

# REPORT DOCUMENTATION PAGE

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<b>14. ABSTRACT</b> This TOP provides standardized tests for assessing the safety and performance of wheeled ground vehicles with Advance Driver Assistance Systems. This TOP does not address driving automation, cooperative driving automation or conventional cruise control unless conventional cruise control and adaptive cruise control are linked.						
<b>15. SUBJECT TERMS</b> Adaptive Cruise Control    Backup Warning Systems    Blindspot Monitoring Systems    Cross Traffic Alert Systems Lane Departure Warning Systems    Forward Vehicle Collision Warning Systems    Lane Keeping Assist Systems Forward Vehicle Collision Mitigation Systems    Rear Automatic Braking						
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U.S. ARMY TEST AND EVALUATION COMMAND (ATEC)  
TEST OPERATIONS PROCEDURE

\*Test Operations Procedure 02-2-515  
DTIC AD No.

22 August 2022

ADVANCED DRIVER ASSISTANCE SYSTEMS (ADAS)

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1. SCOPE.

a. Standardized tests are provided for evaluating Advanced Driver Assistance Systems (ADAS), including:

(1) Adaptive Cruise Control (ACC) Systems.

(2) Active Safety Systems.

(a) Warning.

1 Backup Warning (BUW) Systems.

2 Blind Spot Monitoring (BSM) Systems.

3 Cross Traffic Alert (CTA) Systems.

4 Lane Departure Warning (LDW) Systems.

5 Forward Vehicle Collision Warning Systems (FVCWS) (including Following Distance Warning).

(b) Intervention.

1 Forward Vehicle Collision Mitigation Systems (FVCMS) and Automatic Emergency Braking (AEB) Systems.

2 Lane Keeping Assistance Systems (LKAS).

3 Rear Automatic Braking (RAB).

4 Electronic Stability Control (ESC).

5 Anti-lock Braking System (ABS).

6 Traction Control Systems (TCS).

b. This Test Operations Procedure (TOP) generally applies to wheeled ground vehicles with conventional automatic transmissions and automated manual transmissions. This TOP does not address driving automation, cooperative driving automation, or conventional cruise control unless conventional cruise control and ACC are linked.

c. Active safety system terminology is generally consistent with Society of Automotive Engineers (SAE) International Recommended Practice J3063<sup>1\*\*</sup>, Active Safety Systems Terms and Definitions.

## 2. FACILITIES AND INSTRUMENTATION.

### 2.1 Facilities.

<u>Item</u>	<u>Requirement</u>
Level paved road	A level, paved road with one or multiple lane widths of not less than 3.7 meters (m), a longitudinal gradient $\leq 1\%$ , and a side-to-side gradient $\leq 2\%$ . Road sections may be straight or curved, as needed.
Primary road	Public, paved roads with light to moderate traffic, traffic signs and signals, not including city streets, sharp curves, and steep downhill grades.

### 2.2 Instrumentation.

<u>Devices for Measuring Position</u>	<u>Recommended Maximum Error of Combined System</u>
Acceleration	$\pm 5$ centimeters (cm) (2.0 inches (in.))
Velocity	0.02 g
Yaw, roll, and pitch rates	$\pm 0.16$ kilometers per hour (km/h) (0.1 miles per hour (mph))
	$\pm 0.1$ degrees per second

#### 2.2.1 Vehicle Position and Velocity.

Use of Real Time Kinematic (RTK) Global Positioning Systems (GPS) with at least a 5-Hertz (Hz) minimum update frequency is recommended to achieve desired vehicle position accuracy.

#### 2.2.2 Controller Area Network (CAN) Bus.

All relevant vehicle CAN bus data shall be monitored and recorded during testing, pursuant with TOP 01-2-506A<sup>2</sup> Use of Controller Area Network (CAN) Data to Support Performance Testing.

\*\* Superscript numbers correspond to Appendix B, References.

### 2.2.3 Cameras.

When necessary, use video cameras with time stamping to monitor and record operator interface display activity (e.g., warnings, alerts, and system settings) and the intended path of travel (e.g., forward-looking cameras).

### 2.2.4 Additional Instrumentation.

All test vehicles shall be fitted with an independent six degree of freedom (6-DOF) inertial measurement unit (IMU).

### 2.2.5 Recording System.

Install a data logger capable of recording GPS, CAN bus, IMU, radio communication, and video data on the test vehicles. If RTK corrections are to be applied during post-processing, the GPS base station messages shall also be recorded during the tests.

## 3. REQUIRED TEST CONDITIONS.

System Under Test (SUT) refers to the ADAS and vehicle system together.

### 3.1 General Vehicle Test Preparation.

- a. Review all instructional material issued with the test vehicle by the manufacturer, contractor, or government, as well as reports of previous tests on the same types of vehicles. When possible, review findings with the test sponsor and/or ADAS manufacturer to determine if test environments and repetitive test scenarios could induce faults or require system resets.
- b. Prepare and equip the vehicles in accordance with standard use and/or within the specifications presented in the test plan. Fill the fuel tank and other fluid reservoirs.
- c. Ensure that the vehicles received the proper break-in operation and that driveline, tires, brakes, steering, and suspension components are in good serviceable condition.
- d. If ADAS system initialization is required prior to use, follow vehicle and/or ADAS system manufacture instructions.
- e. Instrument the vehicle with GPS antennas (see paragraph 2.2.1), a GPS receiver, a radio frequency (RF) receiver for RTK corrections if correcting in real time, a data logger, CAN Bus connection(s), a network tap for communication information, an IMU, and video cameras.
- f. Verify all necessary wireless communications are adequate and instrumentation/data loggers are functioning properly.

### 3.2 Test Controls.

a. Test engineers and technicians should familiarize themselves with industry test standards listed in Table 1 prior to testing, as appropriate.

TABLE 1. RELEVANT INDUSTRY STANDARDS

NOMENCLATURE	TITLE
Terms and Definitions	
SAE J3063	Active Safety Systems Terms and Definitions
SAE J3016 <sup>3</sup>	Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems
Adaptive Cruise Control	
ISO 15622 <sup>4</sup>	Intelligent transport systems- Adaptive Cruise Control Systems- Performance requirements and test procedures
SAE J2399 <sup>5</sup>	Adaptive Cruise Control Operating Characteristics and User Interface
Back-up Warning	
ISO TR 12155 <sup>6</sup>	Commercial vehicles- Obstacle detection device during reversing- Requirements and tests
ISO 22840 <sup>7</sup>	Intelligent transport systems- Devices to aid reverse manoeuvres- Extended-range backing aid systems (ERBA)
ISO 17386 <sup>8</sup>	Transport information and control systems- Manoeuvring Aids for Low Speed Operation (MALSO)- Performance requirements and test procedures
Blind Spot Monitoring	
SAE J2802 <sup>9</sup>	Blind Spot Monitoring System (BSMS): Operating Characteristics and User Interface
ISO 17387 <sup>10</sup>	Intelligent transport systems - Lane change decision aid systems (LCDAS) - Performance requirements and test procedures
Lane Departure Warning	
SAE J2808 <sup>11</sup>	Lane Departure Warning Systems: Information for the Human Interface
SAE J3045 <sup>12</sup>	Truck and Bus Lane Departure Warning Systems Test Procedure and Minimum Performance Requirements
ISO 17361 <sup>13</sup>	Intelligent transport systems- Lane departure warning systems- Performance requirements and test procedures
Forward Vehicle Collision Warning	
ISO 15623 <sup>14</sup>	Intelligent transport systems- Forward vehicle collision warning systems-Performance requirements and test procedures
SAE J3029 <sup>15</sup>	Forward Collision Warning and Mitigation Vehicle Test Procedure- Truck and Bus
SAE J2400 <sup>16</sup>	Human Factors in Forward Collision Warning Systems: Operating Characteristics and User Interface Requirements

TABLE 1 (CONT)

NOMENCLATURE	TITLE
Forward Vehicle Collision Mitigation (Automatic Emergency Braking)	
SAE J3087 <sup>17</sup>	Automatic Emergency Braking (AEB)- Systems Performance Testing
SAE J3029	Forward Collision Warning and Mitigation Vehicle Test Procedure- Truck and Bus
ISO 22839 <sup>18</sup>	Intelligent transport systems- Forward vehicle collision mitigation systems- Operation, performance, and verification requirements
Lane Keeping Assistance	
ISO 11270 <sup>19</sup>	Intelligent transport systems- Lane keeping assistance systems (LKAS)- Performance requirements and test procedures
ISO 22735 <sup>20</sup>	Road vehicles- Test method to evaluate the performance of lane-keeping assistance systems
Electronic Stability Control /Anti-lock Braking /Traction Control System	
TOP 02-2-718A <sup>21</sup>	Electronic Stability Control
SAE J2536 <sup>22</sup>	Anti-Lock Brake System (ABS) Road Test Evaluation Procedure for Trucks, Truck-trailers and Buses
SAE J46 <sup>23</sup>	Wheel-Slip Brake-Control System Road Test Code
Targets	
ISO 19206-3 <sup>24</sup>	Road vehicles- Test devices for target vehicles, vulnerable road users and other objects, for assessment of active safety functions- Part 3: Requirements for passenger vehicle 3D targets

ISO = International Organization for Standardization

b. Prior to testing, ensure that:

(1) Vehicle training is conducted to ensure all test personnel are familiar and comfortable with technical and operational characteristics of the SUT and with the required test procedures.

(2) All personnel involved with testing receive new user training provided by ADAS system developers, when possible. Understanding all capabilities and limitations of each feature is critical to ensure safe testing.

(3) Vehicle identification, payload condition, total vehicle weight, weight distribution, and center-of-gravity characteristics are recorded.

(4) Pertinent automotive settings such as central tire inflation settings and active suspension settings are recorded.

(5) Data collection run logs are prepared to record all pre-test information, conditions of test, test results, observations, and measurements that would be valuable for analysis and assessment.

(6) All ADAS test items have the same software versions, matching the intended versions specified in the test plan. It is highly recommended that system software versions are not changed during testing. If software updates are necessary during testing, it is recommended that all tests completed with the previous software be repeated with the latest software versions.

(7) ADAS software version numbers and firmware version numbers for each pertinent system component (e.g., ACC, FVCMS, and ESC) are recorded.

(8) ADAS add-on controllers and sensors (not included with the base vehicle) are identified, and, when possible, determine if/how they interface with base vehicle controllers and sensors (e.g., ADAS brake controller and base vehicle brake controller).

(9) All limitations of the system under test are well vetted and understood. Typically, system developers provide system limitations. Examples include minimum and maximum speeds that system features operate within, maximum achievable acceleration and deceleration, and steer actuator rates.

(10) Vehicle operators and test engineers understand all applicable methods to regain manual control and operation of the vehicle (known as driver takeover) and are prepared to disable ADAS operation when necessary. Methods include (but are not limited to) applying service brakes, providing steer input, shifting the transmission to neutral or utilizing system disconnect buttons made available by the manufacturer. Ensure that all methods to regain control are approved by system developers/manufacturers.

### 3.3 Restrictions.

a. If testing FVCMS or other ADAS systems involving braking at or near performance limits, conduct manual brake tests of the base vehicle beforehand to characterize vehicle stopping performance, responses, and safety limitations without ADAS intervention. Refer to TOP 02-2-608<sup>25</sup> Braking, Wheeled Vehicles for guidance on test conduct.

b. Unless otherwise stated in the detailed test plan (DTP), test surfaces shall be dry, and tests shall be conducted in daylight with fair weather conditions and no major visibility reduction. When testing ACC systems on primary roads, avoid city streets, winding roads, sharp curves, steep downhill grades, and heavy traffic, as these conditions are not generally appropriate for ACC use.

## 4. TEST PROCEDURES.

a. ADAS-equipped vehicles may have multiple ADAS components functioning concurrently (e.g., ACC, FVCMS, ESC, ABS, and TCS). The control hierarchy may be

unknown to the testers. Unless other guidance is provided in the DTP or procedures below, test with all ADAS components active (as normally used) to fully characterize interactions between the systems.

b. The use of CAN bus data are indispensable when testing ADAS components, either individually or concurrently. See Clause (paragraph) 2.2.2. Monitor and record CAN bus channels indicating ADAS component status. Identify functional state changes during testing (i.e., components enabled, disabled, or set to standby). Compare occurrences to driver displays and warnings for consistency. When possible, monitoring all ADAS component state changes in real-time. Such changes may affect test safety.

c. Subject vehicle (SV) refers to an individual vehicle with the ADAS being tested. Forward vehicle refers to a vehicle immediately in front of, moving in the same direction, and traveling on the same roadway path as the subject vehicle. Target vehicle (TV) refers to a vehicle that the subject vehicle is expected to track for warning or intervention purposes.

d. Conduct ADAS tests with the subject vehicle configured as described in the DTP, including the payload, tire pressure, and suspension settings.

#### 4.1 Adaptive Cruise Control Systems.

a. ACC systems terminology, definitions, and symbols are generally consistent with ISO 15622 and SAE J2399. Tradenames and terms may vary.

b. Intended for primary road usage, ACC systems control longitudinal vehicle speed using either speed control or following control. Speed control is similar to conventional cruise control, where the driver sets a target speed. Following control temporarily reduces cruise control speed if a slower-moving vehicle obstructs the driving lane, maintaining a set time or clearance gap between the subject vehicle and a forward vehicle. Transitions between speed and following control occur automatically.

c. ACC systems adjust speed by controlling vehicle powertrain and brake systems, but do not handle emergency braking situations. Systems are either Full Speed Range Adaptive (FSRA) or Limited Speed Range Adaptive (LSRA). FSRA systems allow ACC speeds down to a standstill.

d. ACC systems should not react to stationary objects, slow moving vehicles, or oncoming traffic in adjacent lanes.

e. Table 2 outlines ACC test procedures.

TABLE 2. ACC TEST PROCEDURE OUTLINE

CLAUSE NO.	DESCRIPTION
4.1.1	Identify control modes, sensors, controls, displays, and settings
4.1.2	Operating conditions, driver interface and intervention (Safety Tests)
4.1.3	Target detection range and target discrimination
4.1.4	ACC speed and following control performance
4.1.5	Real-world operations

f. General Instructions.

(1) Unless the system specification or DTP provide other guidance, assess ACC performance using the system requirements provided in ISO 15622 Clause 6. At a minimum, control states shall consist of *Standby* and *Active (or Enabled)* states, including *Active Speed*, *Active Following*, and *Active FSRA Hold* (if applicable) sub-states. *FSRA Hold* control holds the subject vehicle at a standstill when stopped by a decelerating forward vehicle, until the operator enables forward motion. Control may also include an *Off* state that only transitions to the *Standby* state.

(2) Conduct tests on a closed, paved road test course, with straight sections available as needed and with sufficient space free of obstacles. Any curved sections used for testing shall have sufficiently large radii and banking to keep vehicle lateral acceleration levels below 0.2g. The horizontal visibility range shall be greater than 1 km. Visibility is the distance at which the illuminance of a non-diffusive beam of white light with a color temperature of 2,700 Kelvin is decreased to 5 percent of its original light source illuminance.

(3) During testing, record the following vehicle CAN bus data channels (at a minimum when possible).

(a) ACC control state or mode (*Off*, *Standby*, *Active Speed*, *Active Following*, and *Hold*).

(b) ACC settings (*Set Speed*, *Gap Time*, and *Gap Clearance*).

(c) ACC target detected.

(d) ACC target detected lamp.

(e) ACC distance to forward vehicle.

(f) ACC forward vehicle speed.

(g) ACC road curvature.

(h) Vehicle speed.

- (i) Transmission gear selection.
- (j) Brake apply
- (k) Brake lamp.

(4) Measure and record subject and target forward vehicle speeds and positions independently using RTK GPS. When using RTK GPS to determine vehicle clearances, account for offsets between the antennae and the front and rear of the vehicles.

(5) For the tests described in Clauses 4.1.2, 4.1.3, and 4.1.4, indicate whether the control states switched as expected and if visual, audible, or haptic indications or warnings alerted the driver when appropriate. Document any anomalies or safety concerns observed, including whether the system switched states inadvertently. During automatic vehicle braking in *Active Following* control, determine if the vehicle brake lights illuminated.

(6) For tests involving two or more vehicles operating concurrently, the subject vehicle and forward vehicle operators shall be in direct radio communication and ready to take evasive action if collision is imminent. Drivers shall pre-coordinate evasive actions to avoid contact.

(7) Prior to testing, ensure the ACC sensors are clean and not covered by dust, soil, ice, or vehicle fluids.

#### 4.1.1 Identify Control Modes, Sensors, Controls, Displays, and Settings.

Prior to testing, using system documentation, requirements documents, the DTP, pre-test system training, and inspection.

- a. List and describe ADAS control hierarchy if the vehicle is equipped with ADAS features other than ACC (e.g., FVCMS, ESC, and ABS). Document if ACC can be isolated from other ADAS features.
- b. List and describe the control states of the ACC system.
- c. At a minimum, list the following ACC system settings shown in Table 3 (see ISO 15622 and SAE J2399 for additional guidance). Some variation in the parameter set may be necessary with different ACC systems. Determine ACC system limitations on time and clearance gap settings.

