returned back in its original lane of travel after the aborted lane change attempt, it applies and maintains a steady state brake pressure to achieve a constant low level deceleration of about 2 m/sec^2 (0.2 g). P1 driver could use the decelerometer mounted in the vehicle to gauge vehicle's deceleration.
3. At the completion of test P1 stops and gets ready for the next run.

P2 Driving Instructions:

6. After receiving signal from SV, P2 accelerates to 15.7 m/s (35 mph) and engages the cruise control.
7. During this period P2 maintains its relative position with respect to SV and matches its speed with SV.
8. P2 should carefully monitor the SV vehicle, which would be changing lane and moving to the lane 6 currently occupied by P2.
9. When SV is changing lane, P2 driver should maintain its designated lane to the best of his ability and judgment (in order to elicit an LDW alert); however, if P2 driver senses a crash is imminent with SV, it could move into the left adjacent lane 7.
10. At the completion of test P2 stops and gets ready for the next run.

5.2.4. 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. No-Warn (NW) Tests

This section of the report details the No-Warn test procedures for the IVBSS Light Vehicle platform. These tests are 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.

6.1. NW-1 No warning when SV closely follows POV

The purpose of this test is to verify that the IVBSS system does not issue a warning in a close-following situation, where SV is driving behind a POV with a constant 1 second headway gap.

6.1.1. Test Overview and Concept

In this test, the SV closes in on a POV ahead in the same lane at a low relative speed from a distance. Once the headway reaches 1 second, the SV follows the POV for a period of time. IVBSS should not issue any warning for this close-following situation.

Figure 59 shows the initial, transitional, and final conditions for a no warn test when SV closely follows POV. The test begins with the SV approaching the POV at a low relative speed from a distance. Both vehicles are traveling in the center of the same lane. Once the headway reaches 1 second, the SV matches the speed of POV and follows the POV at this close headway gap for a period of time (10 second). The test ends after no warning is issued after 10 seconds of driving.

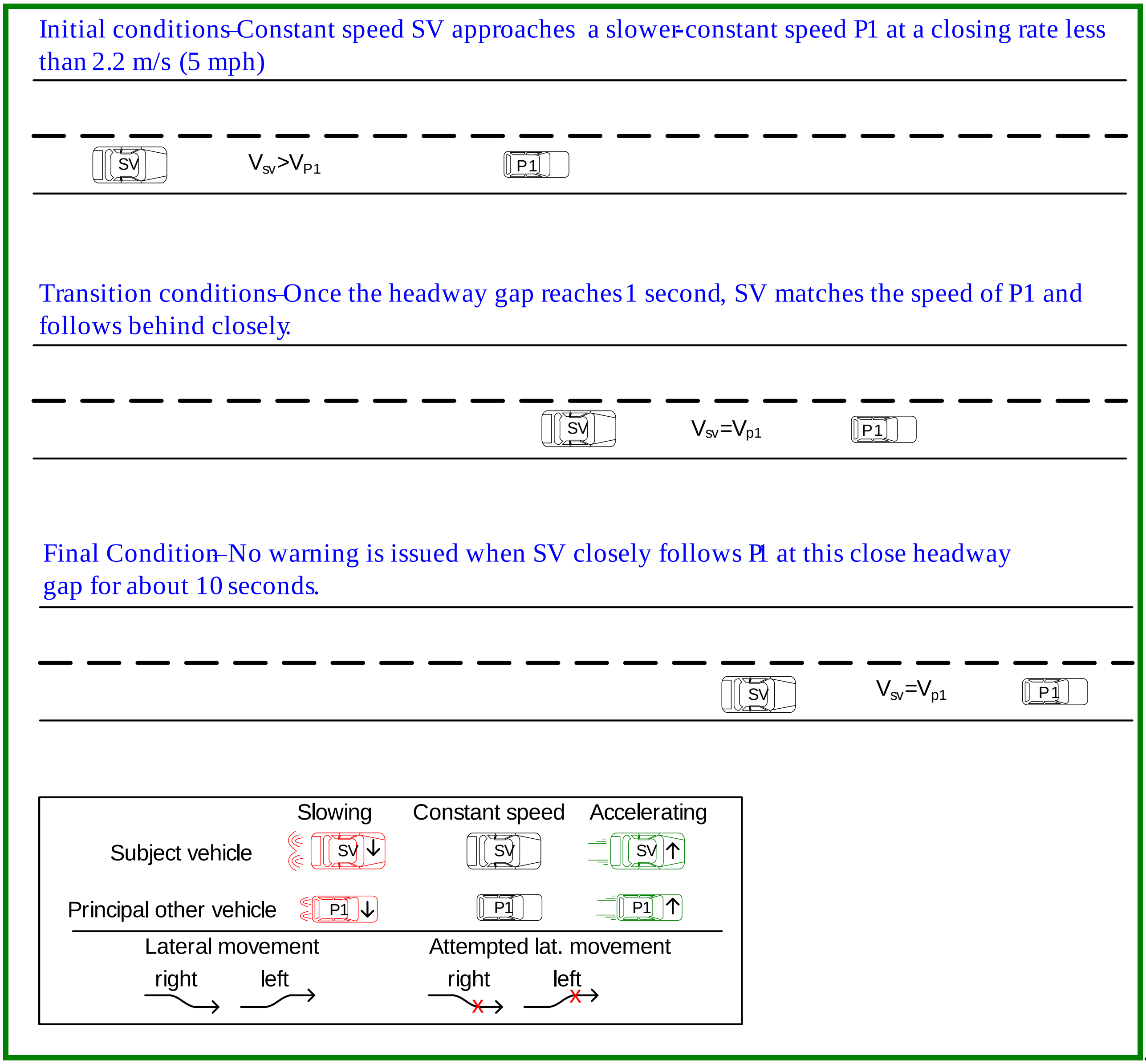


Figure 59: Initial and final conditions for no warning when SV closely follows POV.

6.1.2. Performance measures and evaluation criteria

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.

Table 60: Run validity criteria for no warning when SV closely follows POV.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s (Initial)	20.1 (45 mph)	N/A
V_{SV}, m/s (Final)	17.9 (40 mph)	± 0.9 (2.0 mph)
V_{P1}, m/s	17.9 (40 mph)	± 0.9 (2.0 mph)
$Rdot_{SP1}$, m/s	0	± 1.8
D1, m	50	N/A
D2, m (Headway Gap)	18	± 2

A successful test requires that no warning be issued during this test.

6.1.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track.

Figure 60 below is the suggested track layout for conducting this test.

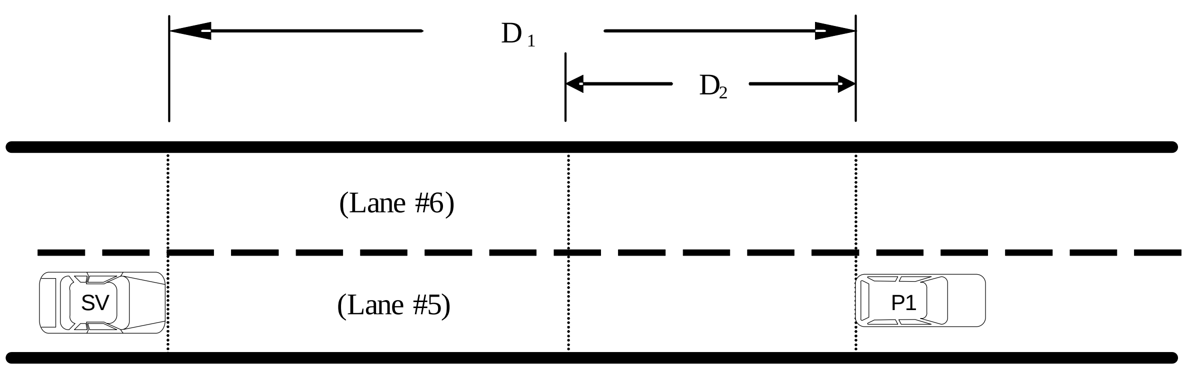


Figure 60: Track Layout for no warning when SV closely follows POV.

All specific speeds and initial conditions for this test are given in Table 60.

Referring to Figure 60, both SV and P1 start in the lane 5 of the skid pad track with an initial gap of D1. Both SV and P1 should match their speeds when the range between SV and P1 is D2 and maintain this close headway gap of D2, m.

SV Driving Instructions:

12. SV gives signal to P1 to start the test.
13. SV accelerates to 20.1 m/s (45 mph) and monitors the range between SV and P1.
14. SV driver monitors the range displayed by the IVBSS system and slowly creeps upon the P1 vehicle till he reaches the desired headway gap of D2, m.
15. When the headway gap between SV and P1 reaches D2, SV should reduce its speed to 17.9 m/s (40 mph) to match with the speed of P1 and engage the cruise control.
16. SV should follow P1 at this close headway gap of D2 for about 10 seconds.
17. The test is completed when no crash alert is issued after 10 seconds of driving. However, if the crash alert occurs or if the SV driver senses a crash is imminent, SV steers and moves to the left adjacent lane to avoid striking P1.
18. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

7. After receiving signal from SV, P1 accelerates to 17.9 m/s (40 mph) and engages the cruise control.
8. P1 maintains its lane and speed throughout the test.
9. At the completion of test P1 stops and gets ready for the next run.

6.1.4. 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. NW-2 No warning when SV on curve passes stopped POV in adjacent lane on curve (Required Test)

The purpose of this test is to verify that the IVBSS system does not issue a warning when SV passes a stopped POV in the adjacent lane, when both the vehicles are in a curve.

6.2.1. Test Overview and Concept

This test is conducted on a curved road (~300 m radius), where the SV, traveling counter clockwise in the inner left lane, approaches a stopped POV in the right adjacent lane on a curve. IVBSS should not issue any warning.

Figure 61 shows the initial, transitional, warning, and conflict resolution conditions for this no warn test when SV on a curved road, passes a stopped POV in the adjacent lane on curve. The test begins with a constant speed SV approaching a stopped POV in the adjacent right lane, in the steady state portion of the curve. Next, the figure illustrates SV passing the stopped POV in the adjacent lane. Finally, no warning is issued and SV stops after completing the test.

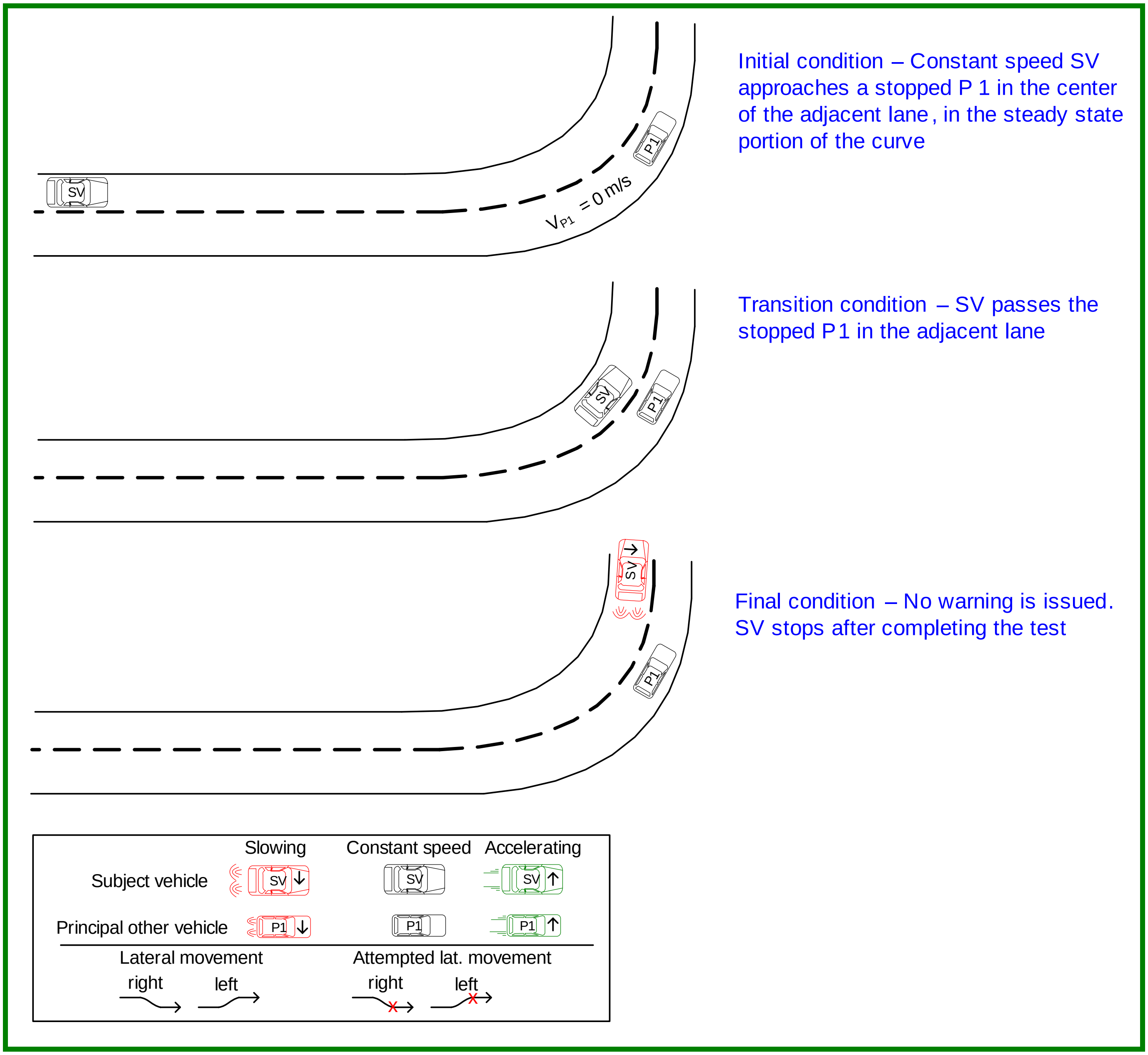


Figure 61: Initial and final conditions for no warning when SV passes stopped POV in adjacent lane on curve.

6.2.2. Performance measures and evaluation criteria

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.

Table 61: Run validity criteria for no warning when SV passes stopped POV in adjacent lane on curve.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	± .8 (1.8 mph)
V_{P1}, m/s	0	N/A
Track Curve Radius (m)	300	± 30
D1 (Initial R_{SP1}), m	200	N/A
D2 (Steady State R_{SP1}), m	120	N/A

A successful test requires that no warning be issued during this test.

6.2.3. Track Setup and Driving Instructions

The track to be used for this test is the Dana Track in Ottawa Lake, MI as shown in Figure A6 in Appendix A. Figure 62 below is the suggested track layout for conducting this test.

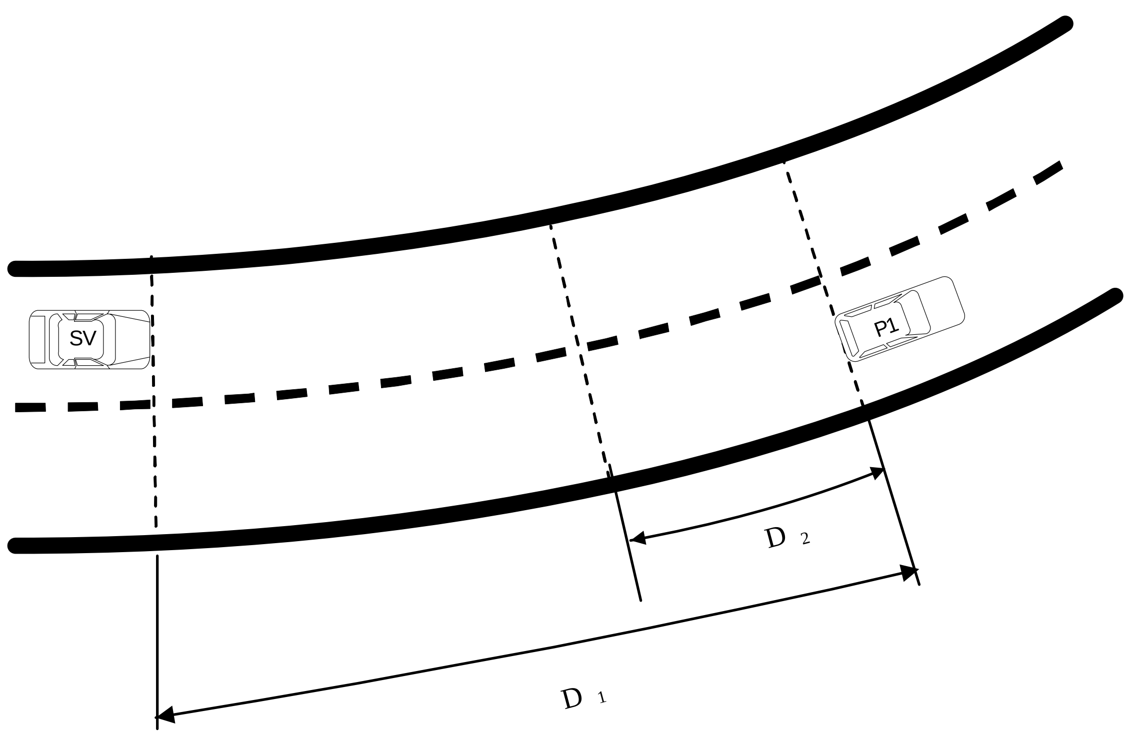


Figure 62: Track Layout for no warning when SV passes stopped POV in adjacent lane on curve.
All specific speeds and initial conditions for this test are given in Table 61.

Referring to Figure 62, P1 is stopped in the middle lane, in the curved section of the Dana Track and SV is stopped about D1 (200 m) behind this P1 vehicle in the adjacent left inner lane. SV should reach its steady state constant speed when the range between SV and P1 is D2 (120 m).

SV Driving Instructions:

4. SV accelerates to 15.7 m/s (35 mph) and engages the cruise control at 15.7 m/s (35 mph).
5. No warning should be issued when SV passes the stopped P1 in the adjacent right lane.
6. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

3. P1 remains stopped in its designated middle lane.
4. The driver of P1 stays out of his vehicle during the entire test sequence for all the test runs.

6.2.4. 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. NW-3 No warning when faster POV cuts in front of SV at a very close headway gap (Required Test)

This test determines whether or not the IVBSS system allows for close cut-in lane changes without warning, as commonly experienced during naturalistic driving.

6.3.1. Test Overview and Concept

The purpose of this test is to verify that the IVBSS system does not issue a warning when a faster POV cuts in front of SV at a very close headway gap.

Figure 63 shows the initial, transitional, warning, and conflict resolution conditions for this no warn test. The test begins with a constant speed POV approaching a slower moving SV in the adjacent lane. Next, the figure illustrates the transition condition, that, immediately after passing the SV, faster moving POV signals and moves to the right adjacent lane. No warning is issued for this event. Finally, P1 is in the center of SV lane and moving away.

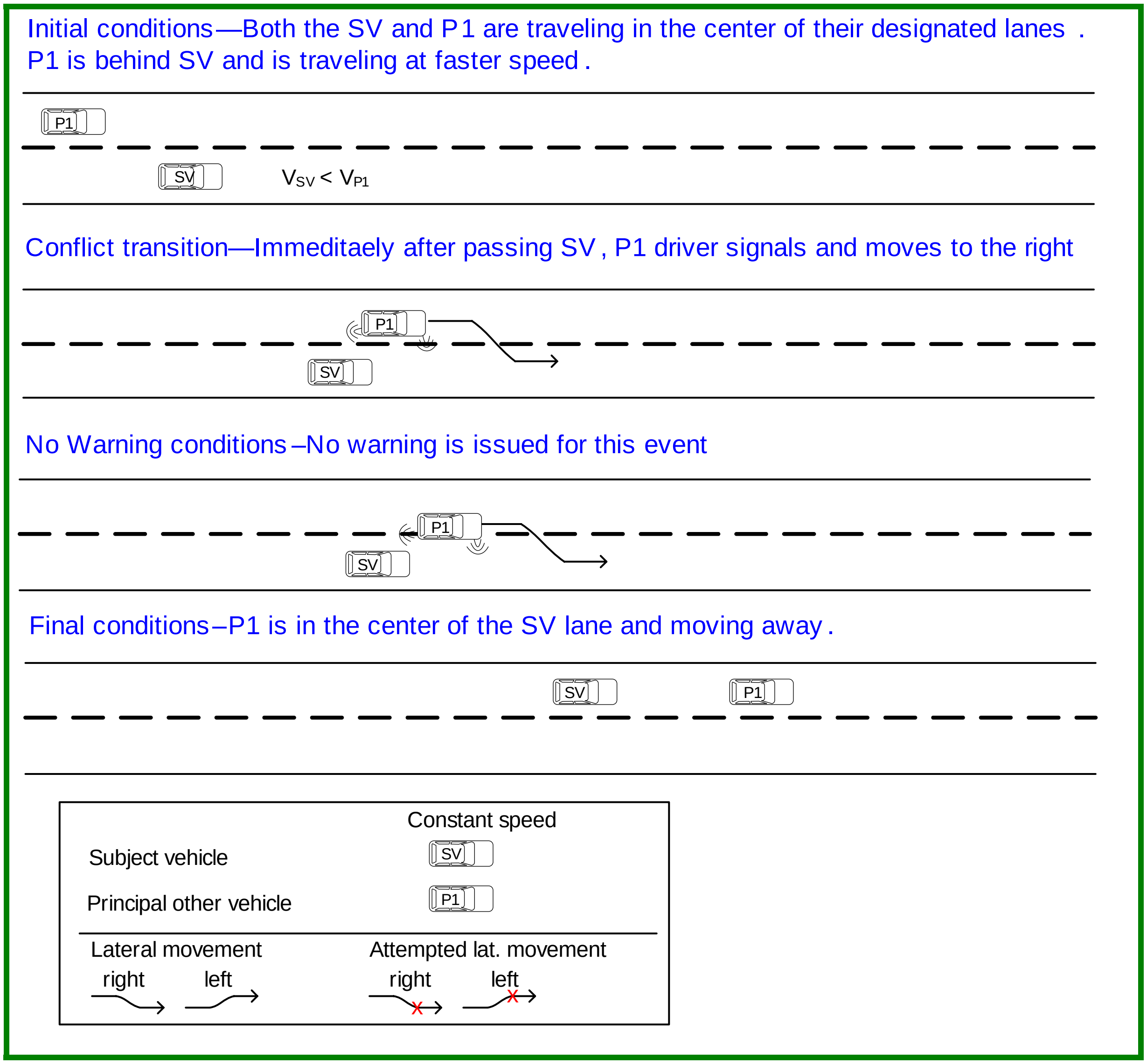


Figure 63: Initial and final conditions for no warning when faster POV cuts in front of SV at a very close headway gap.

6.3.2. Performance measures and evaluation criteria

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 62.