TABLE 3. ACC SYSTEM SETTINGS

PARAMETER	DEFINITION
$a_{\text{lateral, max}}$	Maximum allowed lateral acceleration in curves
$a_{\text{stopping, max}}$	Maximum stopping acceleration allowed in the <i>Active</i> state
$\tau_{\text{min}}$	Minimum selectable time gap <sup>a</sup> (if ACC system permitted)
$\tau_{\text{max}}$	Maximum selectable time gap <sup>a</sup> (if ACC system permitted)
$\tau_{\text{default}}$	Default time gap <sup>a</sup>
$c_{\text{min}}$	Minimum clearance under steady state conditions <sup>a, b</sup>
$c_{\text{default}}$	Default clearance gap <sup>a, b</sup>
$v_{\text{set, low or } v_{\text{low}}}$	Minimum selectable set speed or minimum operating speed <sup>c</sup>
$v_{\text{set, max or } v_{\text{max}}}$	Maximum selectable set speed or maximum operating speed
$d_0$	Distance, below which detection of a target vehicle is not required
$d_1$	Distance, below which neither distance measurement nor determination of relative speed is required
$d_{\text{max}}$	Maximum detection range on straight roads

<sup>a</sup> May be vehicle speed dependent.

<sup>b</sup>  $c_{\text{min}}$  and  $c_{\text{default}}$  may be the same value.

<sup>c</sup> FSRA systems may operate at speeds below the minimum set speed to maintain the set gap with the target vehicle.

d. Indicate if other ADAS features can control the ACC set speed, along with associated conditions.

e. Document the driver controls, displays, and warnings available for driver interface and interaction with the ACC system (e.g., means for manually switching to ACC *Standby*, *Active*, or *Off* and means to adjust *Set Speeds*, *Time Gaps*, or *Clearance Gaps*), lists of visible and audible warnings, and descriptions of visible lights and symbols. Include any diagnostics and reaction to failure indicators or warnings. Include photographs, as appropriate. Examples of typical displays and warnings include:

- (1) ACC *Active* (or *Enabled*).
- (2) ACC *Standby*.
- (3) ACC set speed (or target speed).
- (4) Forward vehicle detected.
- (5) Collision (or impact) warning.

f. Identify the vehicle operating conditions necessary for the ACC to become *Active*. Factors may include transmission selection, brake pedal force condition, vehicle speed, and driver state. Also, identify if the ACC system is automatically on (in *Standby*) after starting the vehicle or if the ACC system has an *Off* state requiring the driver to manually switch the system on.

g. Identify the driver intervention actions enabling manual control of the vehicle. Table 4 provides typical examples.

TABLE 4. TYPICAL DRIVER ACTIONS ENABLING MANUAL CONTROL

DESCRIPTION
Driver manually using a switch, push button, touch pad, or touch screen to switch from <i>Active</i> to <i>Standby</i> (or <i>Off</i> )
Driver manually applying the service brake or accelerator pedal to intervene and switch from <i>Active</i> to <i>Standby</i>
Driver manually downshifting or shifting to neutral to intervene and switch from <i>Active</i> to <i>Standby</i>

h. Document the sensors used by the ACC system for control and feedback (e.g., Light Detection and Ranging (LiDAR), radar, optical cameras and sensors for wheel-speed, brake application, gear selection, and engine speed). Indicate the location of the LiDAR, radar, and optical camera sensors on the vehicle.

i. Document sensors used to monitor driver state such as steering torque sensors, steering wheel haptic sensors, and driver gaze detection if they affect ACC activation.

j. Document if vehicle features include conventional cruise control and if the driver must manually select between the two cruise control systems.

k. Document the other vehicle systems controlled by the ACC system to regulate vehicle speed, including the types of vehicle brakes used (e.g., foundation brakes, engine retarder brake, and electrical brake), the transmission controller and the engine controller.

#### 4.1.2 Operating Conditions, Driver Interface and Intervention (Safety Tests).

Conduct safety tests listed in Table 5 to verify vehicle-operating conditions necessary for *Active* control and driver actions available to regain manual control, prior to other performance tests. Perform these tests with other ADAS capabilities enabled to characterize interactions between various ADAS systems, unless the DTP provides other guidance.

TABLE 5. LIST OF ACC SAFETY TESTS

CLAUSE NO.	DESCRIPTION
4.1.2.1	Ensuring the ACC remains Off when switched Off (no forward vehicle)
4.1.2.2	Ensuring the ACC remains in <i>Standby</i> when switched to <i>Standby</i> (no forward vehicle)
4.1.2.3	Operating in <i>Active Speed</i> control (no forward vehicle)
4.1.2.4	Operating in <i>Active Following</i> control (with a forward vehicle, straight road)

4.1.2.1 Ensuring the ACC Remains Off When Switched Off (no forward vehicle).

**Note:** Not all ACC systems incorporate an *Off* state.

a. With the subject vehicle initially off, start the vehicle in *Park*, remain at a standstill and verify the state of the ACC system (i.e., *Off* or *Standby*). If the vehicle started in *Standby*, switch to *Off* (if possible) and verify whether the state change occurred.

b. With the ACC system *Off* and transmission in *Drive*, slowly accelerate the subject vehicle forward to above  $v_{max}$ , then slowly decelerate to a standstill. Verify that the system did not switch states. Repeat using the other lower forward gear selections, but limit speeds as appropriate for the gear state.

c. At a standstill with the engine running, place the transmission in *Reverse* and *Neutral* (for at least 10 seconds each), and then back to *Drive*. Verify that the system did not switch states.

4.1.2.2 Ensuring the ACC remains in *Standby* when switched to *Standby* (no forward vehicle).

a. Follow ACC Operators Manual instructions to place the ACC in *Standby* with the vehicle running.

b. With the transmission in *Drive*, slowly accelerate the subject vehicle to above  $v_{max}$ , then slowly decelerate to a standstill. Verify that the system did not switch states. Repeat using the other lower forward gear selections, but limit speeds as appropriate for the gear state.

c. At a standstill with the engine running, place the transmission in *Reverse* and *Neutral* (for at least 10 seconds each), and then back to *Drive*. Verify that the system did not switch states.

4.1.2.3 Operating in *Active Speed* Control (no forward vehicle).

a. With the ACC in *Standby*, operate the subject vehicle in *Drive* (accelerating slowly) to a speed slightly below  $v_{low}$ . Verify the ACC state stayed in *Standby*. Attempt to activate the speed setting (at the current speed), following Operator Manual instructions. Verify the ACC

state did not change from Standby to Active. Note any driver warnings or alerts indicating the speed was too low to activate speed control.

- b. With the ACC in *Standby*, slowly accelerate the subject vehicle to a speed slightly above  $v_{low}$ . Verify the ACC state stayed in *Standby*.
- c. With the ACC in *Standby*, slowly accelerate the subject vehicle to a predetermined speed 8-16 km/h (5-10 mph) below  $v_{set, max}$ . Activate the speed setting (at the current speed), following Operator Manual instructions. Verify the ACC state changed from *Standby* to *Active* and that the actual vehicle speed regulated to the set speed,  $v_{set}$ .
- d. Manually apply the service brakes to slow the subject vehicle to a speed slightly above  $v_{low}$ . Verify that the ACC state switched from *Active* to *Standby* when the brake pedal was applied. Repeat the procedures in paragraph 4.1.2.3.c.
- e. With the ACC still *Active*, slowly accelerate the subject vehicle to a predetermined speed approximately 8 km/h (5 mph) above  $v_{set, max}$ . Verify that the ACC state switched from *Active* to *Standby* when the throttle pedal was applied or when  $v_{set, max}$  was exceeded. Attempt to activate the speed setting (at the current speed), following Operator Manual instructions. Verify the ACC state did not change from *Standby* to *Active*. Note any driver warnings or alerts indicating the speed was too high to activate speed control. Manually apply the service brakes to slow the subject vehicle to a speed slightly above  $v_{low}$ . Repeat the procedures in paragraph 4.1.2.3.c.
- f. With the ACC still *Active*, attempt to manually (using a switch, push button, touch pad, or touch screen) deactivate the speed setting, following Operator Manual instructions. Verify the ACC state changed from *Active* to *Standby*. Repeat the procedures in paragraph 4.1.2.3.c. It is recommended to repeat this step a minimum of three times.
- g. With the ACC still *Active*, allow the subject vehicle to coast to a speed below  $v_{low}$  (without applying the service brakes). Verify that the ACC state changed from *Active* to *Standby* when the speed reached below  $v_{low}$ . Operate the vehicle to a standstill and then place in *Park*.

#### 4.1.2.4 Operating in Active Following Control (with a forward vehicle).

Prior to testing, if the subject vehicle ACC time or clearance gap setting is not set by the ACC system, manually set a safe time or clearance gap (as appropriate) within the bounds determined in paragraph 4.1.1.c, following Operator Manual instructions.

- a. Perform step 4.1.2.3.c with the subject vehicle. Operate a forward target vehicle (passenger vehicle or light truck) on the test course straight ahead of the subject vehicle at a distance greater than the manufacturer stated  $d_{max}$ .
- b. On a straight section of the test course, slow the target vehicle (deceleration less than 0.12g) to a steady state speed 8-16 km/h (5-10 mph) below the subject vehicle set speed, but

above  $v_{low}$ . Verify the subject vehicle detected the forward vehicle and changed from *Active Speed* to *Active Following* control by adjusting its speed and following the forward vehicle at the nominal time or clearance gap. Record the clearance distance between the subject and forward vehicle when the subject vehicle detected the forward vehicle and when the subject vehicle changed from ACC *Active Speed* to *Active Following* control. Verify the subject vehicle driver was notified when the forward vehicle was detected, and the state change occurred.

c. With the subject vehicle still in following control, slowly accelerate the forward vehicle to a speed above  $v_{set, max}$ . Verify the subject vehicle changed from *Active Following* control to *Active Speed* control by following the forward vehicle at the nominal time or clearance gap up to the original subject vehicle set speed and then maintaining the set speed.

d. Repeat the steps in paragraphs 4.1.2.4.a and 4.1.2.4.b. Slow the forward vehicle further (deceleration less than 0.12g) to a steady state speed approximately 8 km/h (5 mph) below  $v_{low}$ . Record the behavior of the subject vehicle and verify if the subject vehicle state changed from *Active Following* to *Active Speed* or *Standby*, or if no state change occurred. Record the subject vehicle speed at any transition and the clearance distance between vehicles.

e. Repeat the steps in paragraphs 4.1.2.4.a and 4.1.2.4.b. Slow the forward vehicle further (deceleration less than 0.12g) to a standstill. Presumably, the subject vehicle will also stop with a safe gap between the vehicles. Record the behavior of the subject vehicle and verify if the subject vehicle state changed from *Active Following* to *Standby* or *Hold*, or if no state change occurred. Record the subject vehicle speed at any transition and the clearance distance between vehicles. If the subject vehicle switched to *Hold* when stopped, test the so-called “Go” transition following instructions in the ACC Operators Manual to enable moving forward. Observe if the subject vehicle automatically resumes following control or if the driver must re-enable ACC following or speed control.

f. Repeat the steps in paragraphs 4.1.2.4.a and 4.1.2.4.b. Slow the forward vehicle further (deceleration less than 0.12g) to a temporary speed approximately 8 km/h (5 mph) below  $v_{low}$ , then immediately accelerate the forward vehicle (gradually) to an intermediate speed between  $v_{low}$  and  $v_{set, max}$ . Record the behavior of the subject vehicle and verify state changes. Record the subject vehicle speed at any transition and the clearance distance between vehicles.

#### 4.1.3 Target Detection Range and Target Discrimination.

a. Conduct tests listed in Table 6 to determine target detection range and discrimination performance. ACC systems may use LiDAR, radar sensors, and forward-looking cameras for forward object and vehicle detection. The number and type of sensors used varies across manufacturers. Detection depends on the target range, reflectivity, size, and position relative to the subject vehicle.

TABLE 6. LIST OF ACC TARGET DETECTION AND DISCRIMINATION TESTS

CLAUSE NO.	DESCRIPTION	
4.1.3.1	Detection range on straight roads	
	Options	Procedure A (Standby state)
		Procedure B (Active state)
4.1.3.2	Target discrimination	
	Scenarios	Two forward vehicles-lateral <ul style="list-style-type: none"> <li>– Passing in left lane (straight road)</li> <li>– Passing in left lane (curved road)</li> <li>– Forward vehicle changing lanes (straight road)</li> <li>– Subject vehicle changing lanes (straight road)</li> </ul>
		Two forward vehicles-longitudinal (straight and curved roads)
		On-coming vehicle in adjacent lane
		Stationary objects (straight and curved roads)

b. It is not possible to test all detection scenarios, so focus on detecting three targets normally encountered by the subject vehicle on primary roads, namely a compact or mid-sized passenger car, a light truck, and a vehicle of the same model as the subject vehicle. Additional targets and scenarios may be tested based on the DTP guidance and ACC system requirements, including the targets and scenario specified in ISO 15622 Clauses 7.2 and 7.4, motorcycles, trailers, pedestrians, pedestrians on bicycles, wildlife, and other motor vehicles.

#### 4.1.3.1 Detection Range on Straight Roads.

Verify the detection zone distances shown in Figure 1 on a straight road using a compact or mid-sized passenger car, a light truck, and a vehicle of the same model as the subject vehicle. Two procedures are presented. Procedure A assumes the ACC system updates the CAN bus channels associated with detection (e.g., AccTargetDetected) and range (e.g., DistanceFwdVeh) in the ACC *Standby* state. Procedure B assumes the ACC only updates detection and range in the ACC *Active* state, likely prohibiting the ability to determine  $d_0$  and  $d_1$ . It is recommended to test with both procedures for results comparison. These procedures may need to be adapted for an ACC system that operates differently.

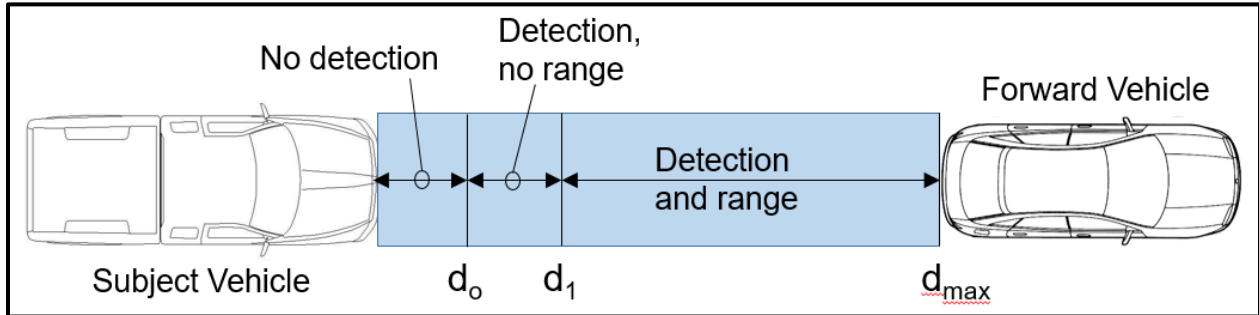


Figure 1. Zones of forward vehicle detection.

a. Procedure A (*Standby* state). Park one of the three target vehicles on a straight, level paved road, with no obstacles close to the target. Start testing from a range greater than  $d_{max}$  as stated by the manufacturer. With the subject vehicle in the ACC *Standby* state at its idle road speed, slowly approach the forward vehicle from behind, as shown in Figure 1, with a lateral offset no greater than 0.5 m (1.6 feet (ft)). Record and observe RTK GPS position of both vehicles, CAN bus channels associated with detection and range, and the subject vehicle speed. As the subject vehicle gets close to the forward vehicle, the driver carefully slows the subject vehicle using the service brakes but continues forward until reaching a range of 2 m (6.5 ft). Compare driver display and alert results (e.g., target detected) to digital CAN bus data to assess consistency. From the recorded results, determine the measured distances  $d_0$ ,  $d_1$ , and  $d_{max}$ . Repeat for the other two target vehicles.

**Note:** Some ACC systems may not include all three zones.

b. Procedure B (*Active* state).

(1) If subject vehicle time or clearance gap is selectable, set the value to the minimum possible value ( $\tau_{min}$  or  $c_{min}$ ) following Operator Manual instructions.

(2) With the ACC in *Standby*, slowly accelerate the subject vehicle to a predetermined speed approximately 16 km/h (10 mph) above  $v_{low}$ . Activate the set speed (at the current speed), following Operator Manual instructions. Verify the ACC state changed from *Standby* to *Active* and that the actual vehicle speed regulated to the set speed,  $v_{set}$ .

(3) Maneuver one of the three target vehicles ahead of the subject vehicle at a range greater than  $d_{max}$  as stated by the manufacturer and lateral offset no greater than 1.0 m (3.3 ft).

(4) On a straight, level paved road, slow the target vehicle to a speed between  $v_{low}$  and  $v_{set}$  until Active Following control occurs, and the minimum time or clearance gap is established. Then, if the subject vehicle is the FSRA type, slowly decelerate the forward vehicle until both vehicles stop.

(5) Compare driver display and alert results (e.g., target detected) to digital CAN bus data to assess consistency. From the recorded results, determine the measured distance  $d_{\max}$  and  $d_1$ , if possible.

(6) Repeat for the other two target vehicles.

**Notes:** Some ACC systems may not include all three zones. The  $v_{\text{set}}$  speed and the slowed target vehicle speed (in step (4)) may need to be adjusted based on test course length dimensions.

#### 4.1.3.2 Target Discrimination.

Target discrimination tests assess the ACC systems ability to differentiate between multiple targets and react accordingly to the proper target. At a minimum, conduct the basic target discrimination tests listed below using the three target vehicles identified in paragraph 4.1.3.1. The target vehicles may be fitted with the standard LiDAR and radar target reflectors described in ISO 15622 Clause 7.2, if required by the DTP.

a. Two Forward Vehicles-Lateral. Perform lateral discrimination tests initially on a straight, two-lane paved road (each lane 3.7-m (12-ft) wide), with no obstacles present on the road shoulders.