Table 62: Run validity criteria for no warning when faster POV cuts in front of SV at a very close gap.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	17.9 (40 mph)	± 0.9 (2.0 mph)
V_{P1}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
$LatV_{P1}$, m/s	0.65	N/A
D1, m	200	N/A
D2, m (range b/w SV and P1 at the time of LC by P1)	10	± 2.0

A successful test requires that no warning be issued during this test.

6.3.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track.

Figure 64 below is the suggested track layout for conducting this test.

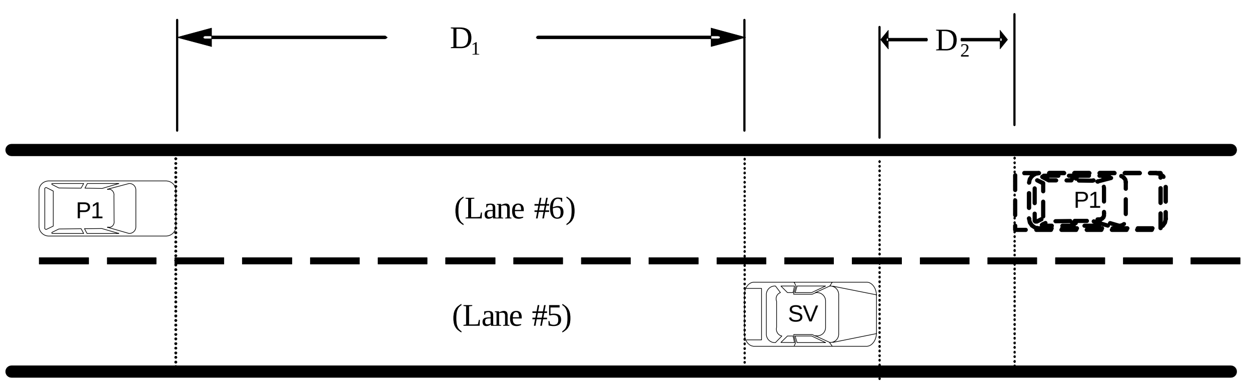


Figure 64: Track Layout for no warning when faster POV cuts in front of SV at a very close headway gap.

All specific speeds and initial conditions for this test are given in Table 62.

Referring to Figure 64, SV and P1 are placed in lane 5 and lane 6 of the skid pad track respectively such that P1 is D1, m behind SV.

SV Driving Instructions:

6. SV signals P1 to start the test.
7. SV accelerates to 17.9 m/s (40 mph) and engages the cruise control.
8. SV should carefully monitor the P1 vehicle slowly approaching from behind, which will be changing lanes and moving to the lane 5 currently occupied by SV.
9. SV should monitor the range between SV and P1 when P1 is changing lane. This lane change by P1 should occur when P1 is D2, m ahead of SV.
10. When P1 is changing lane, SV driver should maintain its designated lane to the best of their ability, however, if SV driver senses a crash is imminent with P1, it could move into the right adjacent lane 4.
11. No warning should be issued when faster moving P1 is changing lane in front of SV.
12. The test ends 2 second after the POV is in the center of SV lane.
13. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

5. After receiving signal from SV, P1 accelerates to 20.1 m/s (45 mph) and engages the cruise control.
6. P1 driver signals and initiates a moderate lane change move (lateral velocity of 0.5 to 0.8 m/s) to the right lane 5, immediately after P1 rear bumper passes the front bumper of the SV vehicle. This lane change by P1 should occur when P1 is D2, m ahead of SV.
7. No warning should be issued during this close cut-in scenario as P1 is traveling faster and thus moving away from SV after the lane change.
8. At the completion of test P1 stops and gets ready for the next run.

6.3.4. 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. NW-4 No warning when SV in middle lane approaches slower moving POV’s in left and right adjacent lanes (Required Test)

The purpose of this test is to verify that the IVBSS system does not issue a warning when the SV approaches from behind and passes between two slower moving large vehicles in adjacent lanes.

6.4.1. Test Overview and Concept

Figure 65 shows the initial, transitional, warning, and conflict resolution conditions for this no warn test. The top of the figure shows that the SV is traveling at a constant speed in the center of the middle lane, approaching two slower moving large vehicles, P1 and P2 in the left and right adjacent lanes respectively. The next figure shows SV about to pass these two large vehicles in the adjacent lanes. No warning is issued at any time and the test is completed when SV has passed the two vehicles.

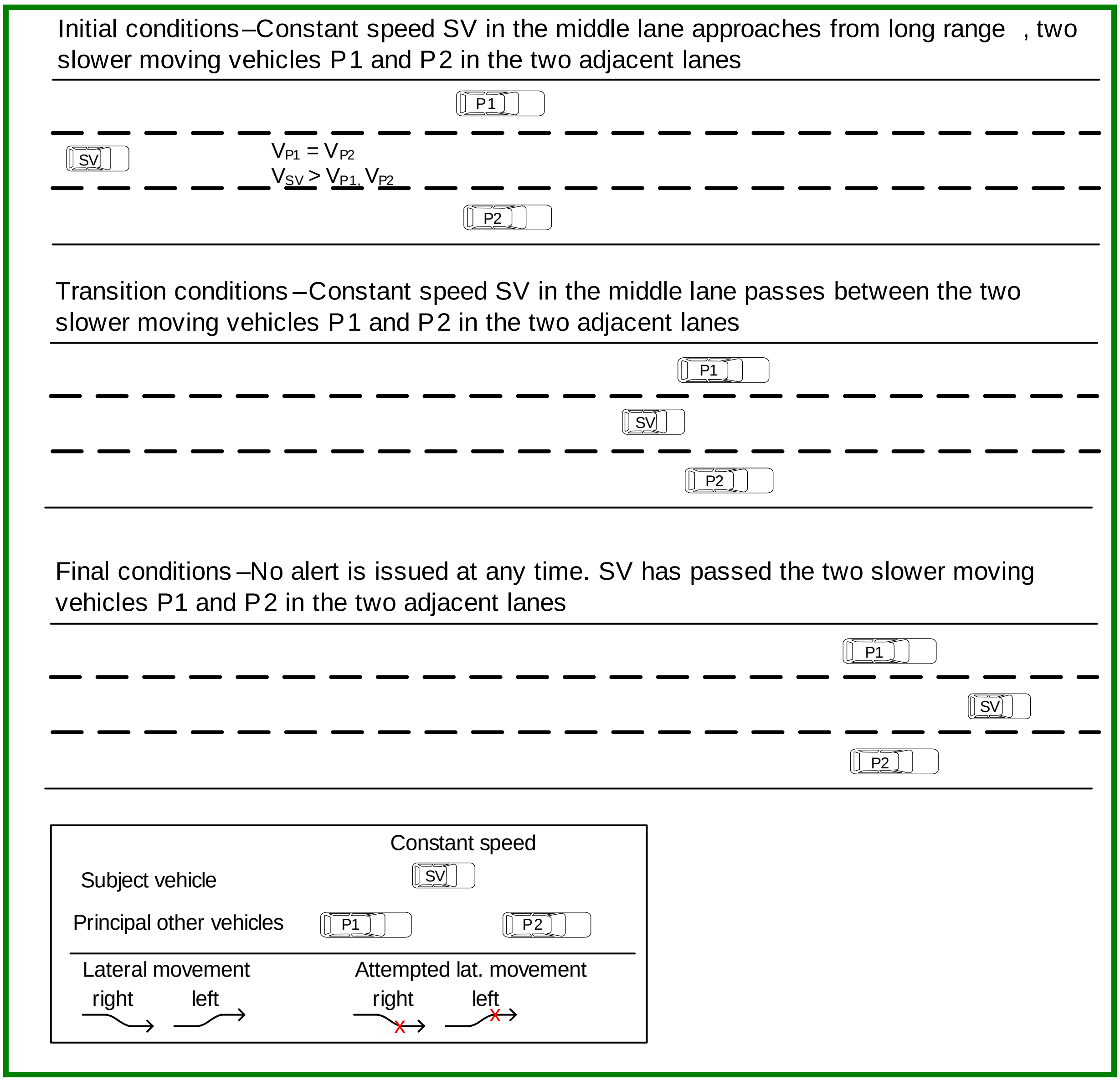


Figure 65: Initial and final conditions for no warning when SV in middle lane approaches slower moving POVs in left and right adjacent lanes.

6.4.2. Performance measures and evaluation criteria

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.

Table 63: Run validity criteria for no warning when SV in middle lane approaches slower moving POVs in left and right adjacent lanes.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	17.9 (40 mph)	± 0.9 (2.0 mph)
V_{P2}, m/s	17.9 (40 mph)	± 0.9 (2.0 mph)
D1, m	200	N/A

A successful test requires that no warning be issued during this test.

6.4.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track.

Figure 66 below is the suggested track layout for conducting this test.

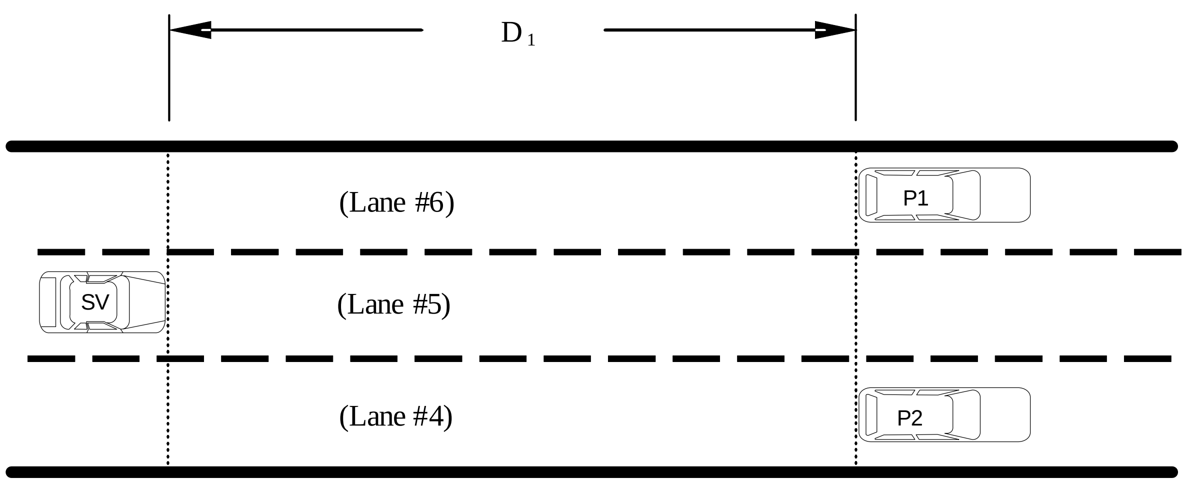


Figure 66: Track Layout for no warning when SV in middle lane approaches slower moving POVs in left and right adjacent lanes.

All specific speeds and initial conditions for this test are given in Table 63.

Referring to Figure 66, P1 and P2 are placed in lane 6 and lane 4 of the skid pad track respectively and SV is placed in lane 5 D1, m behind P1 and P2.

SV Driving Instructions:

1. SV signals P1 and P2 to start the test.
2. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control.
3. SV approaches the slower moving P1 and P2 in the two adjacent lanes and continues driving till it passes between the two vehicles in the two adjacent lanes.
4. No warning should be issued during this test.
5. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

1. After receiving signal from SV, P1 accelerates to 17.9 m/s (40 mph) and engages the cruise control.
2. P1 maintains its position with respect to P2 and continues driving until SV has passed the P1.
3. At the completion of test P1 stops and gets ready for the next run.

P2 Driving Instructions:

1. After receiving signal from SV, P2 accelerates to 17.9 m/s (40 mph) and engages the cruise control.
2. P2 maintains its position with respect to P1 and continues driving until SV has passed the P2.
3. At the completion of test P2 stops and gets ready for the next run.

6.4.4. Exceptions to the standard test conditions

There are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions, except that both the POVs (P1 and P2) are larger vehicles (van or truck).

6.5. NW-5 No warning with poor lane keeping and continuous barrier on the left with good lane marking (Required Test)

This test is intended to verify that no warning is issued for poor lane keeping, when SV is weaving within the lane, with a continuous barrier on the left with clear lane markings.

6.5.1. Test Overview and Concept

This test explores the ability of the IVBSS system to issue no warnings in response to a vehicle driving with poor lane keeping (i.e. wandering in its own lane).

Figure 67 shows the initial, transitional and final conditions for the no-warn with poor lane keeping. The initial conditions are in the top of the figure and show a constant speed SV traveling in the center of its designated lane. Then, at a predetermined range, the driver of the SV starts weaving within its own lane with slow lateral speed. Next, the figure illustrates that a warning should not occur during this lane wandering. Finally, the bottom of the figure shows SV returns to the center of the lane.

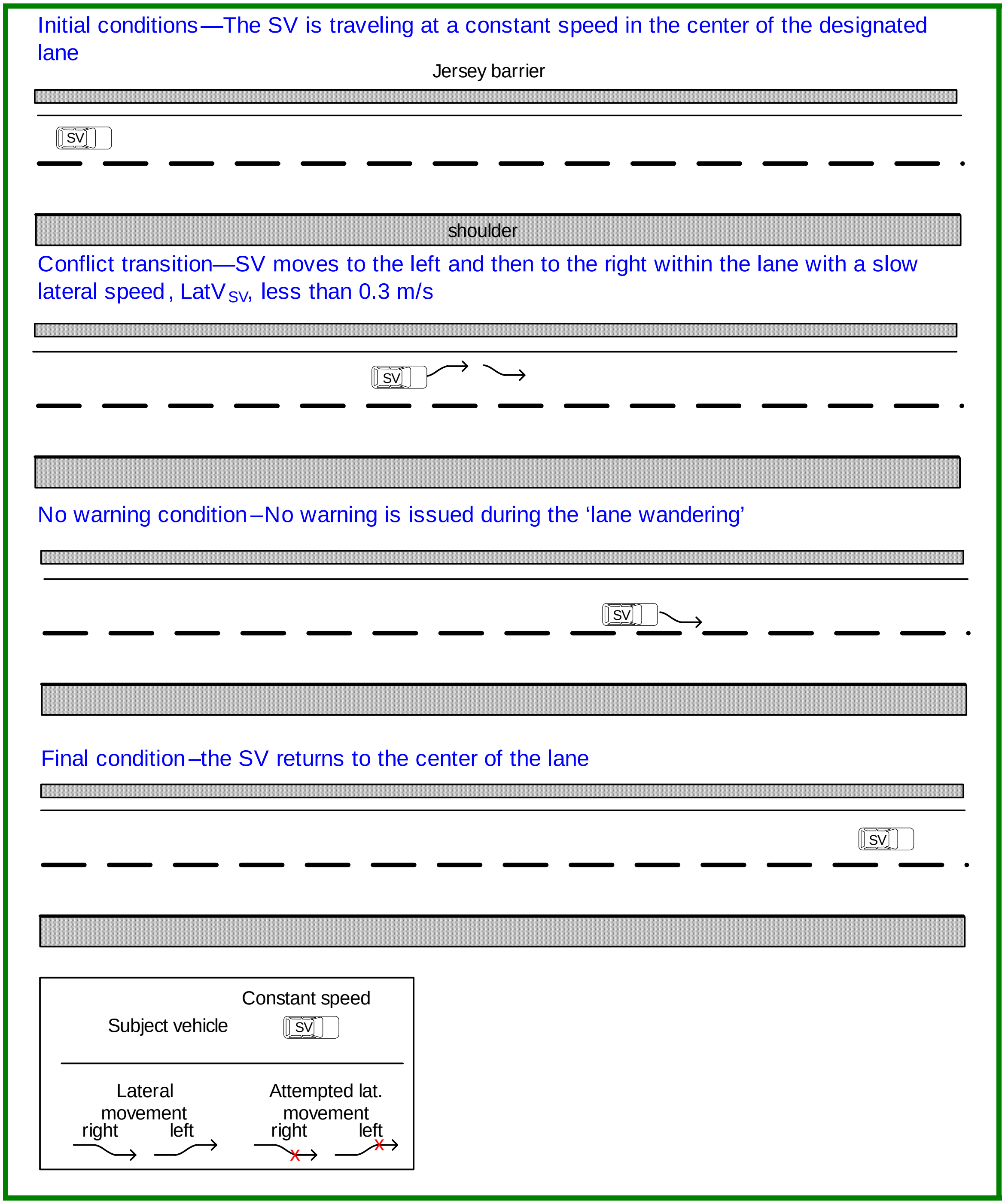


Figure 67: Initial and final conditions for no warning with poor lane keeping.

6.5.2. Performance measures and evaluation criteria

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 64.

Table 64: Run validity criteria for no warning with poor lane keeping.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	± .8 (1.8 mph)
$LatV_{SV}$, m/s	0.2	± 0.1
Lane Width, m	3.7	N/A
$Abs(LOff_{SV})$, m/s	0.4	± 0.1
Turn Signal Status	Off	N/A
D1, m	300	N/A
D2, m	100	N/A

A successful test requires that no warning be issued during this test.

6.5.3. Track Setup and Driving Instructions

The track to be used for this test is the Dana Track in Ottawa Lake, Michigan as shown in Figure A6 in Appendix.

Figure 68 below is the suggested track layout for conducting this test.

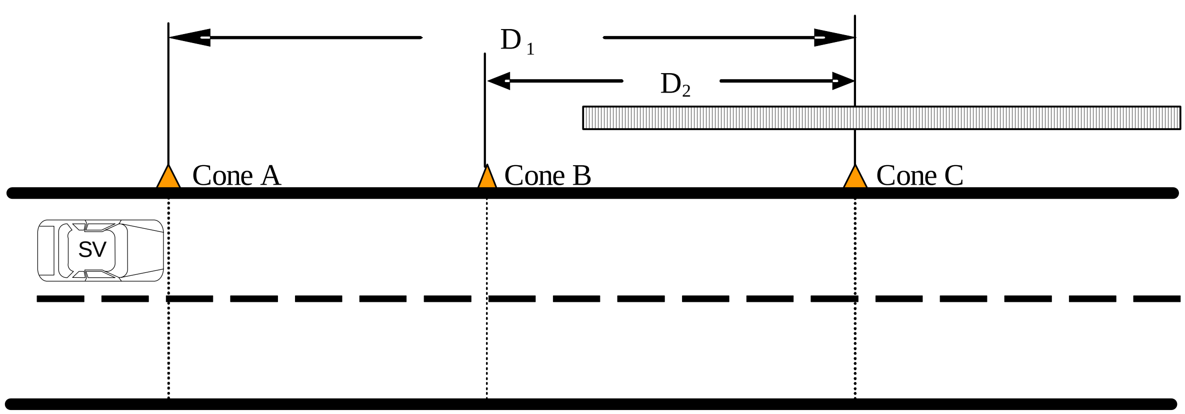


Figure 68: Track Layout for no warning with poor lane keeping.

All specific speeds and initial conditions for this test are given in Table 64.

Referring to Figure 68, a continuous barrier shall be setup along the outside lane boundary of the inner most lane of Dana Track straight section. The continuous barrier shall be 1-meter outside of the lane boundary (from the lane boundary on the left side of the SV). The continuous barrier shall be comprised of 76 m (250 ft) of plastic water-filled Jersey barriers.

The track needs to be prepared such that there are good lane markings on both sides of the vehicle.

Cone C is placed near the midpoint of the Jersey barrier. Cones A and B are at specific distance from Cone C based on the values given in Table 64.

SV starts at Cone A and should reach its steady state constant speed before reaching cone B.

SV Driving Instructions:

6. SV starts at the beginning of the straight section of the Dana track from Cone A and accelerates to 15.7 m/s (35 mph) and engages the cruise control at 15.7 m/s (35 mph).
7. SV should reach this speed before reaching cone B.
8. At cone B, SV begins a slow lane wandering motion, drifting first towards left and then towards right with a lateral drift rate of about .3 m/s.
9. The lateral drift on either side, from the lane center should be less than 0.5 m. This lateral drift information could be monitored through the appropriate CAN signal variable using a laptop, however, it is expected that SV driver would execute this slow lane weaving motion based on their driving experience.
10. No warning should be issued during this poor lane keeping event.
11. At the completion of test SV stops and gets ready for the next test run.

6.5.4. Exceptions to the standard test conditions

This test calls for placing a jersey barrier on the side of the road. Besides this, there are no exceptions to the default conditions as detailed in the section Definitions and Standard Test Conditions.

6.6. NW-6 No warning when SV changes lane into adjacent POV that is behind the SV rear bumper (Required Test)

The purpose of this test is to verify that the IVBSS system does not issue a warning when the SV driver changes lanes in front of a slowly approaching POV in an adjacent lane. Since the POV driver has adequate time to react to the SV lane-change due to both the range between the POV and rear of the SV and the slow closing rate between the vehicles, a warning should not be issued to the SV driver.

6.6.1. Test Overview and Concept

This test especially explores the ability of the IVBSS system to suppress warnings in response to the vehicle merging into a lane with a vehicle far behind but traveling at a faster speed.

Figure 69 shows the initial, transitional, and final conditions for a lane-change event in which no warning should be issued. The test begins with the POV traveling slightly faster than the SV in the center of their designated lanes. At a predetermined range the SV driver signals and change lanes to the right with a lateral velocity, $LatV_{SV}$, between 0.5 and 0.8 m/s. No warning should be issued because the POV driver has ample time to react to the SV lane change. The test is complete when the SV is ahead in the center of the POV lane.