(1) If the ACC following time gap is selectable, set the gap to  $\tau_{\max}$ . Note that  $\tau_{\max}$  or  $\tau_{\text{default}}$  may be speed dependent.

(2) Select an initial test speed,  $v_{\text{start}}$ , between  $v_{\text{low}}$  and  $(v_{\text{set, max}} - 11 \text{ km/h (7 mph)})$ . For most military wheeled vehicles, 64 km/h (40 mph) is recommended. Multiple initial speeds may be tested.

(3) Start the test event with the subject vehicle and two forward vehicles positioned as shown in Figure 2 and traveling at the same steady state speed selected. Initially, the target vehicle is the smallest of the three available target vehicles and the forward vehicle is the largest of the three. The subject vehicle is in *Active Following* control, with its test speed regulated by the target vehicle. Record the ACC system settings, control states, vehicle speeds and range between the subject and target vehicles. Record RTK GPS of the three vehicles independently.

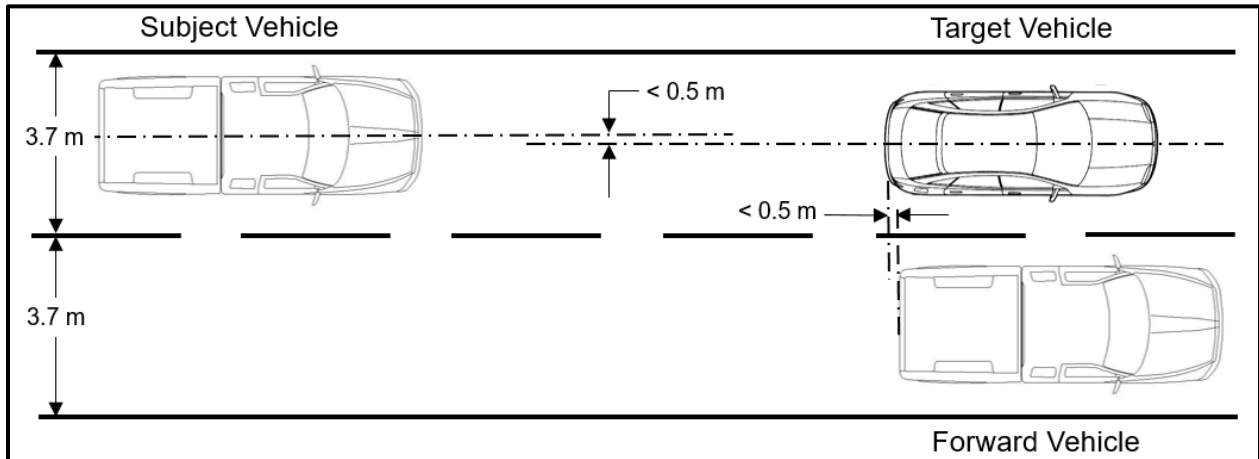


Figure 2. Lateral target discrimination test initial conditions.

(4) Increase the target vehicle speed from  $v_{start}$  to  $(v_{start} + 11 \text{ km/h (7 mph)})$ , staying below  $v_{set, max}$ , while the forward vehicle remains at the initial speed. The test event is successfully completed when the subject vehicle passes the forward vehicle in the adjacent lane. Verify the subject vehicle followed the appropriate vehicle, the range value between the subject and target vehicle was continuous, and the subject vehicle remained in *Active Following* control. Note any driver warnings or alerts.

(5) Repeat the previous two steps transposing the target and forward vehicles.

(6) Repeat the previous three steps for the following additional scenarios.

(a) All three vehicles traveling on a nominal 500-m (1640-ft) constant radius curve, in both turn directions. If a 500-m radius curve is not available, select a test curve with a radius as close to 500-m as possible and ensure the test speeds are appropriate for the turn radius.

(b) All three vehicles traveling straight as in Figure 2, but the forward vehicle changes lanes after the target vehicle clears the forward vehicle, positioning itself between the subject and target vehicle. The lane change maneuver only occurs if safe clearance is available between the three vehicles at the range of test speeds. Observe and record the subject vehicles ACC system reaction to the maneuver and note any driver warnings or alerts.

(c) All three vehicles traveling straight as in Figure 2, but the subject vehicle changes lanes (without applying the brakes or throttle), positioning itself behind the forward vehicle. The target vehicle does not accelerate in this scenario. Observe and record the subject vehicles ACC system reaction to the maneuver and note any driver warnings or alerts.

b. Two Forward Vehicles-Longitudinal. Conduct longitudinal discrimination tests initially on a straight road with two forward vehicles operating in the same lane and the subject vehicle following both vehicles, as shown in Figure 3. Vehicle 1 is the smallest of the forward

vehicles and is the target vehicle. Conduct the tests only if the size difference between forward vehicles 1 and 2 is such that both vehicles are visible from the subject vehicle sensors. No obstacles should be present on the road shoulders.

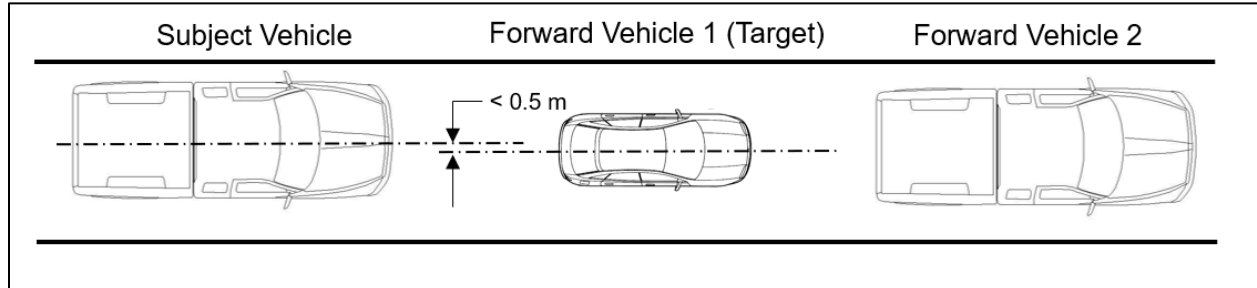


Figure 3. Longitudinal discrimination tests initial conditions.

(1) If the ACC following time gap is selectable, set the gap to  $\tau_{\max}$ . Note that  $\tau_{\max}$  or  $\tau_{\text{default}}$  may be speed dependent.

(2) Select an initial subject vehicle set speed,  $v_{\text{set}}$ , greater than  $v_{\text{low}}$  and less than  $v_{\text{set, max}}$ . For most military wheeled vehicles, 64 km/h (40 mph) is recommended. Multiple initial speeds may be tested.

(3) Start with the subject vehicle traveling in *Active Speed* control at  $v_{\text{set}}$ , with the two forward vehicles traveling the same speed a distance ahead greater than  $(\tau_{\max} \times v_{\text{set}})$ . Establish a three-second gap between the two forward vehicles (approximately 175 ft at 40 mph). Record the ACC system settings, control states, vehicle speeds and range between the subject and any forward vehicle. Record RTK GPS of the three vehicles independently.

(4) Slow both forward vehicles to a speed between  $v_{\text{low}}$  and  $v_{\text{set}}$ , maintaining the distance between the forward vehicles. Complete the maneuver after the subject vehicle switches to Active Following control and begins to slow with the forward vehicles. Verify which vehicle was detected by the subject vehicle by comparing CAN bus range results with RTK GPS position data.

(5) Repeat the previous two steps on a nominal 500-m (1640-ft) constant radius curve, in both turn directions. If a 500-m radius curve is not available, select a test curve with a radius as close to 500-m as possible and ensure the test speeds are appropriate for the turn radius.

**Note:** The  $v_{\text{set}}$  speed and the slowed target vehicle speed (in step d) may need to be adjusted based on test course length dimensions.

c. On-coming Vehicle in Adjacent Lane. Conduct on-coming vehicle discrimination tests initially on a two-lane (each lane 3.7 m (12 ft wide)), nominal 500-m (1640-ft) constant radius curve (or as close as possible), replicating the scenario depicted in Figure 4. The test

lanes should be clear of any obstacles other than the test vehicles. Initially, Vehicle 1 is the smallest of the forward vehicles and is the target vehicle.

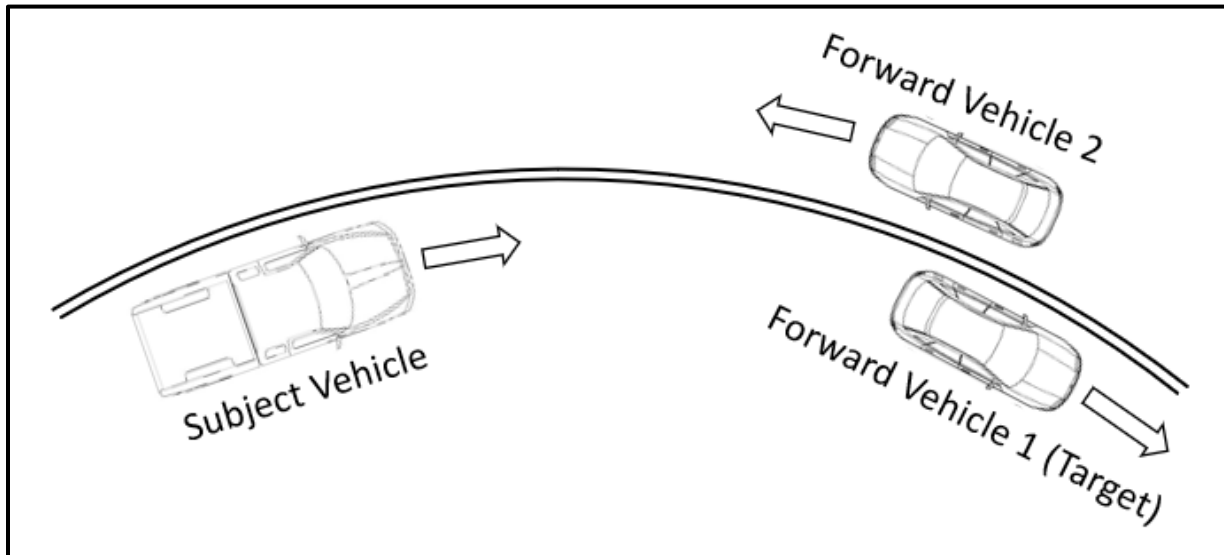


Figure 4. On-coming vehicle discrimination test.

(1) If the ACC following time gap is selectable, set the gap to  $\tau_{\max}$ . Note that  $\tau_{\max}$  or  $\tau_{\text{default}}$  may be speed dependent.

(2) Select an initial test speed appropriate for the capabilities of the subject vehicle, but greater than  $v_{\text{low}}$  and less than  $v_{\text{set, max}}$ . For most military wheeled vehicles, 64 km/h (40 mph) is recommended. Multiple speeds may be tested.

(3) The subject vehicle is in *Active Following* control, with its test speed regulated by target vehicle 1 when forward vehicle 2 passes to the left at the same test speed in the opposite direction. Record the ACC system settings, control states, vehicle speeds and range between the subject and any forward vehicle. Record RTK GPS of the three vehicles independently.

(4) When the subject vehicle passes target vehicle 2, the test event is successfully concluded. Observe and record the subject vehicles ACC system reaction to the maneuver and note any driver warnings or alerts.

(5) Repeat the previous two steps transposing the forward vehicles and then with only forward vehicle 2 on the road. In the second case, the subject vehicle is in *Active Speed* control.

(6) If the subject vehicle reacted to forward vehicle 2, repeat the previous steps on a straight section of the road.

d. Stationary Objects.

(1) Conduct tests passing stationary objects positioned on the road shoulders (left and right side), while the subject vehicle travels in the lane adjacent to the shoulder. Unless the DTP provides other guidance, use the smallest and largest of the three target vehicles identified at the beginning of Clause 4.1.3 as the objects. Conduct tests on a straight road (curved road optional) with the subject vehicle operating in *Active Speed* control at a set speed between  $v_{low}$  and  $v_{set, max}$ . Multiple speeds may be tested.

(2) Record the ACC system settings, control states, vehicle speed, instances of forward vehicle detections, and range to any objects detected. Note any driver displays, warnings or alerts indicating an object was detected (e.g., target detected or stationary object alert). The objects shall not be detected as target vehicles.

4.1.4 ACC Speed and Following Control Performance.

Unless the DTP provides other guidance, conduct the tests listed in Table 7 to characterize ACC speed and following control performance further. The forward target vehicle selection for this portion of testing is not critical, as long as the forward vehicle represents one detected by the ACC system. Unless the DTP provides other guidance, use one of the three target vehicles recommended in Clause 4.1.3.

TABLE 7. ACC PERFORMANCE TESTS

CLAUSE NO.	DESCRIPTION
4.1.4.1	Active speed control settings and controls
4.1.4.2	Active following control settings
4.1.4.3	Active following control braking and accelerating

4.1.4.1 Active Speed Control Settings and Controls.

a. Verify the ACC  $v_{low}$  and  $v_{set, max}$  setting values by operating the vehicle at speeds above and below the manufacturer stated values while attempting to enable *Active Speed* control. No obstacles or forward vehicles are on the road. At all speeds tested, verify that steady state speeds were achieved and record any differences between the set speed and actual speed.

b. While operating in *Active Speed* control at multiple set speeds between ACC  $v_{low}$  and  $v_{set, max}$ , apply the brake to switch to *Standby* and decrease the vehicle speed 8-16 km/h (5-10 mph), while staying above  $v_{low}$ . Activate the *Resume* feature and observe if the ACC system switched back to *Active Speed* control and if vehicle speed returned to the previous set speed with a reasonable acceleration. Determine and record the average acceleration value.

c. Verify the cruise control set speed (+) and (–) features function appropriately across a range of set speeds.

d. If safe to do so on available test courses, verify the maximum allowed lateral acceleration in curves,  $a_{\text{lateral, max}}$ , stated by the manufacturer. Operate the subject vehicle on a constant radius curve in *Standby* at speeds (below  $v_{\text{set, max}}$ ) known to produce lateral acceleration levels slightly below and slightly above  $a_{\text{lateral, max}}$ . Attempt to set the speed to switch to *Active Speed* control and observe the ACC system reaction. If the manufacturer stated setting is unknown, test up to  $0.2g$ .

#### 4.1.4.2 Active Following Control Settings.

With the subject vehicle and target vehicle operating on a straight road in *Active Following* control at various constant speeds between  $v_{\text{low}}$  and  $v_{\text{set, max}}$ , determine the time gap between the vehicles using RTK GPS, vehicle speed and target range data. Verify that the ACC target range results match the RTK GPS clearance results. Verify  $\tau_{\text{max}}$  and  $\tau_{\text{min}}$  settings if the time gap is driver selectable and  $\tau_{\text{default}}$  if not driver selectable. The time gaps may be speed dependent.

#### 4.1.4.3 Active Following Control Braking and Accelerating.

If the subject vehicle is equipped with a FVCMS, disable the FVCMS to avoid braking due to that system.

a. Unless the DTP provides other guidance, test *Active Following* control braking at the deceleration limit stated by the manufacturer  $a_{\text{stopping, max}} \pm 0.03g$  or between  $0.20$  and  $0.25g$ , as appropriate. Start testing with the subject and forward vehicle operating at a speed just below  $v_{\text{set, max}}$  and decelerate to  $v_{\text{low}}$ . Perform three trials with the same conditions. Record time differences between the start of target and subject vehicle decelerations and gap clearances between the vehicles. Report any unsafe conditions. Automatic brake activation shall not lead to locked wheels for periods longer than anti-lock devices (i.e., ABS) would allow.

b. For FSRA systems, repeat the procedures in paragraph 4.1.4.3.a., but decelerate the vehicles to a standstill.

c. Unless the DTP provides other guidance, test the *Active Following* control acceleration behavior at the maximum target vehicle acceleration (of the three selected target vehicles). Start testing with the subject and forward vehicles operating at a speed just above  $v_{\text{low}}$  and accelerate to above  $v_{\text{set, max}}$ . Perform three trials with the same conditions. Determine and record delta times between the start of target and subject vehicle accelerations and gap clearances between the vehicles. Report any unsafe conditions. If the subject vehicle cannot follow the target at the maximum acceleration level, repeat testing at lower acceleration levels, as necessary.

#### 4.1.5 Real-World Operations.

##### 4.1.5.1 Brake Overuse Warning.

If the ACC system is equipped with a brake overuse warning based on brake temperature measurements or estimations, operate the subject vehicle on a level paved road test course while making repetitive brake snubs from 64 km/h (40 mph) to 40 km/h (25 mph). Heat the foundation brakes to a temperature slightly exceeding the stated ACC manufacturer upper limit at the brake position(s) equipped with manufacturer sensors(s). Observe if the brake overuse warning occurs. Prior to testing, install test thermocouples or infrared temperature sensors at the brake position(s) equipped with the manufacturer sensors. For thermocouples installed in the brake linings, refer to Federal Motor Vehicle Safety Standards (FMVSS) 135<sup>26</sup>, 105<sup>27</sup>, and 121<sup>28</sup> for proper installation guidance.

##### 4.1.5.2 Driving on Real Roadways.

If previous testing (Clauses 4.1.1 through 4.1.4) indicates it is safe to operate the subject vehicle on public primary roads, proceed with testing under controlled conditions (e.g., fair weather, with escort vehicles, and with necessary permits). Avoid city streets, winding roads, sharp curves, steep downhill grades, and heavy traffic, as these conditions are not generally appropriate for ACC use. Initially, operate the subject vehicle ACC in *Standby*, observing and documenting warning and alerts. When road conditions are appropriate for steady state cruising, proceed to *Active Speed* control operations. Finally, when it is safe to do so, use a test escort vehicle as a forward target vehicle and operate in *Active Following* control, varying the speed to match speed limits and traffic stops. Observe system behavior, warnings and alerts and report any anomalies and unsafe conditions encountered. If an unsafe event is encountered, pause testing until the unsafe condition is reconciled.