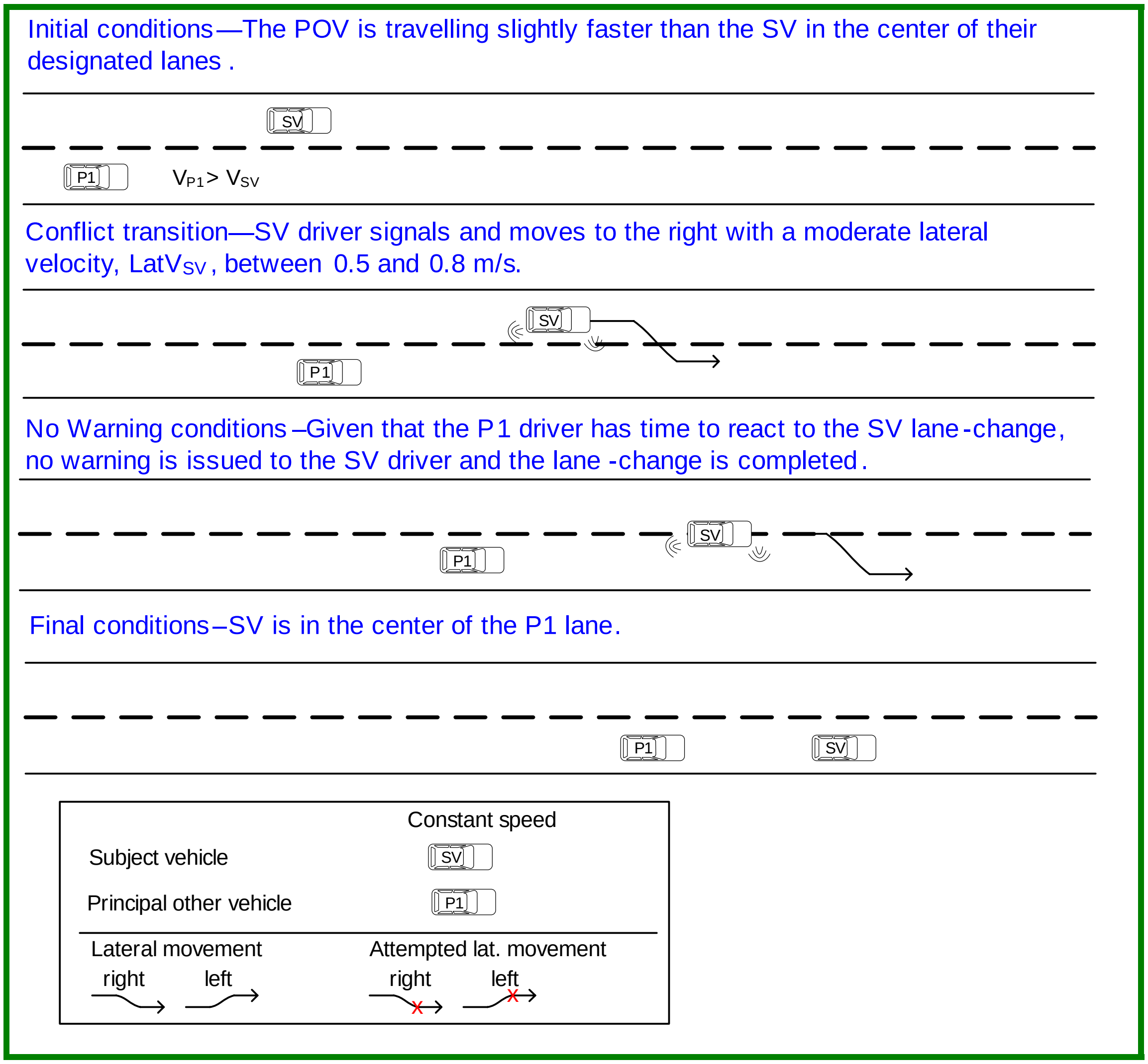


Figure 69: Initial and final conditions for no warning when SV changes lane into adjacent POV that is behind the SV rear bumper.

6.6.2. Performance measures and evaluation criteria

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.

Table 65: Run validity criteria for no warning when SV changes lane into adjacent POV that is behind the SV rear bumper.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	22.4 (50 mph)	± 1.1 (2.5 mph)
V_{P1}, m/s	24.6 (55 mph)	± 1.2 (2.8 mph)
$LatV_{SV,}$ m/s	0.65	± 0.15
Turn Signal Status	On	N/A
D1, m (Initial Gap)	70	N/A
D2, m (at start of Lane Change)	25	± 3
D3, m (at Lane Change completion)	15	± 3

A successful test requires that no warning be issued during this test.

6.6.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix A. It is to be ensured that there are good lane markings on the track.

Figure 70 below is the suggested track layout for conducting this test.

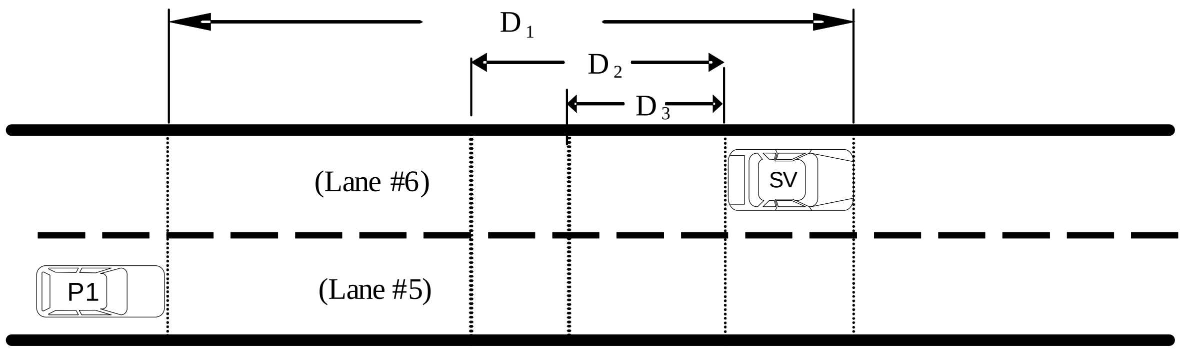


Figure 70: Track Layout for no warning when SV changes lane into adjacent POV that is behind the SV rear bumper.

All specific speeds and initial conditions for this test are given in Table 65. SV and P1 are placed in lane 6 and lane 5 of the skid pad track respectively such that P1 is about D1, m behind SV.

SV Driving Instructions:

6. SV signals P1 to start the test.
7. SV accelerates to 22.4 m/s (50 mph) and engages the cruise control.
8. SV driver signals and initiates a lane change move (lateral velocity of 0.5 m/s to 0.8 m/s) to the right lane, when P1 vehicle, slowly approaching from behind, is approximately D2, m behind SV rear bumper. This lane change position is to be determined by the SV driver based on his own judgment, however, he may get some help from another IVBSS equipped vehicle or IMS system in determining this position.
9. No warning should be issued during this test.
10. Test ends 2 seconds after SV reaches lane center.
11. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

5. After receiving signal from SV, P1 accelerates to 24.6 m/s (55 mph) and engages the cruise control.
6. P1 should carefully monitor the SV vehicle ahead in lane 6, which would be changing lane and moving to the lane 5 currently occupied by P1.

7. When SV is changing lane, P1 driver should maintain its designated lane to the best of his ability and judgment, however, if P1 driver senses a crash is imminent with SV, it could move into the right adjacent lane 4.
8. Test ends 2 seconds after SV reaches lane center.
9. At the completion of test P1 stops and gets ready for the next run.

6.6.4. 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. NW-7 No warning when SV changes lane and POV is two lanes over in blind spot (Required Test)

The purpose of this test is to verify that the IVBSS system does not issue a warning during a lane change for vehicles that are two lanes over and not a threat.

6.7.1. Test Overview and Concept

Figure 71 shows the initial, transitional, warning, and conflict resolution conditions for this no warn test. The test begins with the SV and POV traveling at the same speed in the center of their designated lanes, with the POV front bumper behind the SV driver. The POV is driving two lanes over the SV lane on the left side. Next, SV driver signals and moves to the left with a lateral velocity, $LatV_{SV}$, between 0.5 and 0.8 m/s, to be in the empty lane adjacent to P1 lane. No warning should be issued and the test is completed when SV has changed the lane and is driving in the lane adjacent to the P1 lane.

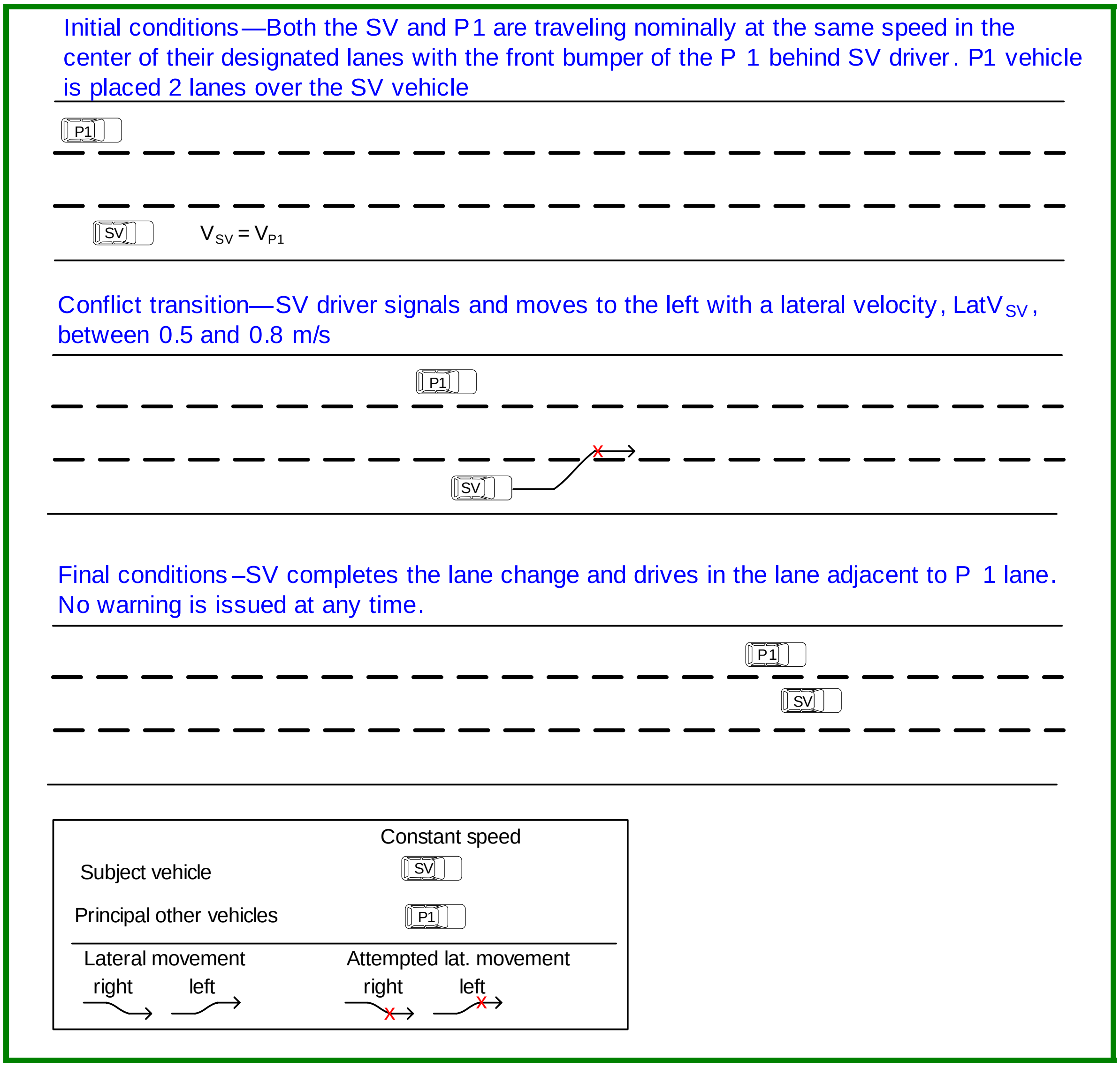


Figure 71: Initial and final conditions for no warning when SV changes lane and POV is two lanes over in blind spot.

6.7.2. Performance measures and evaluation criteria

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 66.

Table 66: Run validity criteria for no warning when SV changes lane and POV is two lanes over in blind spot.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
V_{P1}, m/s	20.1 (45 mph)	± 1.0 (2.2 mph)
$LatV_{SV,}$ m/s	0.65	± 0.15
P1 Position	P1 front bumper behind SV driver	N/A
Turn Signal Status	On	N/A
D1, m	200	N/A

A successful test requires that no warning be issued during this test.

6.7.3. Track Setup and Driving Instructions

The track to be used for this test is the Skid Pad Track at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure A5 in Appendix. It is to be ensured that there are good lane markings on the track.

Figure 72 below is the suggested track layout for conducting this test.