#### 4.2 Active Safety Systems.

Active safety systems sense and monitor conditions inside and outside the vehicle for the purpose of identifying perceived present and potential dangers to the vehicle, occupants, and/or road users, and automatically intervene to help avoid or mitigate potential collisions via various methods, including alerts to the driver, vehicle system adjustments, and/or active control of the vehicle subsystems (brakes, throttle, suspension, etc.).

##### 4.2.1 Backup Warning Systems.

a. BUW systems provide detection of obstacles primarily to the rear of the subject vehicle and/or provide indirect rear visibility to help the driver compensate for rear blind spots. Systems warn the driver about the presence of an object behind the subject vehicle using visual, audible, and/or tactile alarms. Systems may follow the steering angle for detection of obstacles in the path of travel in curves. BUW systems are organized into two types, based on backing speed and range: low-speed, short range, and extended range.

b. Low-speed, short range BUW systems employ non-contact sensors to aid the driver when backing at speeds up to 5 km/h (approximately walking pace) and detect obstacles typically to 3.0 m maximum range. Control of the vehicle remains the responsibility of the driver. Maneuvering aids for low-speed operation (MALSO) may be used as low-speed, short range BUW systems. However, MALSO employ sensors at the front and rear of the vehicle and assist the driver during parking and maneuvering situations at very low speeds, up to 1.8 km/h. MALSO are not included in the scope of this procedure. Refer to ISO 17386 for guidance when testing MALSO.

c. Extended-range backing aids (ERBA) are detection devices with non-contact sensors that assist the driver during low- to mid-speed backing maneuvers, typically up to 11 km/h. ERBA systems are not intended for short-range detection of obstacles located immediately behind the vehicle. ERBA systems typically use ultrasonic and radar sensors for detection and ranging and provide the driver with information based on the distance to the detected obstacles. ERBA systems calculate a dynamic estimate of collision danger and warn the driver when immediate attention is required to prevent a collision with the obstacle. A dynamic warning is necessary for the higher vehicle speeds that occur in backing events where the relative closing velocities between the vehicle and the obstacle are greater as compared to low-speed situations. Control of the vehicle remains the responsibility of the driver.

d. Table 8 outlines BUW test procedures.

TABLE 8. BUW TEST PROCEDURES

CLAUSE NO.	DESCRIPTION
4.2.1.1	Identify sensors, warnings, displays and settings
4.2.1.2	Monitoring range
4.2.1.3	Speed range, engagement latency and detection latency
4.2.1.4	Sensor fault self-test

e. General Instructions.

(1) ISO TR 12155 provides requirements and test procedures for low-speed, short range commercial truck BUW warning systems. ISO 22840 provides requirements and test procedures for ERBA systems employed on passenger cars, pick-up trucks, light vans, and sport utility vehicles. Neither standard may be appropriate for use on military wheeled vehicles. Unless the system specification or DTP provide other guidance, assess military vehicle BUW system performance based on the attributes and test procedures described below.

(2) Conduct tests on a dry, straight, and level paved road test course, with sufficient space free of obstacles other than test objects described in the following procedures. The ambient conditions should be free of precipitation, between 0 °Celsius (C) and 35 °C

(32 °Fahrenheit (F) and 95 °F), with wind speed sufficiently low to prevent unintended movement of the test objects (described below).

(3) Prior to testing, ensure the BUW sensors are clean and not covered by dust, soil, ice, or vehicle fluids.

#### 4.2.1.1 Identify Sensors, Warnings, Displays, and Settings.

Prior to testing, using system documentation, requirements documents, the DTP, system training, and inspection:

- a. Determine the speed and detection range (azimuth and elevation) limitations of the BUW system. Identify azimuth pre-warning, main warning, and collision warning ranges, if they exist.
- b. Determine whether when reverse gear is selected, the detection device is automatically activated. If possible, determine the maximum activation time.
- c. Determine whether a visual and/or audible readiness-for-service (or system activation) indication is provided to the driver.
- d. Document the displays and warnings available for driver interface and interaction with the BUW system. Include any self-tests and reaction to failure indicators or warnings. Include photographs of visible displays if possible.
- e. Document the sensors used by the BUW system (e.g., ultrasonic, LiDAR, radar, and/or optical cameras). Indicate the location of the sensors on the vehicle.
- f. Determine the maximum allowed detection latency of the system, from the time an object is detected to when the warning is given.
- g. Determine system operational characteristics, requirements and limitations when using trailers without detection devices.
- h. Document whether or not the BUW system is integrated with any other active safety systems and whether or not function of the other active safety systems can be isolated from BUW system function.

#### 4.2.1.2 Monitoring Range.

The rearward monitoring zone and range capability is determined from two tests, an azimuth grid test and an elevation grid test. When testing the rearward monitoring zone of BUW systems with ultrasonic- and LIDAR-based sensors, utilize azimuth and elevation test objects listed in Table 9. When testing BUW systems with radar-based sensors, utilize the azimuth and elevation test objects listed in Table 10. Other sensor types may require test objects with different dimensions and materials.

TABLE 9. STANDARD TEST OBJECTS, ULTRASONIC- AND LIDAR-BASED SENSORS

ZONE COVERAGE	DIMENSIONS	MATERIAL
Azimuth	75 mm (3 in.) nominal outside diameter, 1 m length	Plastic tube, grey
Elevation	75 mm (3 in.) nominal outside diameter, 0.3 m length	Plastic tube, grey

TABLE 10. STANDARD TEST OBJECTS, RADAR BASED SENSORS

ZONE COVERAGE	DIMENSIONS	MATERIAL
Azimuth	50 mm (2 in.) nominal outside diameter, 1 m length	Metal
Elevation	50 mm (2 in.) nominal outside diameter, 0.3 m length	Metal

a. Construct an azimuth test grid in accordance with Figure 5, with the 0.2 m x 0.2 m grid centerline aligned with the vehicle centerline. Align a vehicle reference point (e.g., rear bumper outer face) with the start of the grid. With the BUW system activated and the vehicle stationary in reverse gear, systematically position the azimuth test object vertically, supported by the ground, at the azimuth grid positions shown in Figure 5. If separate pre-warning, main warning, and collision warning zones are not pre-defined, test at the rearmost position (as shown) and at two intermediate reference lines. At each test point, detection shall occur unambiguously with an uninterrupted sequence of the warning signals appropriate to the warning zone. Record where the warning signals did and did not occur. Additional test points may be included outboard and further rearward of the overall warning zone. Outboard warnings may be driver nuisances, and positions further rearward may define the distance limits of the sensors.

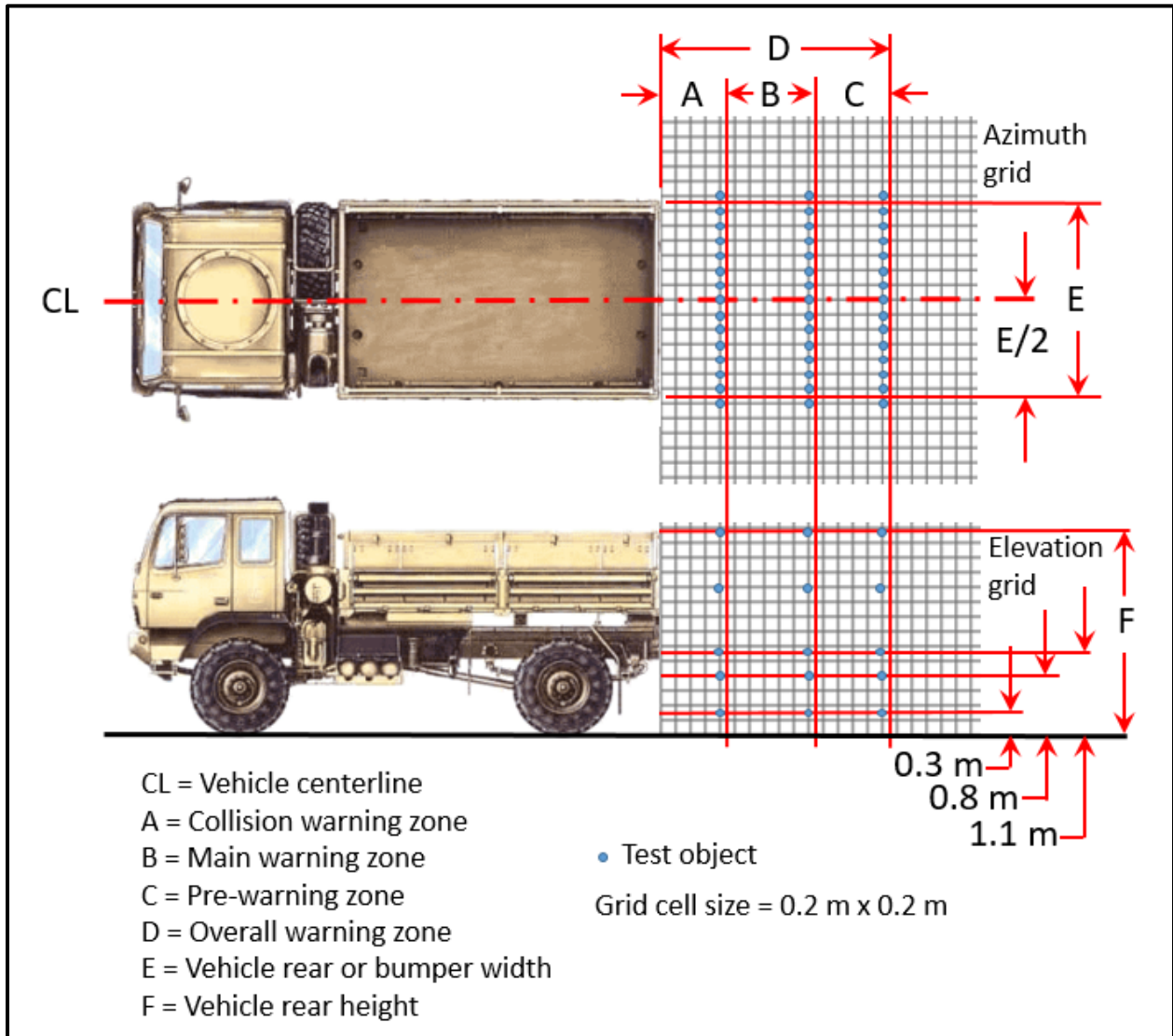


Figure 5. Azimuth and elevation monitoring range test dimensions.

b. Calculate the coverage ratio for each sub-area of the grid. The coverage ratio is the ratio of detected points to the total test points in each sub-zone. Sensor type and/or sensor positioning can often create large non-detected areas.

c. With the BUW system activated and the vehicle stationary in reverse gear, systematically position the elevation test object horizontally, parallel to the rear of the vehicle, at the elevation grid locations shown in Figure 5. Suspend the elevation test object by thin wire between two vertical stanchions outside of the monitoring zone. The wire shall be invisible to the sensors. Azimuth placement of the test object at each vertical position is at the centerline, the two outermost points, one intermediate point to the right of the centerline, and one intermediate point to the left of the centerline (five positions per elevation position). If separate pre-warning, main warning, and collision warning zones are not pre-defined, test at the rearmost position (as

shown) and at two intermediate reference lines. At each test point, detection shall occur unambiguously with an uninterrupted sequence of the warning signal appropriate to the warning zone. Record where the warning signals did and did not occur. Additional test points may be included (e.g., with the test object below 0.3 m or resting on the ground) to identify nuisance warnings or lack of coverage.

#### 4.2.1.3 Speed Range and Detection Latency.

a. Starting with the azimuth test grid described in paragraph 4.2.1.2, position the azimuth test object along the grid centerline at the rearmost azimuth grid point detected in paragraph 4.2.1.2.

b. Drive the vehicle straight forward a sufficient distance where the test object is not detectable and stop. Use traffic pylons or other lane markers to ensure the vehicle is moved on a straight path.

c. Record vehicle speed, transmission CAN messages, and BUW system CAN messages (if present).

d. Engage reverse gear with the vehicle stationary and verify the BUW system engages and that the test object is not detected.

e. Backup the vehicle in a straight path at a constant speed, while keeping the vehicle and grid centerlines aligned as closely as possible (a tolerance is not required), until the test object is detected. If not detected, stop the vehicle before striking the test object. Sequentially test at speeds ranging from 0.5 mph to the maximum speed attributed to the BUW system, with at least three test speeds.

f. If possible, from the recorded CAN messages, determine BUW engagement latency from when reverse gear is selected and detection latency from when the test object is detected to when the warning is issued to the driver.

g. If a distance indicator is provided with the BUW system, determine distance accuracy by comparing the distance readout to the actual distance from the rear of the vehicle to the obstacle at detection. This may be accomplished when the vehicle is stationary using a steel tape or dynamically using vehicle differential GPS, accounting for the offsets between the GPS antennae and the BUW sensors.

#### 4.2.1.4 Sensor Fault Self-Test.

a. Intentionally reduce the effectiveness of sensor signal generation and echo reception (e.g., by applying soil to sensor surfaces) so that the azimuth test object is not detectable at the midpoint of the pre-warning, main warning, or overall warning zones.

b. Observe the behavior of the BUW system after engagement to determine if a fault is indicated to the driver.

#### 4.2.2 Blind Spot Monitoring Systems.

a. BSM systems warn the driver of possible collisions from a lane change maneuver by detecting vehicles to the sides and rear of the subject vehicle. BSM systems supplement interior and exterior rear-view mirrors and do not eliminate the need for mirrors. Systems will not intervene to prevent a possible collision and the responsibility for safe operation of the vehicle remains with the driver. Lane marking recognition and/or lane detection is not required.

b. BSM system classification is based on the minimum coverage zone and function, as defined in ISO 17387. Type I (Blind Spot Warning) systems provide coverage of the blind zones shown in Figure 6 and only warn the SV driver if an adjacent vehicle is within or enters the blind zones. Type II (Closing Vehicle Warning) systems provide coverage rearward of datum line B, between datum lines G and F and datum lines K and L, and provide a warning when the estimated time to collision is less than or equal to that indicated by Equation 1, where  $V$  is the closing speed (or speed difference) between vehicles. Type III (Lane Change Warning) systems provide Type II and I capabilities.

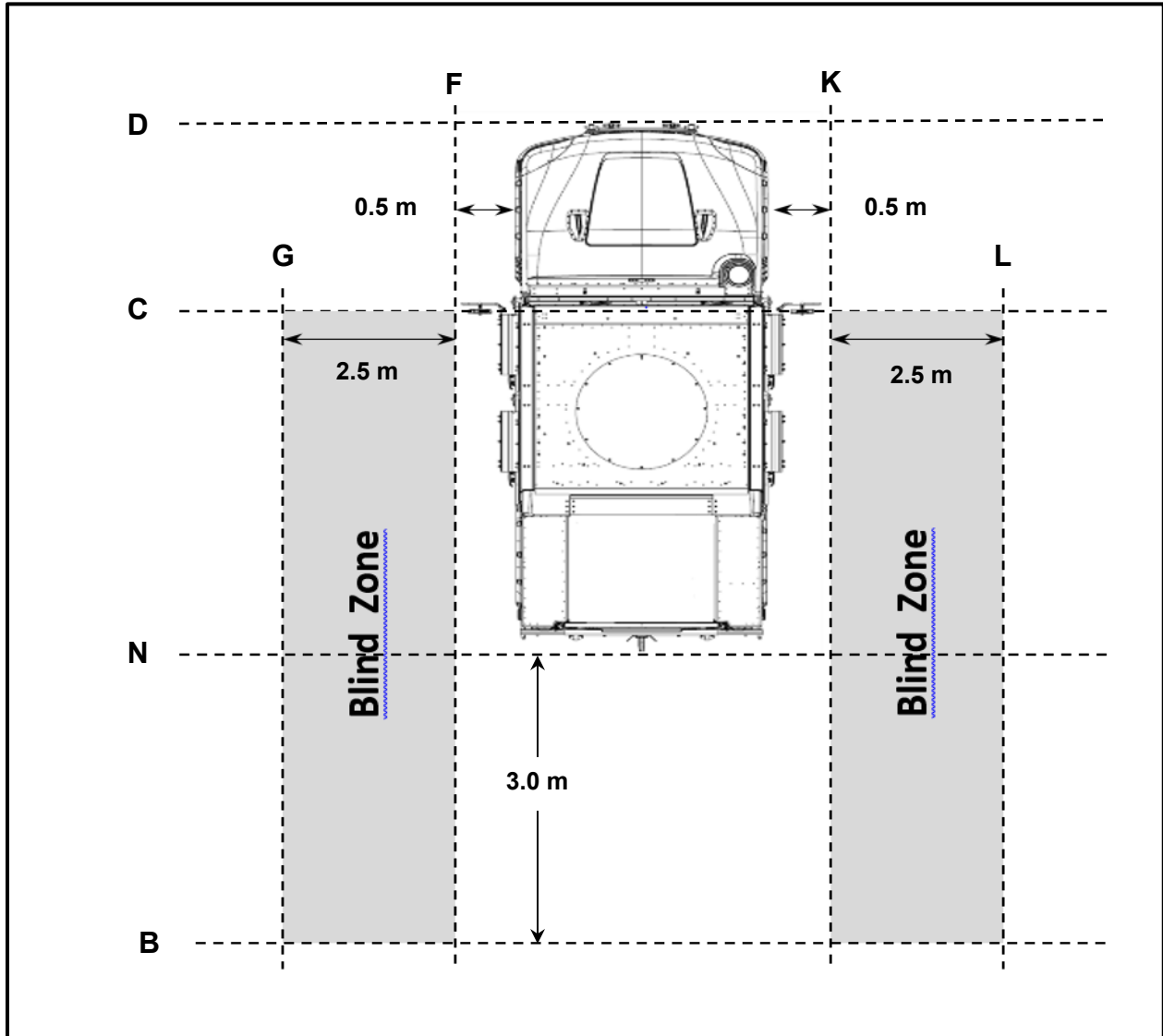


Figure 6. Subject vehicle blind zones and datum lines.

$$\text{Closing Time (sec)} = 0.0278 V(\text{km/h}) + 1.5 \quad (\text{Equation 1})$$

c. Figure 6 datum line designation letters are consistent with ISO 17387. For military vehicle use, datum line C aligns with the rearmost part of the SV side mirror housing, in the housing's fully extended operating position, and is perpendicular to the SV longitudinal centerline. Datum line D aligns with the forward most edge of the SV and is perpendicular to the SV centerline. Datum line N aligns with the rearmost edge of the SV and is perpendicular to the SV centerline. Datum lines F and K are parallel to the SV longitudinal centerline, 0.5 m outboard of the outermost edge of the SV body, excluding any side view mirror(s).

d. Type II and III systems are further classified as listed in Table 11, based on performance limitations for maximum target vehicle closing speed and minimum roadway radius of curvature. Some systems may meet or exceed multiple types.

TABLE 11. TYPE II AND TYPE III BSM SYSTEM SUB-CLASSIFICATION

TYPE	MAXIMUM TARGET VEHICLE CLOSING SPEED	MINIMUM ROADWAY RADIUS OF CURVATURE
	km/h (mph)	m (ft)
A	36 (22)	125 (410)
B	54 (34)	250 (820)
C	72 (45)	500 (1640)

e. Table 12 outlines BSM test procedures.

TABLE 12. BSM TEST PROCEDURES

CLAUSE NO.	DESCRIPTION
4.2.2.1	Identify BSM system type, activation criteria, states, sensors, warnings, displays and settings
4.2.2.2	Type I BSM (Blind spot warning) tests
4.2.2.3	Type II BSM (Closing vehicle warning) tests
4.2.2.4	Type II BSM (Lane Change warning) tests

f. General Instructions.

(1) Unless the system specification or DTP provide other guidance, assess BSM performance using the system requirements provided in ISO 17387 for Type 1 systems at a minimum, with Type II and III systems optional.

(2) Conduct tests on a dry, straight, and level paved road test course, with sufficient space free of obstacles other than the subject and target vehicles described in the following procedures. The ambient conditions should be free of precipitation, between 0 °C and 35 °C (32 °F and 95 °F). The horizontal visibility range shall be greater than 1 km. Visibility is the distance at which the illuminance of a non-diffusive beam of white light with a color temperature of 2,700 K is decreased to 5 percent of its original light source illuminance.

(3) Prior to testing, ensure the BSM sensors are clean and not covered by dust, soil, ice, or vehicle fluids.

(4) Conduct tests with a single target vehicle. The recommended target vehicle is a production compact or mid-sized passenger car.

(5) During testing, record the following vehicle CAN bus data channels (at a minimum when possible).

(a) BSM activation state or mode (*System Active; System Not Active; System Active, Non-Warning; System Active, Warning*).

(b) BSM target detected.

(c) BSM target detected warning lamps (including associated warning zone).

(d) BSM faults.

(e) Subject vehicle speed.

(f) Target vehicle closing speed.

(g) Time to collision.

(6) If the BSM warning is a visible display and the control signal for the display is not available on the CAN bus for recording, it is recommended to use a photocell within a light-blocking enclosure around the BSM display to observe display timing. If the warning is audible or haptic, microphones or accelerometers may be used to observe warning timing.

(7) Measure and record subject and target forward vehicle speeds and positions independently using RTK GPS. When using RTK GPS to determine vehicle position with zones, account for offsets between the antennae and the front, rear, and sides of the vehicles.

(8) Measure target vehicle longitudinal and lateral velocity using a 2-axis optical sensor.

(9) For tests involving two vehicles operating concurrently, the subject vehicle and target vehicle operators shall be in direct radio communication and ready to take evasive action if collision is imminent. Drivers shall pre-coordinate evasive actions to avoid contact.

#### 4.2.2.1 Identify BSM System Types, States, Sensors, Warnings, Displays and Settings.

Prior to testing, using system documentation, requirements documents, the DTP, system training, and inspection:

a. Identify the BSM system types, coverage zones, coverage zone limitations, and warning levels available (as defined in ISO 17387). *Warning level 1* is a cautionary warning, while *warning level 2* (generally optional) is an imminent warning. Describe Type II performance limitations and warning requirements (if the BSM includes Type II features).

- b. Identify the means necessary to activate the BSM system (e.g., continuous activation, manual switch activation, turn signal activation or SV speed activation).
- c. Identify the BSM evaluation criteria or parameters monitored by the BSM for warning generation (e.g., turn signal status, SV steering input status, SV lane position status, and lateral clearance status). Warning generation may require multiple conditions.
- d. Identify response time specifications from when the target satisfies warning requirements to when the warning indication is activated and from when a warning is no longer allowed to when the warning indication is deactivated. The specifications are used for comparison to measurements.
- e. Identify any conditions associated with blind spot warning suppression (generally optional features).
- f. Document the sensors used by the BSM system (e.g., ultrasonic, LiDAR, radar, and/or optical cameras). Indicate the location of the sensors on the vehicle.
- g. Document the displays and warnings available for driver interaction with the BSM system, including visible, audible, and/or haptic warnings. Include any diagnostics (self-tests) and reaction to failure requirements, indicators or warnings. Include photographs, as appropriate.
- h. Identify BSM operational characteristics when connecting trailers to the SV.

#### 4.2.2.2 Type I BSM (Blind spot warning) Tests.

Conduct the following four tests to assess performance of Type I BSM (Blind Spot Warning Systems) in accordance with ISO 17387 clauses 5.3.3.2 through 5.3.3.5, using a production compact or mid-sized passenger car as the target vehicle. Apply the SV response time and warning suppression specifications identified in 4.2.2.1 of this TOP.

- a. Target vehicle overtaking subject vehicle.
- b. Subject vehicle overtaking target vehicle.
- c. False warning.
- d. Target vehicle moving laterally.

#### 4.2.2.3 Type II BSM (Closing Vehicle Warning) Tests.

Conduct the following three tests to assess performance of Type II BSM (Closing Vehicle Warning Systems) in accordance with ISO 17387 clauses 5.4.3.2 through 5.4.3.4, using a production compact or mid-sized passenger car as the target vehicle. Apply the SV response

time and warning suppression specifications identified in paragraph 4.2.2.1 of this TOP. Tests on straight roads are required, and tests on curved roads are optional unless required by the DTP.

- a. Target vehicle overtaking subject vehicle.
- b. Subject vehicle overtaking target vehicle.
- c. False warning test.

#### 4.2.2.4 Type III BSM (Lane Change Warning) Tests.

Conduct the following four tests to assess performance of Type III BSM (Lane Change Warning Systems) in accordance with ISO 17387 clauses 5.5.3.2 through 5.5.3.5, using a production compact or mid-sized passenger car as the target vehicle. Apply the SV response time and warning suppression specifications identified in 4.2.2.1 of this TOP. Tests on straight roads are required, and tests on curved roads are optional unless required by the DTP.

- a. Target vehicle overtaking subject vehicle.
- b. Subject vehicle overtaking target vehicle.
- c. False warning test.
- d. Target vehicle moving laterally.

#### 4.2.3 Cross Traffic Alert Systems.

a. CTA systems warn the driver of possible collisions with traffic crossing in front of or behind the subject vehicle when driver visibility is obstructed, such as when exiting a parking space or when crossing a busy intersection. Systems provide either front CTA, rear CTA, or both. CTA capability may be incorporated with BSM capability, using the same sensors.

b. CTA systems detect vehicles approaching at speeds up to a system specified maximum speed from the right or left of the SV, with the SV at low speed (perhaps less than 5 mph) in forward or reverse gear. CTA zone coverage decreases when sensors are partially, mostly, or fully obstructed, as illustrated in Figure 7, potentially limiting available driver reaction time to avoid a collision. Systems will not intervene to prevent a possible collision and the responsibility for safe operation of the vehicle remains with the driver.

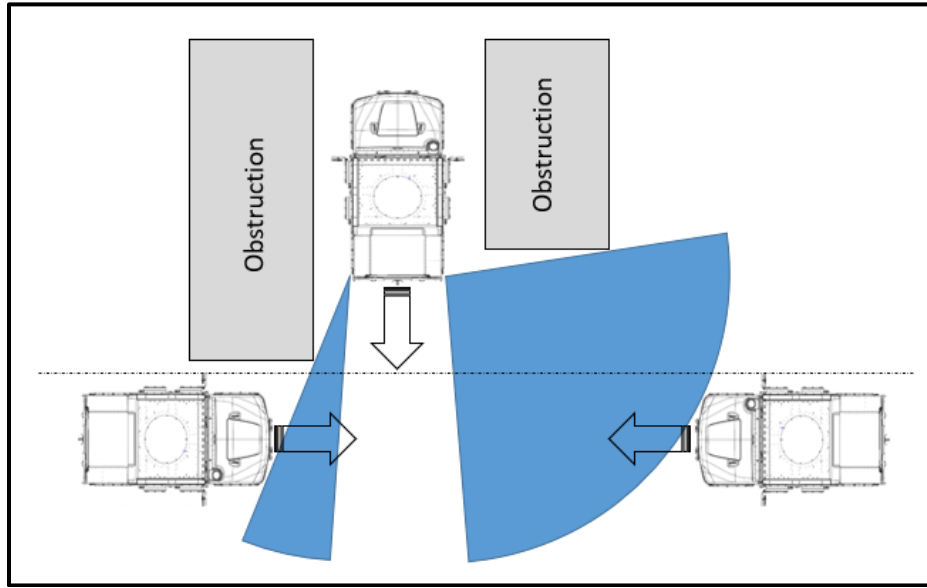


Figure 7. CTA coverage zone obstruction example.

c. Table 13 outlines CTA test procedures.

TABLE 13. CTA TEST PROCEDURES

CLAUSE NO.	DESCRIPTION
4.2.3.1	Identify CTA forward and reverse functionality, activation criteria, states, sensors, warnings, displays and settings
4.2.3.2	Coverage and warning tests

d. General Instructions.

(1) Unless the system specification or DTP provide other guidance, assess CTA system performance using the following basic requirements.

(a) For vehicles equipped with front CTA, with the SV moving slowly forward (less than 5 km/h (3 mph)), the system shall detect target vehicles (TVs) moving transversely to the path of the SV within the manufacturer specified coverage zones. Detection shall occur at TV speeds within manufacturer specifications when moving in both transverse path directions.

(b) For vehicles equipped with rear CTA, with the SV moving slowly in reverse (less than 5 km/h (3 mph)), the system shall detect TVs moving transversely to the path of the SV within manufacturer specified coverage zones. Detection shall occur at TV speeds within manufacturer specifications when moving in both transverse path directions.

(c) CTA systems (front or rear) shall issue a warning that differentiates between detection on the right or left side of the vehicle.

(d) The overall system response time from target detection to warning indication shall be no more than 300 msec.

(e) The overall system response time from when the TV leaves the detection zones to when warning indication is deactivated shall be no more than 1 sec.

(2) Conduct tests on a dry, straight, and level paved road test course, with sufficient space free of obstacles other than the SV, TV, and Jersey barriers, as shown in Figure 8. Traffic and reference lines may be painted or temporarily placed on the roadway. The ambient conditions should be free of precipitation, between 0° C and 35° C (32° F and 95° F). The horizontal visibility range shall be greater than 1 km. Visibility is the distance at which the illuminance of a non-diffusive beam of white light with a color temperature of 2,700 K is decreased to 5 percent of its original light source illuminance.

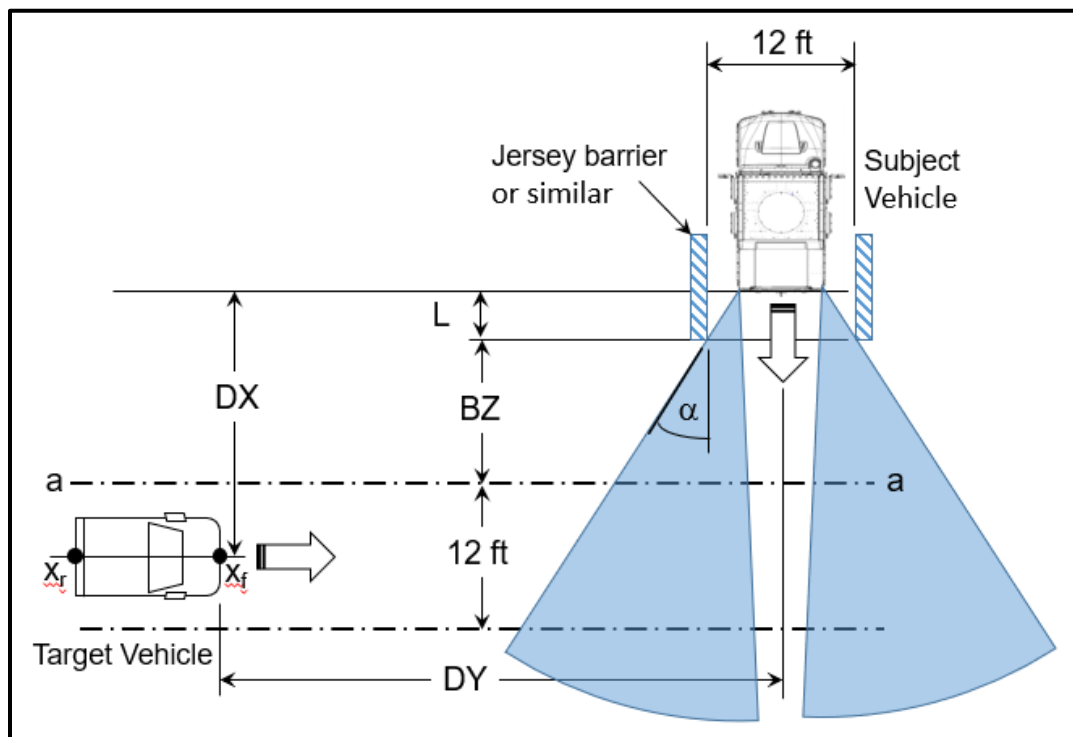


Figure 8. Test course layout.

(3) The TV shall be a surrogate three-dimensional (3D) test target, as described in ISO 19206-3, and often referred to as a guided soft target or soft car.

(4) Prior to testing, ensure the CTA sensors are clean and not covered by dust, soil, ice, or vehicle fluids.

(5) During testing, record the following vehicle CAN bus data channels (at a minimum when possible).

(a) CTA activation state or mode (*System Active; System Not Active; System Active, Non-Warning; System Active, Warning*).

(b) CTA target detected.

(c) CTA target detected warning lamps.

(d) CTA faults.

(e) Subject vehicle speed.

(f) Target vehicle speed.

(6) Measure and record subject and target vehicle positions and speeds independently using RTK GPS. When using RTK GPS to determine distances shown in Figure 8 (e.g., front and rear of the vehicle and CTA sensor positions), account for offsets between the antennae and the front, rear, and sides of the vehicles.

(7) If the CTA warning is a visible display and the control signal for the display is not available on the CAN bus for recording, it is recommended to use a photocell within a light-blocking enclosure around the CTA display to observe display timing. If the warning is audible or haptic, microphones or accelerometers may be used to observe warning timing.

#### 4.2.3.1 Identify CTA Forward and Reverse Functionality, Activation Criteria, States, Sensors, Warnings, Displays and Settings.

Prior to testing, using system documentation, requirements documents, the DTP, system training, and inspection:

a. Identify the CTA system type(s) (e.g., front, rear, or both), coverage zones, and coverage zone limitations, including trailering capability.

b. Identify the means necessary to activate the CTA system (e.g., continuous activation, manual switch activation, SV gear activation, and SV speed activation).

c. Identify subject and target vehicle minimum and maximum speeds for detection, detection ranges, and trailering requirements.

d. Identify response time specifications from when the TV satisfies warning requirements to when the warning indication is activated and from when a warning is no longer allowed to

when the warning indication is deactivated. The specifications are used for comparison to measurements.

e. Document the sensors used by the CTA system (e.g., ultrasonic, LiDAR, radar, and/or optical cameras). Indicate the location of the sensors on the vehicle and trailer if applicable.

f. Document the displays and warnings available for driver interaction with the CTA system, including visible, audible, and/or haptic warnings. Include any diagnostics (self-tests) and reaction to failure requirements, indicators, or warnings. Include photographs, as appropriate.