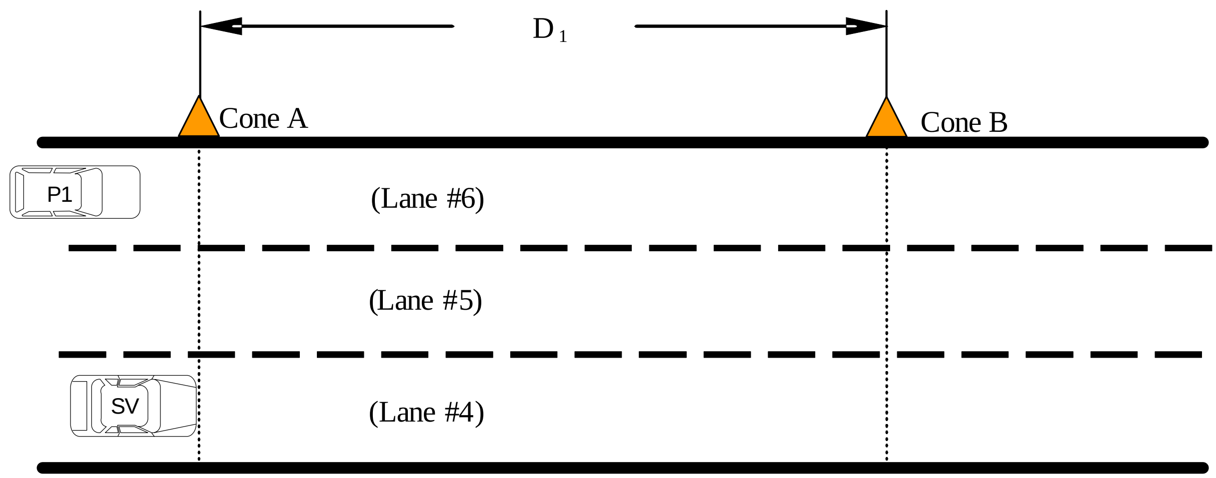


Figure 72: Track Layout for no warning when SV changes lane and POV is two lanes over in blind spot.

All specific speeds and initial conditions for this test are given in Table 66.

Referring to Figure 72, SV and P1 are placed in lane 4 and lane 6 of the skid pad track respectively such that P1's front bumper is behind SV driver.

SV Driving Instructions:

18. SV signals P1 to start the test.
19. SV accelerates to 20.1 m/s (45 mph) and engages the cruise control at 20.1 m/s (45 mph).
20. SV should reach this speed before reaching cone B.
21. At cone B, SV signals and initiates a left lane change at a moderate rate of lateral drift (0.5 to 0.8 m/s), to be in the empty lane adjacent to the P1 lane.
22. Once the lane change is completed the SV driver should cut-off the turn signal.
23. No warning should be given as SV is moving in an empty lane and there is no threat of collision.
24. The test ends when SV has completed the lane change.
25. At the completion of test SV stops and gets ready for the next test run.

P1 Driving Instructions:

11. After receiving signal from SV, P1 accelerates to 20.1 m/s (45 mph) and engages the cruise control.

12. During this period P1 maintains its relative position with respect to SV and matches its speed with SV.
13. P1 should carefully monitor the SV vehicle, which would be changing lane from lane 4 and moving to the empty lane 5, adjacent to the P1 lane 6.
14. When SV is changing lane, P1 driver should maintain its designated lane.
15. The test ends when SV has completed the lane change.
16. At the completion of test P1 stops and gets ready for the next run.

6.7.4. Exceptions to the standard test conditions

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

6.8. NW-8 No warning when SV is approaching a curve with safe speed in warm/dry condition (Required Test)

This test is intended to verify the appropriateness of a curve speed warning (CSW) system that no CSW warning is given when the SV driving at safe speed encounters a small radii curve in warm/dry condition.

6.8.1. Test Overview and Concept

This test evaluates the IVBSS system's ability to detect whether the vehicle is traveling at a safe speed for an approaching curve in warm/dry condition and not to issue any warning to the driver. The speeds and curve radii are to be consistent with a rural road scenario where this type of crash most often occurs.

Figure 73 shows the initial, transitional, warning, and conflict resolution conditions for a road departure toward a curve with safe speed in warm/dry condition. 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 approaches the small radius curve at safe speed. This is followed by a no warning situation, where the CSW is suppressed due to safe vehicle speed. Then, finally the scenario is complete when SV negotiates the curve at safe speed with no warning.

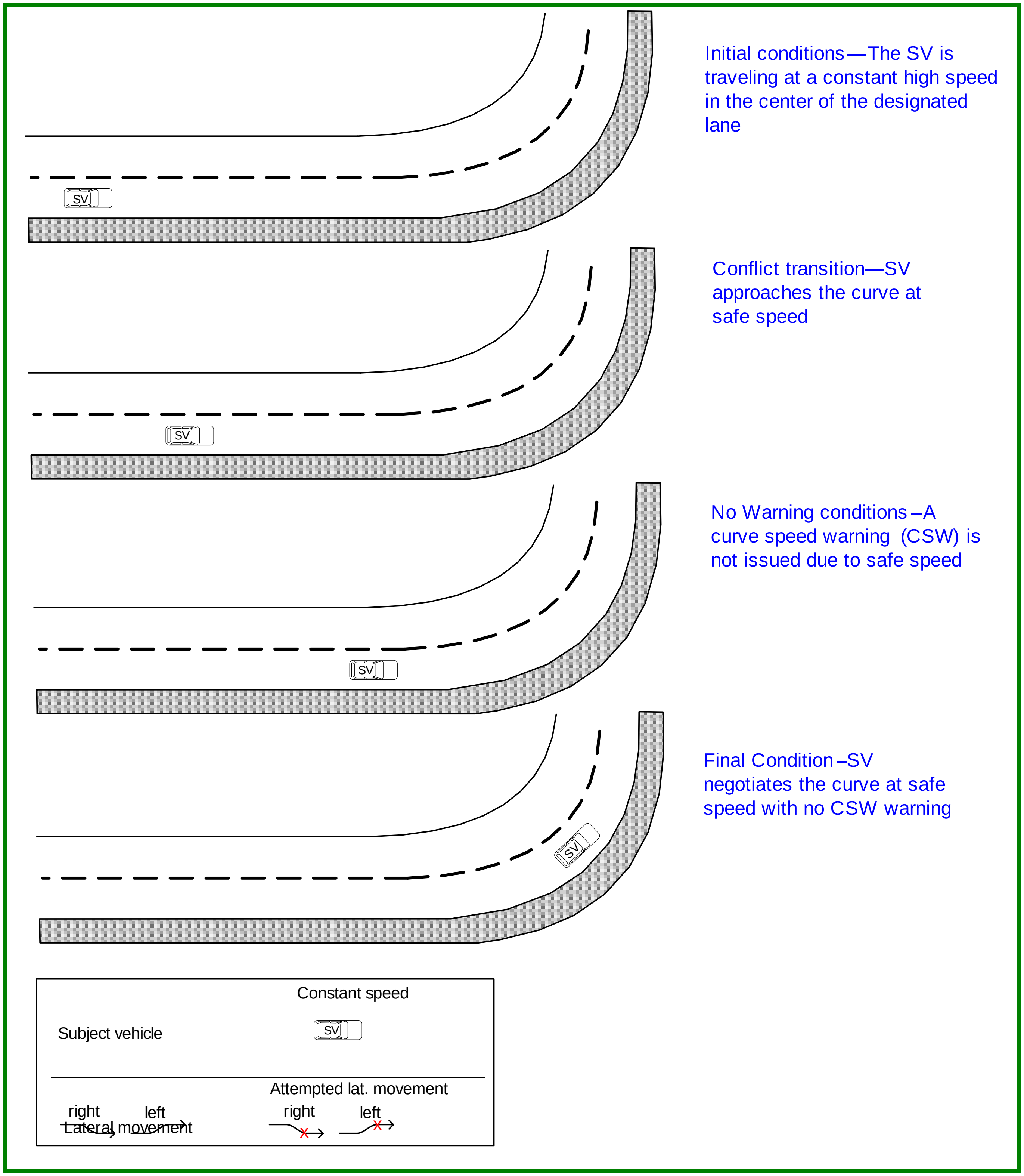


Figure 73: Initial and final conditions for no warning when SV is approaching a curve with safe speed in warm/dry condition.

6.8.2. Performance measures and evaluation criteria

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 67.

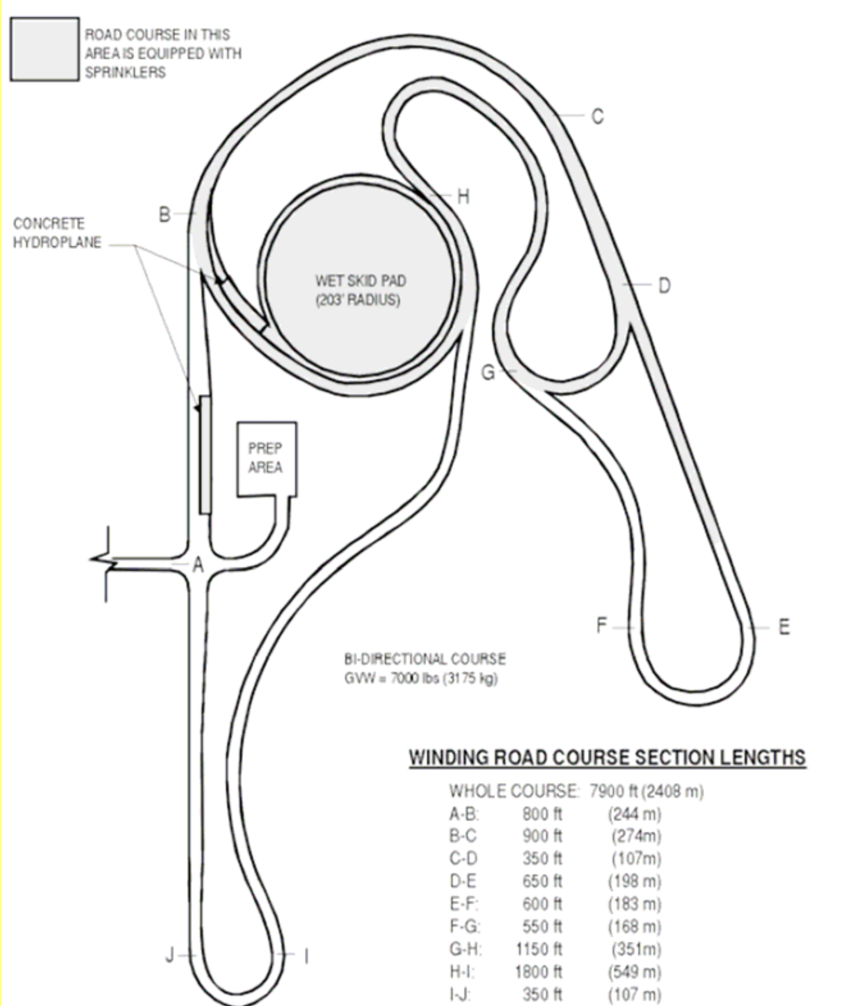
Table 67: Run validity criteria for no warning when SV is approaching a curve with safe speed in warm/dry condition.

Parameter, Unit	*Target Value*	*± Tolerance*
V_{SV}, m/s	15.7 (35 mph)	± 0.8 (1.8 mph)
Curve Radius, m	100	± 10
Straightaway (ED) Length, m	200	N/A
Lane Width, m	3.7	N/A
Wiper Status	Off	N/A

A successful test requires that no warning be issued during this test.