#### 4.2.3.2 Coverage and Warning Tests.

Conduct CTA coverage and warning tests for each CTA type (front or rear) in both crossing directions. Conduct additional tests with trailer capability, if provided.

a. Configure the test course as shown in Figure 8, with the SV oriented for front or rear CTA testing, as appropriate. The distance BZ provides a safety buffer zone between the subject and target vehicles when the vehicles are moving towards each other. The barriers shall be sufficiently tall to prevent line of sight between the SV CTA sensors and the TV prior to initiation of a test event.

b. Start testing with the subject and target vehicles stationary at distances DY equal to 19.5 m (64 ft), L equal to 0.9 m (3 ft), and BZ equal to 3.2 m (12 ft), with the SV in gear.

c. At time  $t_0$ , simultaneously operate the SV toward the buffer zone at approximately 3.2 km/h (2 mph) and accelerate the TV toward the SV at approximately 0.25g to a constant 16 km/h (10 mph) speed.

d. Stop the subject vehicle as soon as a CTA warning is provided to the driver or before reaching datum line aa. Complete the test trial when the warning is deactivated or when the target vehicle passes the SV by a detection range exceeding manufacturer specification. Document if a warning is provided along with warning details (e.g., type, right-side warning, and left-side warning).

e. If a CTA warning occurred, use RTK GPS data to estimate angle  $\alpha$ , if less than 90 degrees, and distances DX and DY when the CTA detected the TV and when the warning was provided to the driver. Also, estimate DY when the warning is deactivated and if the TV had passed the subject vehicle. Document subject and target vehicle speeds when the warning occurred along with pre-test distances BZ, L, and DY.

f. If necessary, adjust pretest distances L and DY to adequately identify CTA detection limits.

g. Repeat testing at various TV speeds within manufacturer detection specifications. It is recommended to test in 8 km/h (5 mph) increments between 8 and 56 km/h (5 and 35 mph). Adjust pretest distances L and DY as necessary to adequately identify CTA detection limits.

h. Repeat the steps above with BZ equal to 1.8 m (6 ft) and subject vehicle speed approximately 1.6 km/h (1 mph), if 1 mph is within CTA manufacturer specifications.

i. Report any anomalies with CTA system function, false alarms, or failures to detect the target vehicle.

#### 4.2.4 Lane Departure Warning Systems.

a. LDW systems use cameras or other sensor technologies to detect traffic lane lines and alert the driver when the vehicle approaches or crosses the lines, using audible, haptic, or visual warnings. The intent is to prevent unintentional lane departure. LDW warnings do not occur if the turn signal is used. Systems will not intervene to prevent a possible collision and the responsibility for safe vehicle operation remains with the driver. The systems rely on distinguishing visible lane markings relative to the pavement surface and may not work well with faded, missing, or irregular lane markings, as well as sand, snow, or water covered roads and during times when the sun is at low elevation relative to the horizon. The LDW threshold width may be adjustable (Figure 9) and may only activate above a predefined speed setting. Trailer LDW is not included in the scope of this TOP.

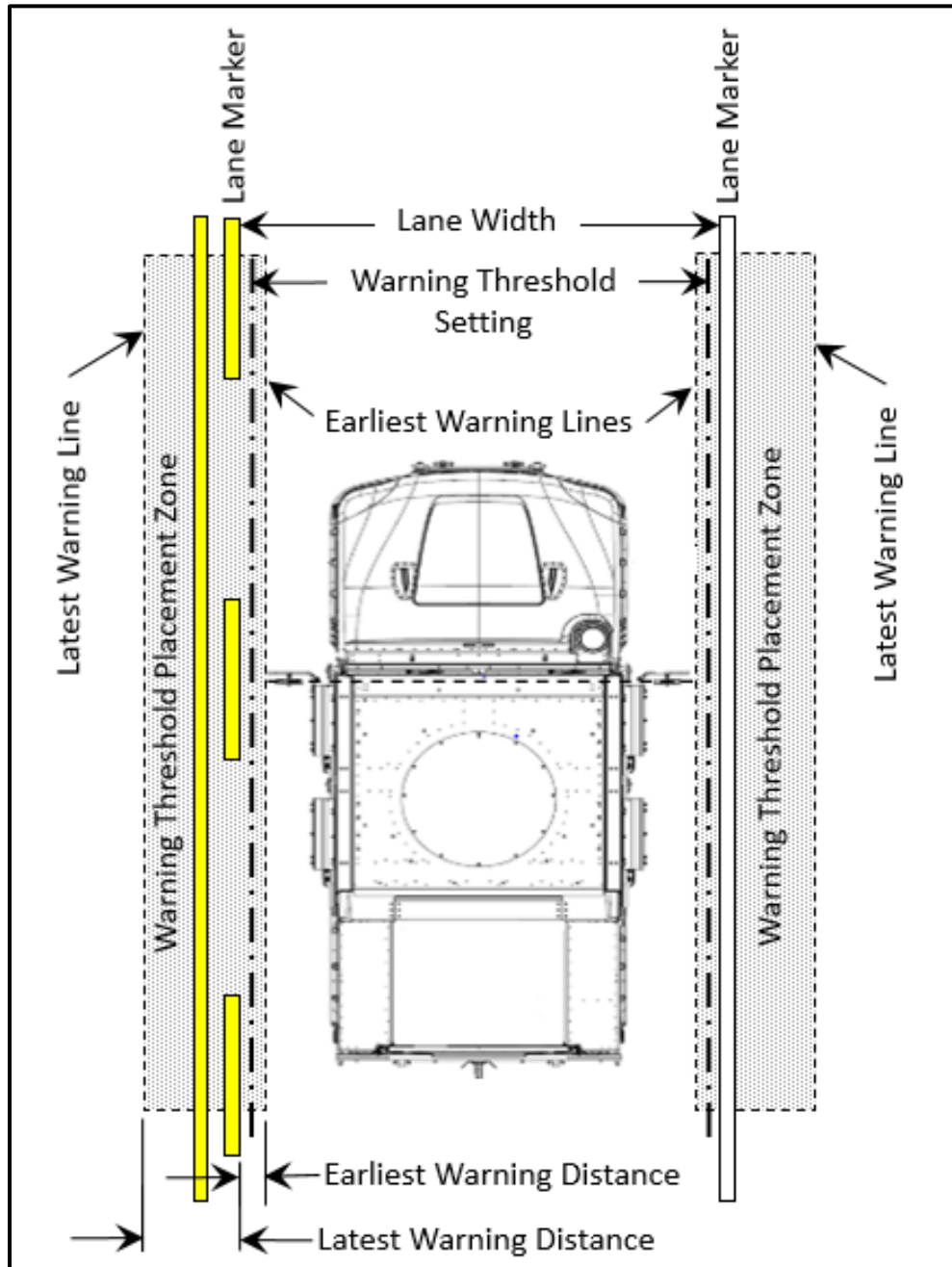


Figure 9. LDW warning threshold setting.

- b. Table 14 outlines LDW test procedures.

TABLE 14. LDW TEST PROCEDURES

CLAUSE NO.	DESCRIPTION
4.2.4.1	Identify LDW system activation states, suppression <sup>a</sup> conditions, system incapable <sup>b</sup> conditions, system inoperable <sup>c</sup> conditions, sensors, warnings, displays, vehicle speed requirements and settings
4.2.4.2	Detection and warning test
4.2.4.3	Suppression test
4.2.4.4	Inoperable/system incapable warning tests
4.2.4.5	Deactivation test

<sup>a</sup> Suppression is a system or driver feature intended to prevent a lane departure warning if an intended lane departure is detected or a warning is not desired for a specific condition.

<sup>b</sup> System incapable is a state of the system in which it is unable to warn the driver of a lane departure due to a temporary condition (e.g., no lanes are detected).

<sup>c</sup> System inoperable is a state of the system where the system is made inoperable by a component failure.

c. General Instructions.

(1) Unless the system specification or DTP provide other guidance, assess LDW performance using the following basic requirements.

(a) The LDW system shall detect position of the subject vehicle relative to the lane boundaries, determine if warning conditions are fulfilled, and warn the driver when the warning condition is fulfilled. An easily perceivable haptic and or audible warning shall be provided. Warnings shall be presented to the driver with a minimum 85 percent pass rate for the entirety of the test conditions stated in paragraph 4.2.4.2 and a minimum 80 percent pass rate for individual lane marker type tests stated in paragraph 4.2.4.2.

(b) Warning threshold setting placement shall be within the zones created by the earliest warning lines and the latest warning lines. The earliest warning line distance from the lane marker is based on lane departure rate, where  $\text{Distance (m)} = 0.5 \times \text{Rate (m/s)}$ . The latest warning line distance is 0.3 m.

(c) The LDW system shall monitor system status for system inoperable (failure), system incapable, and system on/off conditions and indicate system status to the driver.

(d) When the vehicle is equipped with LDW along with other warning systems such as FVCWS, the LWD warning shall be clearly distinguishable to the driver by haptic, audible, or visible modality, or any combination thereof.

(e) An operator's manual shall describe the minimum vehicle speed at which the system operates and the conditions for system incapable.

- (f) LDW system optional features are listed in ISO 17361 Clause 4.4.

**Note:** The basic requirements listed above are based on SAE J3045 and ISO 17361 requirements and were summarized here for clarity when applied to commercial trucks and military vehicles. For passenger vehicle and light trucks (pickups), refer directly to ISO 17361 requirements.

(2) Conduct tests on a dry, straight, and level paved road test course, with sufficient space free of incidental visible road features indicative of the position of the test lane (i.e., pavement seams, curbs, and tracks or ruts left by previous vehicles). The road course consists of two lanes, with the primary test lane 3.66 m (12 ft) wide between the lane markings and runout lane sufficiently wide for safe vehicle runout.

(3) Road striping for tests shall include solid and dashed white lines for the right side of the subject vehicle and solid and dashed white and yellow lines for the left side of the subject vehicle. Striping width is 10.2 cm (4 in.) minimum and 15.2 cm (6 in.) maximum. Striping shall conform to the U.S. Department of Transportation (DOT) Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices (MUTCD)<sup>29</sup>. Additional guidance for lane markings is provided in paragraph 4.2.4.2.

(4) The ambient conditions should be free of precipitation, between 0 °C and 35 °C (32 °F and 95 °F). The horizontal visibility range shall be greater than 1 km. Visibility is the distance at which the illuminance of a non-diffusive beam of white light with a color temperature of 2,700 K is decreased to 5 percent of its original light source illuminance.

(5) Prior to testing, ensure the LDW sensors are clean and not covered by dust, soil, ice, or vehicle fluids.

(6) During testing, record the following vehicle CAN bus data channels (at a minimum when possible).

- (a) LDW activation state or mode.
- (b) LDW incapable state.
- (c) LDW inoperable state.
- (d) LDW suppression state.
- (e) LDW warning state.
- (f) LDW faults.
- (g) LDW warning threshold setting.
- (h) Subject vehicle speed.

(7) Measure and record subject vehicle speed and position using RTK GPS. When using RTK GPS to determine vehicle position relative to lane boundaries, account for offsets between the antennae and the front, rear, and sides of the vehicles. Vehicle-mounted, time-stamped video camera data may also be used to determine vehicle position relative to lane boundaries.

(8) Measure subject vehicle longitudinal and lateral velocity using a 2-axis optical sensor and vehicle yaw rate.

#### 4.2.4.1 Identify LDW System Activation States, Suppression Conditions, System Incapable Conditions, System Inoperable Conditions, Sensors, Warnings, Displays, Vehicle Speed Requirements and Settings.

Prior to testing, using system documentation, requirements documents, the DTP, system training, and inspection:

- a. Identify the LDW activation states, incapable conditions (e.g., lack of lane markers) and responses, inoperable conditions (e.g., component failures) and responses, response to lack of one lane marker, and suppression conditions (e.g., turn signal usage and braking).
- b. Identify the means necessary to activate the LDW system (e.g., continuous activation, manual switch activation, and SV speed activation). Include whether the LDW system requires driver-state feedback for activation (e.g., hands on the steering wheel) and document corresponding system responses and warnings.
- c. Identify threshold-warning settings, if settings are driver adjustable, and the means to adjust the settings (if available).
- d. Document the sensors used by the LDW system (e.g., optical cameras, steering torque, or haptic sensors on steering wheel). Indicate the location of the sensors on the vehicle.
- e. Document the displays and warnings available for driver interaction with the LDW system, including haptic, audible, and/or visible warnings. Include any diagnostics (self-tests), system status and reaction to failure indicators or warnings. Include photographs, as appropriate.

#### 4.2.4.2 Detection and Warning Test.

Conduct detection and warning test events with the primary test lane marked as listed in Table 15. Test sections should be sufficiently long to encompass the lane departure events with consistent markings.

TABLE 15. TEST COURSE LANE MARKINGS

LANE DEPARTURE DIRECTION	TEST SCENARIO	RIGHT SIDE MARKING		LEFT SIDE MARKING	
		Line Type	Color	Line Type	Color
Left	1	Solid or dashed	White	Solid	Yellow
	2	Solid or dashed	White	Dashed	Yellow
	3	Solid or dashed	White	Solid	White
	4	Solid or dashed	White	Dashed	White
Right	5	Solid	White	Solid or dashed	Yellow or white
	6	Dashed	White	Solid or dashed	Yellow or white

a. Construct the test course as shown in Figure 10, applying one of the lane marking test scenarios from Table 15.

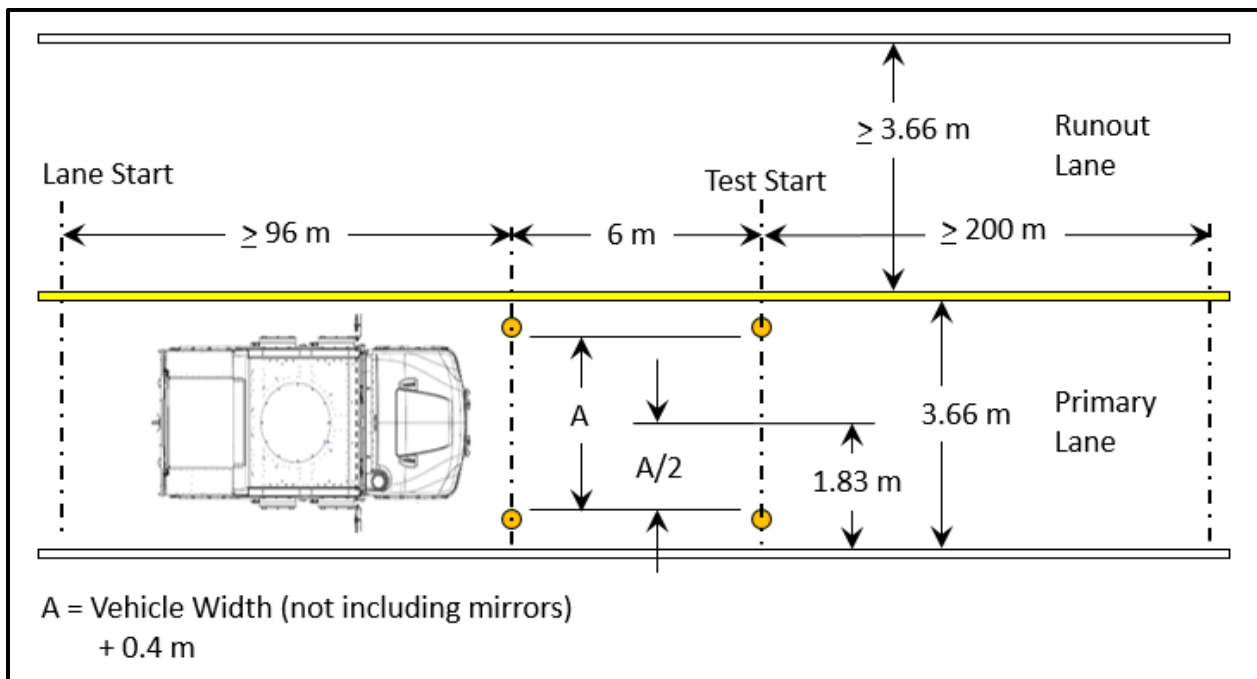


Figure 10. LDW detection and warning test course.

b. Operate the subject vehicle with LDW engaged in the primary test lane, achieving a steady state vehicle speed of 72 km/h (45 mph)  $\pm$  4 km/h (2.5 mph) before reaching the lane start line. Hazard lights are off during the test event. Maintain the speed throughout the test event.

c. Without applying the turn signal or applying the brakes, pass the subject vehicle through the two sets of traffic pylons and initiate a left lane departure at a nominal 0.1 m/s lateral

velocity when the vehicle reaches the second pair of pylons, not exceeding 1.0 deg/s yaw rate. Slow the vehicle once a warning is issued to the driver or the vehicle reaches the center of the runout lane. Repeat the scenario a minimum of four more times (five total). For each event, observe and record the presence of warning indications.

- d. Repeat step in paragraph 4.2.4.2.c using a nominal 0.6 m/s lateral velocity.
- e. Repeat steps in paragraphs 4.2.4.2.b and 4.2.4.2.c for the remaining lane marking scenarios listed in Table 15.
- f. If possible, for each of the test events, use subject vehicle RTK GPS coordinate data, lane boundary dimensions, vehicle dimensions, time-stamped video, and any relevant CAN bus data available to identify the vehicle position relative to the lane boundaries when the LDW system indicated a lane departure and when the driver was warned.

#### 4.2.4.3 Suppression Test.

For each lane departure direction, repeat one of the scenarios from 4.2.4.2 with the turn signal engaged for the appropriate lane departure direction. Repeat the procedure for any other conditions known to cause warning suppression (e.g., brakes applied or hazard lights on). Observe and record LDW system behavior.

#### 4.2.4.4 Inoperable/System Incapable Warning Tests.

- a. Response to a Component Failure (System Inoperable).
  - (1) Cause a component failure, such as rendering a sensor temporarily inoperable causing a loss of camera signal, disconnecting a communication line, or any other failure appropriate for the LDW system technology used.
  - (2) With the LDW system engaged, record any warning signals, fault indications, or system status presented to the driver. Engagement may require operating the vehicle above the defined minimum speed.
  - (3) Undo the component failure. Observe if the warning signal or fault indication clears. An ignition cycle may be required to clear the fault warning or signal.
- b. Response to an External Loss of Input (System Incapable).
  - (1) Operate the subject vehicle with the LDW system engaged in an environment where the external indication of lane position is not present (e.g., no lane markers present or GPS signal shadowed).
  - (2) Drive the subject vehicle straight at 72 km/h (45 mph) with the LDW system engaged.

(3) Conduct a lane departure event between 0.1 m/s and 0.6 m/s lateral velocity. Observe system behavior and driver warnings or system status indications.

4.2.4.5 Deactivation Test.

a. For subject vehicles equipped with means to deactivate the LDW system, turn the LDW system off with the engine running. Observe and record system status signals.

b. Turn the ignition switch off and wait between 10 and 60 seconds. Restart the vehicle. Observe and record system status signals.

4.2.5 Forward Vehicle Collision Warning Systems (including Following Distance Warning).

a. FVCWSs warn the driver of a potential rear-end collision with a vehicle ahead, giving the driver time to apply the brakes and/or make a lane change to avoid or reduce the severity of a collision. A similar function, known as Following Distance Warning (FDW, or Distance Alert), warns the driver if the following time interval to the vehicle ahead becomes too short, also helping to avoid potential collisions. FVCWS and FDW will not intervene to mitigate a possible collision and the responsibility for safe vehicle operation remains with the driver.

b. Forward Vehicle Collision Warning (FVCW) and FDW systems may use LiDAR, radar sensors, and forward-looking cameras for forward object and vehicle detection. The number and type of sensors used varies across manufacturers. Detection depends on the target range, reflectivity, size, and position relative to the subject vehicle.

c. In commercial practice, a single system may incorporate FVCW, FDW and Forward Vehicle Collision Mitigation (FVCM, also known as Automatic Emergency Braking). However, for simplicity, this TOP addresses the functions separately. This section addresses FVCW and FDW, while paragraph 4.2.6 addresses FVCM. FVCWS terminology, definitions, and symbols are generally consistent with ISO 15623. Tradenames and terms may vary.

d. Table 16 outlines FVCWS and FDW test procedures.

TABLE 16. FVCWS AND FDW TEST PROCEDURES

CLAUSE NO.	DESCRIPTION
4.2.5.1	Identify FVCWS and FDW system classification, capabilities, features and limitations
4.2.5.2	FDW performance test
4.2.5.3	FVCWS detection range and collision warning (on Straight Roads) tests
4.2.5.4	FVCWS target discrimination tests
4.2.5.5	FVCWS Inoperable warning test
4.2.5.6	Deactivation test

e. General Instructions.

(1) Prior to FVCWS testing, conduct subject vehicle full-effort brake effectiveness tests at initial speeds ranging from 20 to 60 mph, in 10 mph increments, to characterize the average deceleration performance at each test speed. Conduct the tests at the FVCWS test weight condition(s) specified in the DTP, performing three test events at each initial test speed. For air brake and air-over-hydraulic brake systems, full-effort means a brake application in which the treadle valve pressure in any of the valve's output circuits reaches 586 kilopascal (kPa) (85 pounds per square inch (psi)) within 0.2 seconds after the application is initiated, without wheel lock-up. For hydraulic brake systems, full-effort means a brake application in which the force on the brake pedal reaches 622 Newtons (N) (150 pounds (lb)) within 0.3 seconds after the application is initiated, without wheel lock-up. Conduct brake tests with the ABS active (if available). It is recommended that test event initial foundation brake temperatures are in the range 66-93 °C (150-200 °F). Initial brake temperatures shall not exceed 149 °C (300 °F).

(2) Unless the system specification or DTP provide other guidance, assess FVCWS performance using the system requirements provided in ISO 15623 Clause 5. Assess FDW performance based on manufacturer design intent or DTP guidance, since current industry standards have not addressed FDW performance at the time this TOP was published.

(3) If the subject vehicle is equipped with ACC or conventional cruise control, test with the ACC or conventional cruise control system in standby or off (if possible).

(4) Conduct tests on a closed, level paved road test course, with straight sections available as needed and with sufficient space free of obstacles. Any curved sections used for testing shall have sufficiently large radii and banking to keep vehicle lateral acceleration levels below 0.2g.

(5) The ambient conditions should be free of precipitation, between 0 °C and 35 °C (32 °F and 95 °F). The horizontal visibility range shall be greater than 1 km. Visibility is the distance at which the illuminance of a non-diffusive beam of white light with a color temperature of 2,700 K is decreased to 5 percent of its original light source illuminance.

(6) Prior to testing, ensure forward-looking sensors are clean and not covered by dust, soil, ice, or vehicle fluids.

(7) Unless other guidance is provided in the DTP, conduct tests with two target vehicles. The recommended target vehicles are a production compact (or mid-sized) passenger car and a light truck (pick-up) or larger vehicle. A surrogate 3D test target, as described in ISO 19206-3 and often referred to as a guided soft target or soft car, may be used in lieu of the passenger car target.

(8) During testing, record the following vehicle CAN bus data channels (at a minimum when possible).

- (a) FVCWS and/or FDW activation state or mode (*Off, Standby, Active*).
  - (b) FVCWS and/or FDW settings (e.g., driver's brake reaction time adjustment, if available, or following distance warning setting).
  - (c) FVCWS and/or FDW target detected.
  - (d) FVCWS and/or FDW target detected lamp (or other warning type).
  - (e) FVCWS and/or FDW distance to forward vehicle.
  - (f) FVCWS forward vehicle speed.
  - (g) FVCWS forward vehicle deceleration.
  - (h) FVCWS road curvature.
  - (i) FVCWS suppression state.
  - (j) FVCWS and/or FDW warning state.
  - (k) FVCWS and/or FDW faults.
  - (l) Vehicle speed.
  - (m) Transmission gear selection.
  - (n) Brake apply.
  - (o) ABS status (and/or individual wheel speed).
  - (p) Brake lamp.
- (9) Measure and record subject and target vehicle speeds and positions using RTK GPS. When using RTK GPS to determine vehicle position relative to forward vehicles, account for offsets between the antennae and the front, rear, and sides of the vehicles.
- (10) Measure and record the presence of visible, audible, and haptic warnings using time synchronized cameras, microphones, and accelerometers, when possible.
- (11) Document nuisance warnings that occur (i.e., warnings that should not occur).
- (12) For tests involving two or more vehicles operating concurrently, the subject vehicle and forward vehicle operators shall be in direct radio communication and ready to take evasive action if collision is imminent. Drivers shall pre-coordinate evasive actions to avoid contact.

4.2.5.1 Identify FVCWS and FDW System Classification, Capabilities, Features and Limitations.

Prior to testing, using system documentation, requirements documents, the DTP, pre-test system training, and inspection:

- a. List and describe FVCWS and FDW operating states and document if FVCWS and FDW can be isolated from other ADAS features (e.g., ACC or FVCMS), as well as from each other.
- b. Identify the FVCWS warning triggering method(s) (e.g., time to collision or minimum distance) and threshold values. Collision warnings are a function of the relative velocity between the subject vehicle and target vehicle or object ( $V_{rel}$ ), subject vehicle velocity ( $V_{SV}$ ), clearance distance ( $x_c$ ), vehicle brake reaction time ( $T_b$ ), driver's reaction time ( $T_{resp}$ ), the subject vehicle acceleration ( $A_{SV}$ ), and the target vehicle acceleration ( $A_{TV}$ ). Include relationships between warning settings and vehicle speed.
- c. At a minimum, list the following FVCWS settings shown in Table 17 (see ISO 15623 for additional guidance).

TABLE 17. FVCWS SETTINGS

PARAMETER	DEFINITION
$V_{min}$	Minimum operating velocity
$V_{max}$	Maximum operating velocity
$V_{rel, min}$	Minimum relative vehicle speed allowed
$V_{rel, max}$	Maximum relative vehicle speed allowed
$T_{max}$	Maximum driver's brake reaction time after the warning
$T_{min}$	Minimum driver's brake reaction time after the warning
$T_b$	Brake system response time
$D_0$	Minimum detectable distance without distance measuring capability
$D_1$	Minimum detectable distance with distance measuring capability
$D_2$	Minimum detection distance for a cut-in vehicle
$D_{max}$	Maximum detectable distance

- d. For FDW systems, list the minimum and maximum operating velocities and document the system warning time gap settings. Identify any driver adjustable settings.
- e. Identify the FVCWS classification in terms of roadway curvature, as shown in Table 18.

TABLE 18. FVCWS CLASSIFICATION

CLASS	HORIZONTAL CURVE RADIUS CAPABILITY
I	Curve radius greater than or equal 500 m
II	Curve radius greater than or equal 250 m
III	Curve radius greater than or equal 125 m

f. Document the driver controls, displays, and warnings available for driver interface and interaction with the FVCW and FDW systems, including the following.

- (1) Means for manually switching the systems on and off, if possible.
- (2) Means to adjust the FVCWS driver warning time (between  $T_{min}$  and  $T_{max}$ , if possible).
- (3) Lists and descriptions of displays and visible, audible, and haptic warnings, including operational status and any diagnostics and reaction to failure indicators or warnings.
- (4) Means to make FVCWS and FDW warnings distinguishable from warnings provided by other ADAS features (e.g., ACC and BSM).

g. Document FVCWS functionality, including the following (if possible).

- (1) Sensor type(s) used.
- (2) Whether stationary object warnings are provided.
- (3) Methodology for target selection (when multiple targets are in range).
- (4) Whether preliminary collision warnings are provided, along with conditions.
- (5) Collision warning conditions.
- (6) Whether warning braking is included, where the FVCWS automatically applies the vehicle brakes for a short time period to provide a warning to the driver, along with conditions required and braking levels.
- (7) Warning suppression conditions (see Note below).

**Note:** Suppression is a system or driver feature intended to prevent a collision warning if a warning is not desired for a specific condition.

#### 4.2.5.2 FDW Performance Test.

a. Select three subject vehicle test speeds based on vehicle performance limitations and the FDW system settings, attempting to cover as broad a speed range as possible where the FDW

provides warning. For most military vehicles, it is recommended to test at 48, 72, and 97 km/h (30, 45, and 60 mph).

b. If any FDW settings are driver selectable (e.g., following distance warning setting), adjust the setting to a nominal value following Operator Manual instructions and record the setting for test condition reporting.

c. Operate the subject vehicle and passenger car (or 3D surrogate) target vehicle (see paragraph 4.2.5.e (General Instructions)) on a two-lane test course (straight or curved section with nominal radius equal to or greater than 500 m), with the FDW (or FVCWS, if necessary) activated. With the target vehicle leading the subject vehicle, align both vehicles laterally within 1.0 m.

d. Start the test event with the subject vehicle operating at one of the selected test speeds, the target vehicle operating at the test speed minus 8 km/h (5 mph), and the two vehicles separated by a gap greater than the distance indicated in Equation 2. The FDW time gap setting is based on system specifications, which may vary with vehicle speed.

$$\text{Distance (m)} = \text{Test Velocity (m/s)} \times \text{FDW Time Gap Setting (s)} + 30 \text{ m} \quad (\text{Equation 2})$$

For example, a minimum distance of 125 m (408 ft) is required at 27 m/s (60 mph) with a gap setting of 3.5 s.

e. Record subject and target vehicle position and speed data, relevant CAN bus signals associated with FDW operation, and data from external sensors (cameras, microphones, accelerometers) used to monitor the timing of warnings provided to the driver, while the gap between the vehicles decreases.

f. The test event is complete when the FDW system provides a warning to the driver or the vehicle gap becomes less than two subject vehicle lengths, in which case the subject vehicle driver changes lanes and/or applies brakes as necessary to avoid a collision.

g. Repeat steps in paragraphs 4.2.5.2.c through 4.2.5.2.f to complete five repetitions.

h. Repeat steps in paragraphs 4.2.5.2.c through 4.2.5.2.g for the remaining test speeds.

(1) If the FDW system can be deactivated, repeat one of the test speed scenarios with the FDW deactivated. Verify that no warnings are given.

(2) For each of the test events, compare CAN bus *distance to forward vehicle* results to RTK GPS distance results to verify range accuracy.

(3) Determine the clearance gap and subject vehicle speed at the warning times using RTK GPS data. Calculate the time gap between the vehicles at the warning times. Indicate

the warning type(s) (visual, audible, or haptic). Compare warning distance versus subject vehicle speed results to FDW system specifications, accounting for any driver settings.

#### 4.2.5.3 FVCWS Detection Range and Collision Warning (on Straight Roads) Tests.

FVCWS detection range performance may be tested statically following the general procedures listed in paragraph 4.1.3.1 Procedure A, as applied to the distances  $D_0$ ,  $D_1$ ,  $D_2$ , and  $D_{\max}$  (defined in Table 17). For static tests, use only one standard target vehicle (see paragraph 4.2.5 (General Instructions)), with the FVCWS in the Standby or Active state, as necessary. The dynamic test procedure listed below is preferred for detection range tests and provides the ability to simultaneously assess collision warning performance.

- a. Select three subject vehicle test speeds and three subject-to-target relative speeds ( $V_{\text{rel}}$ ), based on vehicle performance limitations and the FVCWS settings, covering as broad a speed range as possible where the FVCWS provides warning. For most military vehicles, it is recommended to test at subject vehicle speeds of 48, 72, and 97 km/h (30, 45, and 60 mph), with relative speeds at 8, 24, and 40 km/h (5, 15, and 25 mph). Test safety is a primary concern when selecting subject and target vehicle speeds. If necessary, subject and target vehicle drivers may practice at various test speeds in adjacent test lanes, to gauge closing speeds and clearance distances necessary for safe test event completion. Use of a passenger car 3D surrogate target vehicle in lieu of the passenger car target enhances test safety.
- b. If any FVCWS settings are driver selectable (e.g., driver's reaction time ( $T_{\text{resp}}$ )), adjust the setting to a nominal value following Operator Manual instructions and record the setting for test condition reporting.
- c. Operate the subject vehicle and passenger car (or 3D surrogate) target vehicle on a two-lane test course (straight or curved section with nominal radius equal to or greater than 500 m), with the FVCWS activated. With the target vehicle leading the subject vehicle, align both vehicles laterally within 1.0 m.
- d. Start the test event with the subject vehicle and target vehicle operating at one of the selected test speeds and the two vehicles separated by a gap greater than  $D_{\max}$ , as identified by the system manufacturer. Slow the target vehicle to the selected test speed minus the lowest relative speed (preferably minus 8 km/h (5 mph)).
- e. Record subject and target vehicle position and speed data, relevant CAN bus signals associated with FVCWS operation, and data from external sensors (cameras, microphones, accelerometers) used to monitor driver warning timing, while the gap between the vehicles decreases.
- f. The test event is complete when the FVCWS provides a collision warning to the driver or the vehicle gap becomes less than two subject vehicle lengths, in which case the subject vehicle driver changes lanes and/or applies brakes as necessary to avoid a collision.
- g. Repeat steps in paragraph 4.2.5.3.c through 4.2.5.3.f to complete five repetitions.

h. Repeat steps in paragraph 4.2.5.3.c through 4.2.5.3.g for the remaining test speeds and relative speeds.

i. Repeat steps in paragraph 4.2.5.3.c through 4.2.5.3.g at the highest test speed selected with the target vehicle decelerating at 0.3g, rather than simply decreasing target vehicle speed to a lower constant speed. It is recommended that the initial clearance distance between the subject and target vehicle at the test event start is adjusted (possible less than  $D_{max}$ ) to ensure the target vehicle does not stop during the test event.

j. If the FVCWS includes capability to detect stationary objects in the same lane, repeat the steps above with a stationary target vehicle at the three subject vehicle test speeds.

k. For each of the test events, compare CAN bus *distance to forward vehicle* results to RTK GPS distance results to verify range accuracy (if the CAN data are available).

l. Determine the clearance gap and subject vehicle speed at the collision warning times using RTK GPS data. Calculate the time gap between the vehicles at the warning times. Indicate the warning type(s) (visual, audible, or haptic). Compare driver display and alert results (e.g., target detected) to CAN bus data to assess consistency. Compare warning distance versus subject vehicle speed results to FVCWS specifications, accounting for any driver settings.

m. Estimate if the warning time clearance distances were sufficient to avoid a collision between the subject and target vehicles using Equation 3, which assumes the target vehicle travels at a constant velocity.

$$X_{c\_min\_Warning} = \frac{V_r^2}{2 \times (A_{SV} - A_{TV})} + (T_{resp} + T_b) \times V_{rel} \quad (\text{Equation 3})$$

where:

$X_{c\_min\_Warning}$  is the minimum warning clearance distance between the subject and target vehicle necessary to avoid a collision.

$A_{SV}$  is the average braking deceleration capability of the subject vehicle at the vehicle speed when the collision warning is provided. The applied value is based on brake test results required in 4.2.5 General Instruction Step a. If brake performance data are not available, use a default value of 6.67 m/s<sup>2</sup>.

$A_{TV}$  is the target vehicle deceleration during the test event.

$T_{resp}$  is the driver response time setting value or a default value of 0.8 s.

$T_b$  is the braking system response time setting or the default value of zero.

#### 4.2.5.4 FVCWS Target Discrimination Tests.

Target discrimination tests assess the FVCWS ability to differentiate between multiple targets and react accordingly to the proper target. Conduct the target discrimination tests using the two target vehicles identified in paragraph 4.2.5.e(7). Use of the surrogate 3D test target in lieu of the passenger vehicle enhances test safety.

##### a. Two Forward Vehicles- Lateral Discrimination.

(1) If any FVCWS settings are driver selectable (e.g., driver's reaction time ( $T_{resp}$ )), adjust the setting to a nominal value following Operator Manual instructions and record the setting for test condition reporting.