6.8.3. Track Setup and Driving Instructions

The track to be used for this test is the Winding Road Course at the Transportation Research Center (TRC) in E. Liberty, Ohio as shown in Figure 74.



WINDING ROAD COURSE SECTION LENGTHS

WHOLE COURSE:	7900 ft	(2408 m)
A-B:	800 ft	(244 m)
B-C	900 ft	(274m)
C-D	350 ft	(107m)
D-E	650 ft	(198 m)
E-F:	600 ft	(183 m)
F-G:	550 ft	(168 m)
G-H:	1150 ft	(351m)
H-I:	1800 ft	(549 m)
I-J:	350 ft	(107 m)
J-A:	750 ft	(229 m)
D-G:	300 ft	(91m)
H-B:	1200 ft	(366 m)
B-B:	3900 ft	(1189 m)

Figure 74: Track for no warning when SV is approaching a curve with safe speed in warm/dry condition.

Figure 75 below is the suggested track layout for conducting this test. Same track layout is used for this test, which is used for running RD6 (Road departure toward a curve with excessive speed in warm/dry condition). This no-warn test would be executed simultaneously with RD6 test on the WRC track.

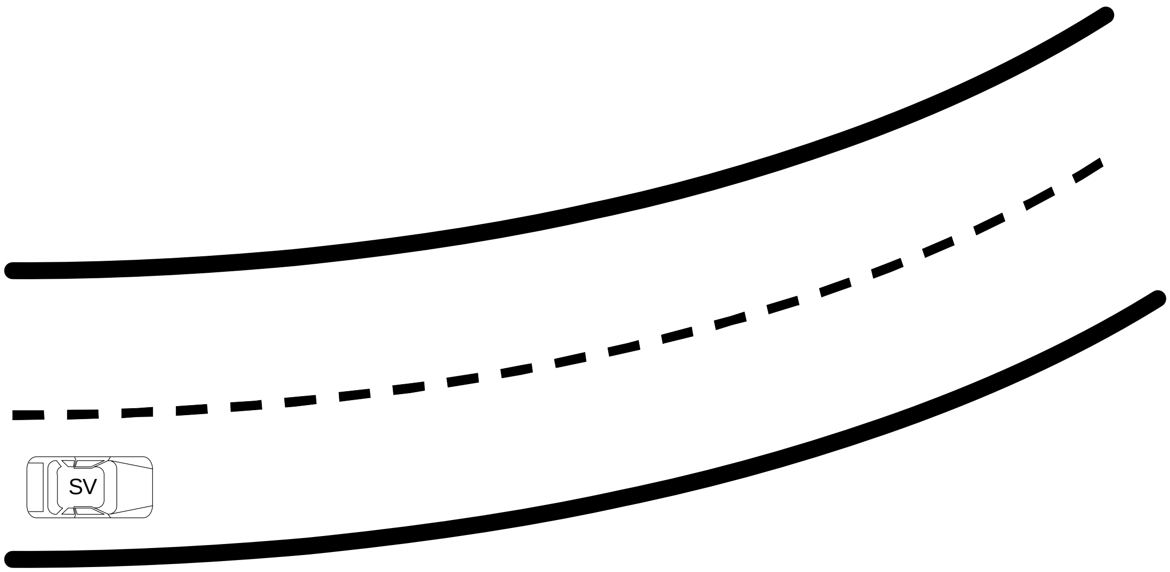


Figure 75: Track Layout for no warning when SV is approaching a curve with safe speed in warm/dry condition.

All specific speeds and initial conditions for this test are given in Table 67.

SV Driving Instructions:

7. SV starts from Point E on the WRC and drives in a counter-clockwise direction (E-D-C-B).
8. SV accelerates to 15.7 m/s (35 mph) and engages the cruise control.
9. SV should drive through the curve without applying the brakes.
10. No warning should be issued as SV is traveling at a safe speed.
11. At the completion of test SV stops and gets ready for the next test run.

6.8.4. Exceptions to the standard test conditions

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

Appendix

A1 Test track facilities

Most of the system verification tests for the Light Vehicle Integrated Vehicle Based Safety System (IVBSS) will be conducted at the TRC Test Track Facility located in E.Liberty, Ohio. System verification will be conducted on the Winding Road Course (WRC), and the Skid Pad tracks. Other access roads will also be used during verification. Figure A1 highlights the TRC test track facility that will be used during this verification phase.

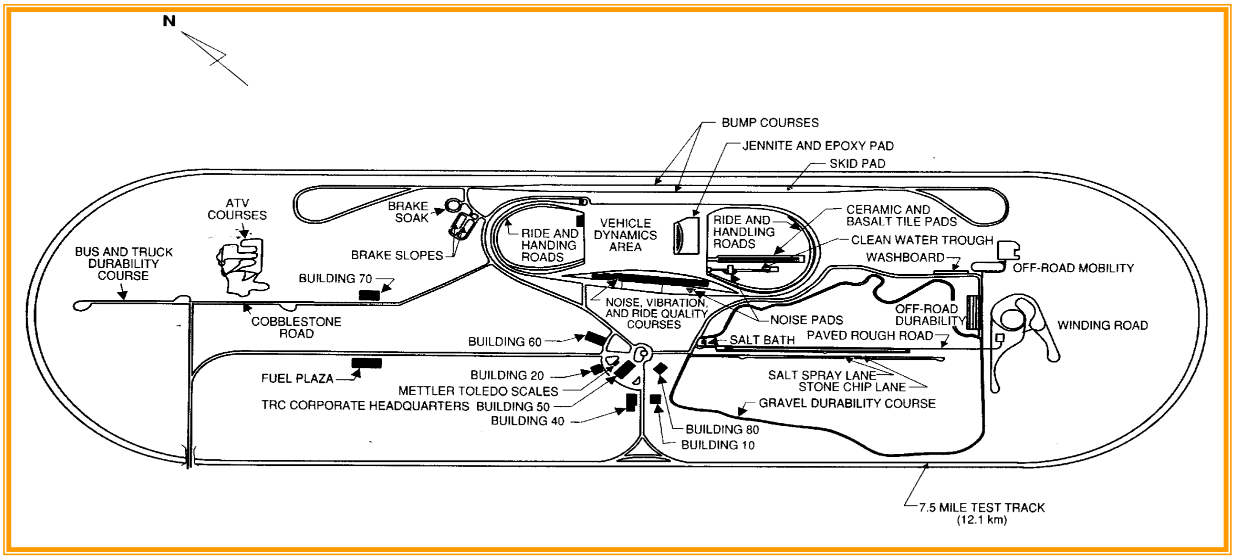


Figure A1. TRC Test Track Facilities

A2 TRC Vehicle Dynamics Area

The vehicle dynamics area (A2 below) consists of two loops [420ft (128 m) radius and 764 ft (233 m) radius] and a center area 1800 ft x 1200 ft (549 m x 366 m) where various vehicle passing maneuvers can be made.

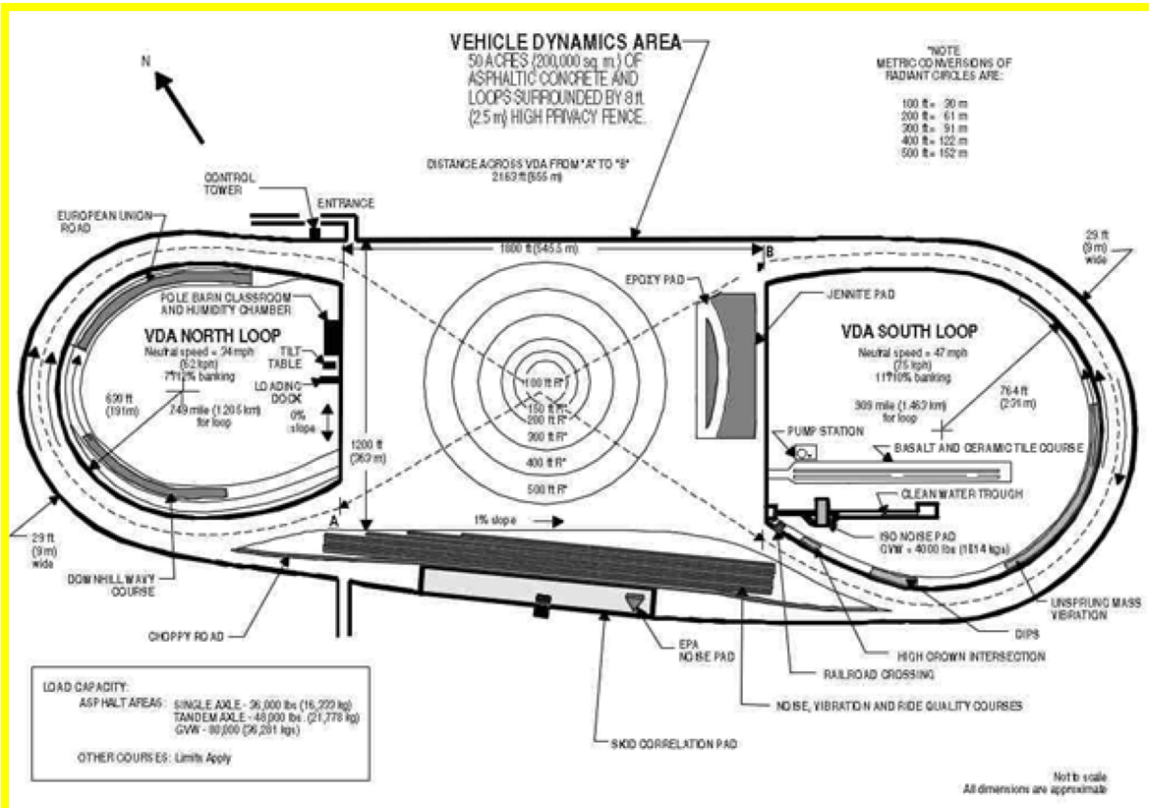


Figure A2. TRC's Vehicle Dynamics Test Area

A3 TRC Winding Road Course

The Winding Road Course will be used to verify the proper operation of some of the IVBSS system. This track is shown in Figure A3. The tests are to be run on the straight track portions B-J and various curve radii ranging from 35 m to 200 m.

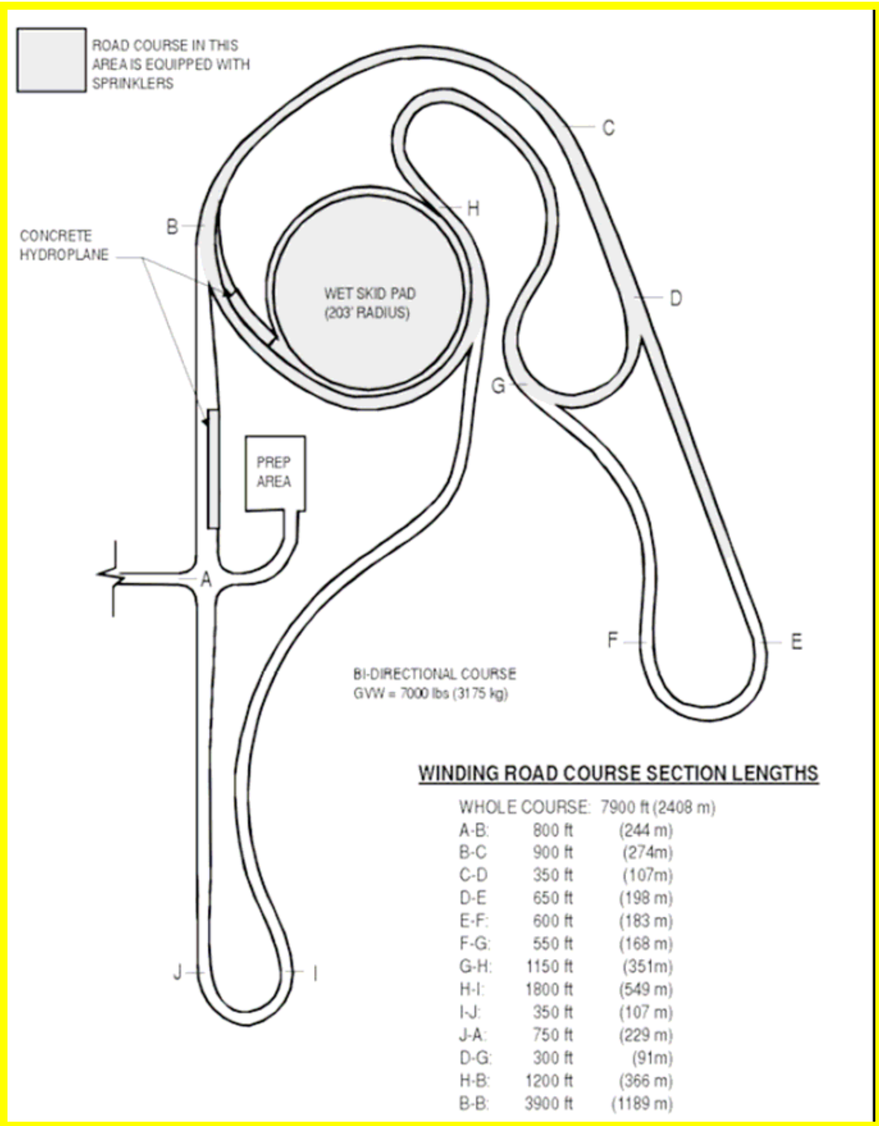


Figure A3. TRC's Winding Road Course

A4 TRC 7.5 Mile Oval Track

The 7.5-mile oval track may be considered to verify portions of the test that can't be accomplished by the Winding Road Track or the Skid Pad Track. Figure A4 below illustrates the 7.5-mile track. The curved sections of the track provide up to one mile of curved roadway.

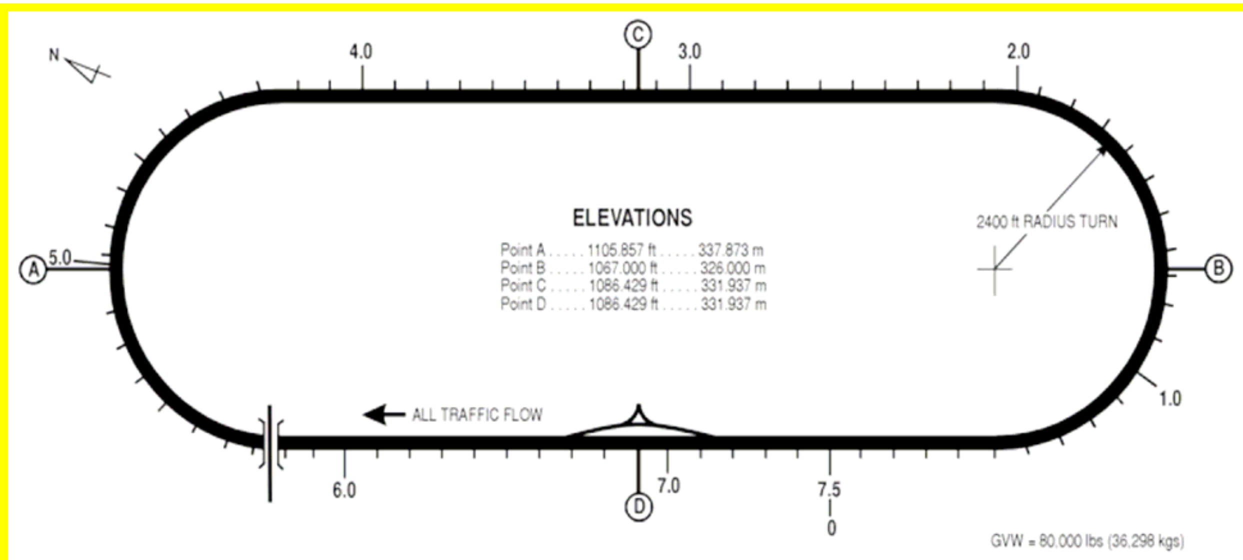


Figure A4. 7.5 Mile Oval Course

A5 TRC Skid Pad Track

The skid pad track has 7 lanes of 3600 ft. (1097 m) long straight-aways. It is expected that lanes 4, 5 and 6 of the Skid Pad will be used.

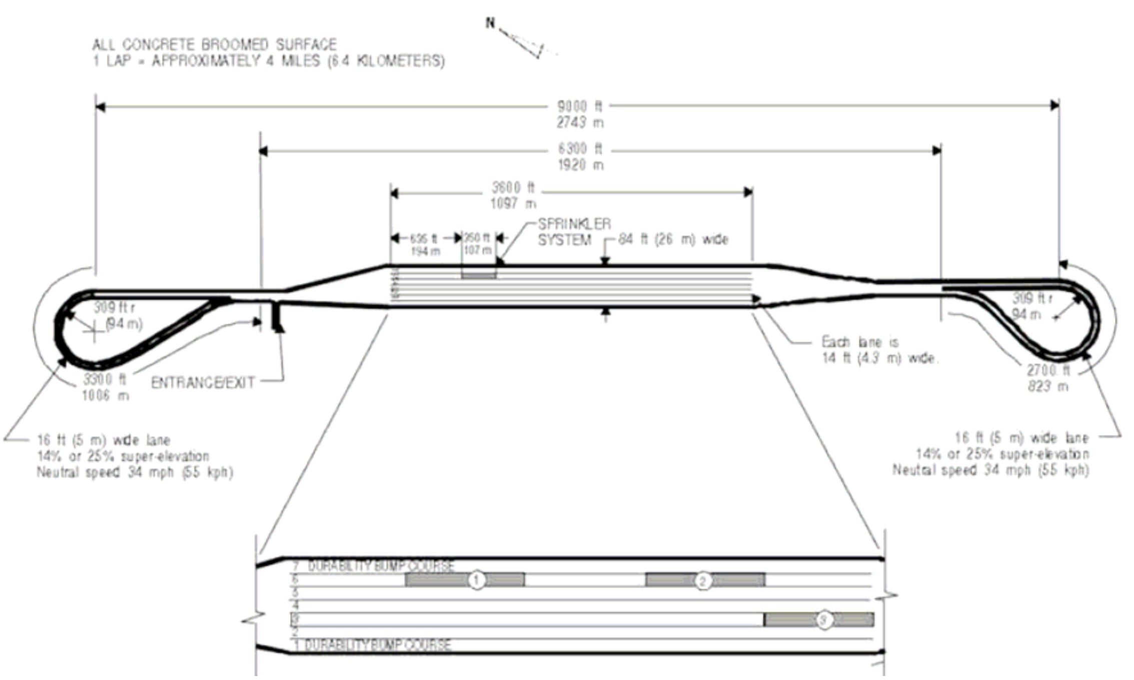


Figure A5. TRC's Multi Lane Skid Pad Course

A6 Dana Test Track Facility

Some of the verifications tests requiring large radius curve will be conducted at Dana track as shown in Figure A6 below. This is an oval shaped track having 3 lanes, with ~ 500 m long straight segment and ~ 285 m radius curved section with 7 deg banked cross-slope.

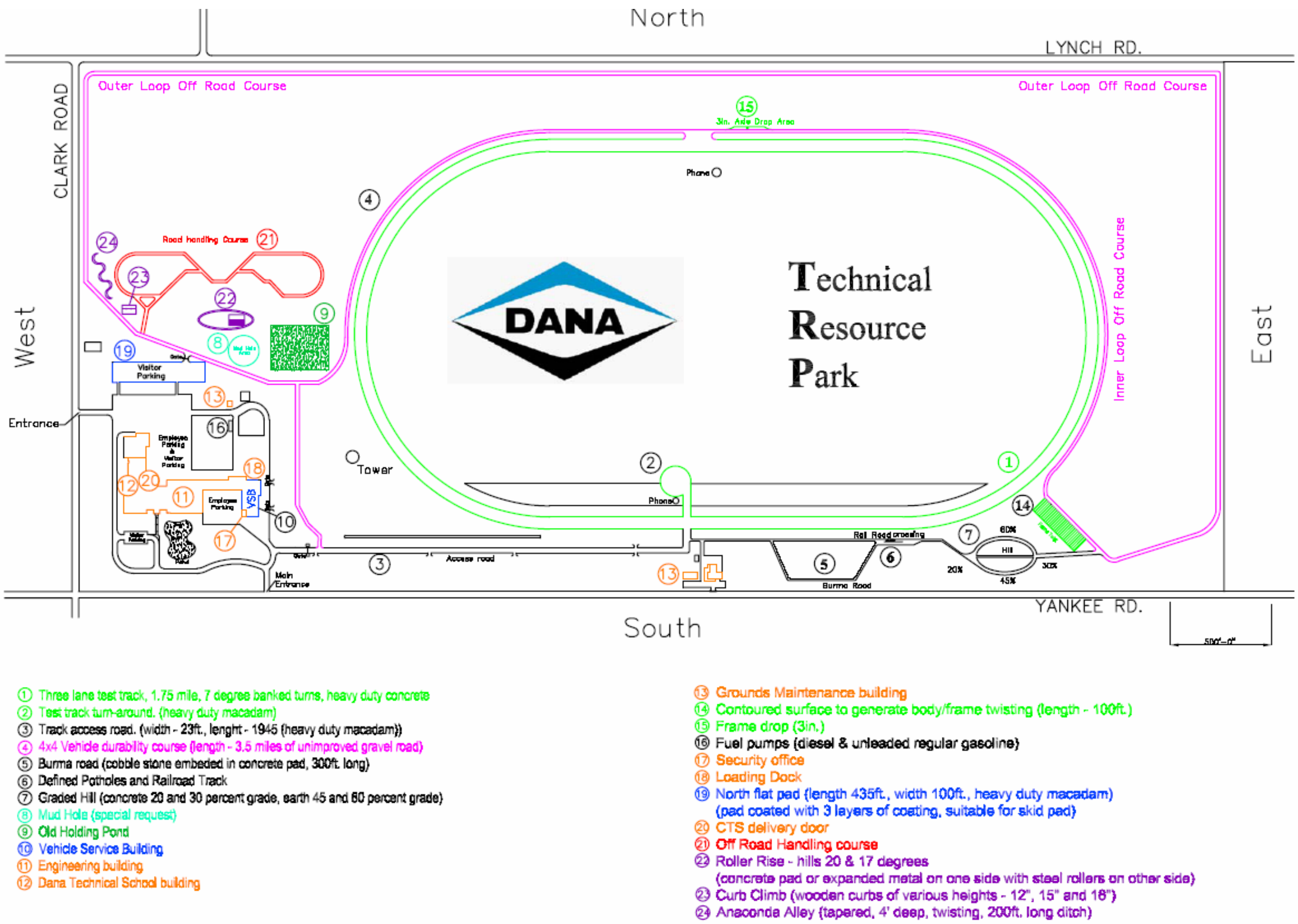


Figure A6. Technical Research Park (TRP) Dana Track