(2) Operate the subject vehicle, passenger car (or 3D surrogate) target vehicle, and larger target vehicle on a straight two-lane test course, with the FVCWS activated, as shown in Figure 2. The passenger vehicle (or 3D surrogate) is the target vehicle in front of the subject vehicle and the other larger vehicle in the adjacent lane is referred to as the forward vehicle. Operate all three vehicles at a nominal constant speed within the normal speed range of the subject vehicle. It is recommended to use 72 km/h (45 mph). Adjust the following distance of the subject vehicle to approximately 30 m (100 ft). Start the test event.

(3) A few seconds after the test event is started, decelerate the forward vehicle to a speed significantly lower than the speed of the subject and target vehicle. A few seconds after the subject vehicle passes the forward vehicle (and the subject vehicle is safely clear of the vehicle in the adjacent lane), decelerate the target vehicle to a speed low enough to produce a subject vehicle preliminary collision warning or collision warning.

(4) Record subject, target vehicle, and forward vehicle position and speed data, relevant CAN bus signals associated with FVCWS operation, and data from external sensors (cameras, microphones, accelerometers) used to monitor driver warning timing.

(5) The test event is complete when the FVCWS provides a collision warning due to the target vehicle in front of the subject vehicle or the vehicle gap becomes less than two subject vehicle lengths, in which case the subject vehicle driver changes lanes and/or applies brakes as necessary to avoid a collision.

(6) Repeat the steps in paragraphs 4.2.5.4.a(2) through 4.2.5.4.a(5) (Two-Forward Vehicle- Lateral Discrimination) to complete five repetitions.

(7) Repeat the steps in paragraphs 4.2.5.4.a(2) through 4.2.5.4.a(6) (Two-Forward Vehicle- Lateral Discrimination) with the vehicle lanes reversed.

(8) Repeat the above steps on a roadway with a nominal 500-m (1640-ft) constant radius curve, and in both turn directions, with the forward vehicle in the outer radius lane only. If a 500-m radius curve is not available, select a test curve with a radius as close to 500-m as

possible and ensure the test speeds are appropriate for the turn radius. Use of a 500-m radius curve applies to Class I, Class II, and Class III FVCWS.

(9) For each test event, indicate if the forward (adjacent lane) or target vehicle produced a collision warning. The result of the test event is a failure if the forward vehicle in the adjacent lane caused the collision warning. The collision warning from the target vehicle in front of the subject vehicle verifies the system was functioning properly.

b. Two Forward Vehicles-Longitudinal Discrimination.

(1) The intent of this test is to verify that when subject vehicle forward-looking sensors see two forward vehicles concurrently in the same lane (a smaller, nearer vehicle and a larger, more distant vehicle), the FVCWS can differentiate when the smaller of the two vehicles decelerates and creates a possible collision condition.

(2) Conduct longitudinal discrimination tests only if the size difference between targets 1 and 2 is such that both vehicles are visible from the subject vehicle sensors when executing the test described below. Verify sensor visibility statically at the suggested following distances. No obstacles should be present on the road shoulders.

(a) If any FVCWS settings are driver selectable (e.g., driver's reaction time ( $T_{resp}$ )), adjust the setting to a nominal value following Operator Manual instructions and record the setting for test condition reporting.

(b) Operate the subject vehicle, passenger car (or 3D surrogate) target vehicle, and larger forward vehicle on a straight two-lane test course, with the FVCWS activated, as shown in Figure 3. The second lane is not used unless an evasive maneuver is required to avoid a collision.

(c) Operate all three vehicles at a nominal constant speed within the normal speed range of the subject vehicle. It is recommended to use 72 km/h (45 mph). Adjust the following distance between the subject vehicle and target vehicle 1 to approximately 30 m (100 ft). Adjust the following distance between the two target vehicles as close as possible while maintaining a safe distance (preferably 1-2 vehicle lengths). Start the test event.

(d) A few seconds after the test event is started, accelerate the subject vehicle until the FVCWS produces a collision warning. Afterwards, decelerate the subject vehicle, returning to the original 30 m (100 ft) following distance. After a few seconds, decelerate target vehicle 1 (only) to a speed low enough for the subject vehicle to produce a collision warning.

(e) Record subject, target vehicle, and forward vehicle position and speed data, relevant CAN bus signals associated with FVCWS operation, and data from external sensors (cameras, microphones, accelerometers) used to monitor driver warning timing.

(f) The test event is complete when the FVCWS provides a collision warning due to target vehicle 1 or the vehicle gap between the subject vehicle and target vehicle 1 becomes

less than two subject vehicle lengths, in which case the subject vehicle driver changes lanes and/or applies brakes as necessary to avoid a collision.

(g) Repeat the steps in paragraphs 4.2.5.4.b(b) through 4.2.5.4.b(f) (Two Forward Vehicle- Longitudinal Discrimination) to complete five repetitions.

(h) For each test event, indicate if both collision warnings were produced. The result of the test event is a failure if both collision warnings are not produced.

c. Overhead Discrimination.

(1) Construct an overhead obstacle representative of a concrete bridge or overhead traffic sign structure, with the clearance height at least 4.3 m (14 ft). It is recommended to make the clearance height adjustable to 4.3, 4.6, and 4.9 m (14, 15, and 16 ft) settings. Lateral spacing of the vertical stanchions shall be sufficiently wide to prevent the stanchions from triggering a collision warning when the subject vehicle is driven beneath the structure. Center the overhead obstacle across the test lane (described below) and set the clearance height initially to 4.3 m (14 ft), if adjustable. Ensure that military vehicle antennas will not strike the obstacle, and if so, take necessary precautions to avoid contact.

(2) If any FVCWS settings are driver selectable (e.g., driver's reaction time ( $T_{resp}$ )), adjust the setting to a nominal value following Operator Manual instructions and record the setting for test condition reporting.

(3) Operate the subject vehicle on a straight one or two-lane test course, with the FVCWS activated, at a nominal constant speed within the normal speed range of the subject vehicle. It is recommended to use 72 km/h (45 mph). After achieving the test speed for a few seconds, pass beneath the overhead obstacle, set to the 4.3 m (14 ft) clearance.

(4) Repeat the previous step to complete five repetitions.

(5) For each test event, indicate if collision warnings are produced. If so, repeat testing at the 4.6 and 4.9 m (15 and 16 ft) settings.

4.2.5.5 FVCWS Inoperable Warning Test.

a. Cause a component failure, such as rendering a sensor temporarily inoperable causing a loss of camera signal, disconnecting a communication line, causing a loss of subject vehicle GPS signal, or any other failure appropriate for the FVCWS technology used.

b. With the FVCWS engaged, record any warning signals, fault indications, or system status presented to the driver. Engagement may require operating the vehicle above the defined minimum speed.

c. Undo the component failure. Repeat step 4.2.5.5.b. Observe if the warning signal or fault indication clears. An ignition cycle may be required to clear the fault warning or signal.

#### 4.2.5.6 FVCWS Deactivation Test.

- a. For subject vehicles equipped with means to deactivate the FVCWS, turn the FVCWS off with the engine running. Observe and record system status signals.
- b. Turn the ignition switch off and wait between 10 and 60 seconds. Restart the vehicle. Observe and record system status signals.

#### 4.2.6 Forward Vehicle Collision Mitigation Systems (FVCMS) and Automatic Emergency Braking (AEB) Systems.

- a. FVCMS mitigate or avoid rear-end collisions with forward vehicles by automatically applying vehicle service brakes after a collision warning occurs if the driver does not respond adequately. Other FVCMS names include AEB, Collision Imminent Braking (CIB) and Forward Collision Avoidance and Mitigation (FCAM). While terminology, tradenames and features may vary, systems generally include target vehicle detection, collision warning, and automatic mitigation braking (MB) features.
- b. Collision warning may include warning braking, where the FVCMS automatically applies the vehicle brakes for a short time period to warn the driver. A similar feature known as speed reduction braking (SRB) may also be included, where the FVCMS automatically applies the brakes to reduce vehicle speed, providing additional time for the driver to analyze and respond to a potential collision.
- c. Mitigation braking may include dynamic brake support (DBS), which supplements a driver's commanded brake input by increasing the output of the foundation brake system if the driver does not brake aggressively enough to avoid a collision.
- d. FVCMS terminology, definitions, and symbols are generally consistent with SAE J3063, SAE J3087, and ISO 22839.
- e. Table 19 outlines FVCMS test procedures.

TABLE 19. FVCMS TEST PROCEDURES

CLAUSE NO.	DESCRIPTION
4.2.6.1	Identify FVCMS system classification, capabilities, features and limitations
4.2.6.2	FVCMS detection range and collision mitigation (on Straight Roads) tests
4.2.6.3	FVCMS target discrimination tests
4.2.6.4	FVCMS inoperable warning test
4.2.6.5	Deactivation test

- f. General Instructions.

(1) Prior to FVCMS testing, conduct subject vehicle full-effort brake effectiveness tests at initial speeds ranging from 20 to 60 mph, in 10 mph increments, to characterize the average deceleration performance at each test speed. Conduct the tests at the FVCMS test weight condition(s) specified in the DTP, performing three test events at each initial test speed. For air brake and air-over-hydraulic brake systems, full-effort means a brake application in which the treadle valve pressure in any of the valve's output circuits reaches 586 kPa (85 psi) within 0.2 seconds after the application is initiated, without wheel lock-up. For hydraulic brake systems, full-effort means a brake application in which the force on the brake pedal reaches 622 N (150 lb) within 0.3 seconds after the application is initiated, without wheel lock-up. Conduct pre-FVCMS brake tests with FVCMS off (if possible) and ABS active (if available). It is recommended that test event initial foundation brake temperatures are in the range 66-93 °C (150-200 °F). Initial brake temperatures shall not exceed 149 °C (300 °F).

(2) Unless the system specification or DTP provide other guidance, assess FVCMS performance using the system requirements provided in ISO 22839 Clause 6, where DBS may be included with MB features. DBS is not specifically addressed in ISO 22839 but is addressed in SAE 3063 and SAE 3087.

(3) If the subject vehicle is equipped with ACC or conventional cruise control, test with the ACC or conventional cruise control system in standby or off (if possible).

(4) Conduct FVCMS tests with vehicle ESC and ABS systems active.

(5) Conduct tests on a closed, straight, and level paved road test course, with sufficient space free of obstacles. The road surface shall be dry with a minimum peak braking coefficient of 0.9 when measured using the 14-inch American Society for Testing and Materials (ASTM) standard reference test tire (ASTM E1136<sup>30</sup>) in accordance with ASTM E1337<sup>31</sup>.

(6) The ambient conditions should be free of precipitation, between 0 °C and 35 °C (32 °F and 95 °F). The horizontal visibility range shall be greater than 1 km. Visibility is the distance at which the illuminance of a non-diffusive beam of white light with a color temperature of 2,700 K is decreased to 5 percent of its original light source illuminance. Wind velocity shall not exceed 18 km/h (11.2 mph).

(7) Prior to testing, ensure forward-looking sensors are clean and not covered by dust, soil, ice, or vehicle fluids.

(8) Conduct MB tests with a surrogate 3D test target (also known as a guided soft target or soft car), as described in ISO 19206-3.

(9) During testing, record the following vehicle CAN bus data channels (at a minimum when possible).

(a) FVCMS activation state or mode (*Off, Standby, Active*).

(b) FVCMS settings (e.g., driver's brake reaction time adjustment, if available).

- (c) FVCMS target detected.
- (d) FVCMS target detected lamp (or other warning type).
- (e) FVCMS distance to forward vehicle.
- (f) FVCMS forward vehicle speed.
- (g) FVCMS forward vehicle deceleration.
- (h) FVCMS SRB state.
- (i) FVCMS DBS state.
- (j) FVCMS road curvature.
- (k) FVCMS suppression state.
- (l) FVCMS warning state.
- (m) FVCMS faults.
- (n) Vehicle speed.
- (o) Transmission gear selection.
- (p) Brake apply.
- (q) ABS status (and/or individual wheel speed).
- (r) Brake lamp.

(10) Measure and record subject and target vehicle speeds and positions using RTK GPS. When using RTK GPS to determine vehicle position relative to forward vehicles, account for offsets between the antennae and the front, rear, and sides of the vehicles.

(11) Measure and record the presence of visible, audible, and haptic warnings using time synchronized cameras, microphones, and accelerometers, when possible.

(12) Measure and record collision timing using a time synchronized camera looking at the front bumper area of the subject vehicle. Avoid interference with subject vehicle sensor visibility when locating the camera.

(13) Document nuisance warnings or brake activations that occur (i.e., warnings and braking that should not occur).

(14) For tests involving two or more vehicles operating concurrently (e.g., target discrimination tests), the subject vehicle and forward vehicle operators shall be in direct radio communication and ready to take evasive action if collision is imminent. Drivers shall pre-coordinate evasive actions to avoid contact.

4.2.6.1 Identify FVCMS Classification, Capabilities, Features and Limitations.

Prior to testing, using system documentation, requirements documents, the DTP, pre-test system training, and inspection:

- a. List and describe FVCMS operating states and document if FVCMS can be isolated from other ADAS features (e.g., ACC).
- b. Identify the FVCMS warning triggering method(s) (e.g., time to collision or minimum distance) and threshold values. Collision warnings are a function of the relative velocity between the subject vehicle and target vehicle or object ( $V_{rel}$ ), subject vehicle velocity ( $V_{SV}$ ), clearance distance ( $x_c$ ), vehicle brake reaction time ( $T_b$ ), driver’s reaction time ( $T_{resp}$ ), the subject vehicle acceleration ( $A_{SV}$ ), and the target vehicle acceleration ( $A_{TV}$ ). Include relationships between warning settings and vehicle speed.
- c. At a minimum, list the following FVCMS settings shown in Table 20 (see ISO 22839 and ISO 15623 for additional guidance).

TABLE 20. FVCMS SETTINGS

PARAMETER	DEFINITION
$V_{min}$	Minimum operating velocity
$V_{max}$	Maximum operating velocity
$V_{rel, min}$	Minimum relative vehicle speed allowed
$V_{rel, max}$	Maximum relative vehicle speed allowed
$T_{max}$	Maximum driver’s brake reaction time after the warning
$T_{min}$	Minimum driver’s brake reaction time after the warning
$T_b$	Brake system response time
$D_0$	Minimum detectable distance without distance measuring capability
$D_1$	Minimum detectable distance with distance measuring capability
$D_2$	Minimum detection distance for a cut-in vehicle
$D_{max}$	Maximum detectable distance

- d. Identify the FVCMS classification in terms of roadway curvature, as shown in Table 21.

TABLE 21. FVCMS CLASSIFICATION

CLASS	HORIZONTAL CURVE RADIUS CAPABILITY
I	Curve radius greater than or equal 500 m
II	Curve radius greater than or equal 250 m
III	Curve radius greater than or equal 125 m

e. Document the driver controls, displays, and warnings available for driver interface and interaction with the FVCMS, including the following.

- (1) Means for manually switching the systems on and off, if possible.
- (2) Means to adjust the FVCMS driver warning time (between  $T_{min}$  and  $T_{max}$ , if possible).
- (3) Lists and descriptions of displays and visible, audible, and haptic warnings, including operational status and any diagnostics and reaction to failure indicators or warnings.
- (4) Means to make FVCMS warnings distinguishable from warnings provided by other ADAS features (e.g., ACC and BSM).

f. Document FVCMS functionality, including the following (if possible).

- (1) Sensor type(s) used.
- (2) Whether stationary object warnings with MB are provided.
- (3) Methodology for target selection (when multiple targets are in range).
- (4) Whether preliminary collision warnings are provided, along with conditions.
- (5) Collision warning conditions.
- (6) Whether warning braking, SRB, and DBS are included.
- (7) Warning suppression conditions (see Note below).

**Note:** Suppression is a system or driver feature intended to prevent a collision warning if a warning is not desired for a specific condition.

#### 4.2.6.2 FVCMS Detection Range and Collision Mitigation (on Straight Roads) Tests.

a. Conduct FVCMS detection range and collision mitigation tests following the procedures listed in paragraph 4.2.5.3 of this TOP, except extend test event duration beyond warnings to allow mitigation braking to occur.

b. The subject vehicle driver may overtake braking control or conduct a lane change if collision with the surrogate 3D test target is likely. If collision with the surrogate target occurs, ensure the vehicle FVCMS sensors are not damaged or misaligned. Correct sensor damage or misalignment before proceeding.

c. Identify warning timing (including warning braking), MB timing (if it occurred or not), estimate if warning timing was sufficient to avoid a collision (see Equation 3) and estimate if MB was effective at avoiding a collision without test driver takeover. If a collision occurred, indicate the subject and target relative speeds at the collision time (using the camera specified in the general instructions for timing). If a driver takeover was required, use subject and target vehicle speeds and decelerations prior to takeover to estimate the relative speed at collision, as if driver takeover did not occur.

d. Indicate if SRB activated and if so, identify the timing, subject and target vehicle speeds, and subject and target vehicle decelerations during SRB activation.

e. Indicate if DBS activated after the driver initially applied the brakes to avoid a collision. If so, identify the timing, subject and target vehicle speeds, and subject and target vehicle decelerations during SRB activation.

#### 4.2.6.3 FVCMS Target Discrimination Tests.

Perform the target discrimination test procedures listed in paragraph 4.2.5.4, with references to FVCWS now referring to FVCMS.

#### 4.2.6.4 FVCWS Inoperable Warning Test.

Perform the inoperable warning test procedures listed in paragraph 4.2.5.5, with references to FVCWS now referring to FVCMS.

#### 4.2.6.5 Deactivation Test.

Perform the inoperable warning test procedures listed in paragraph 4.2.5.6, with references to FVCWS now referring to FVCMS.

#### 4.2.7 Lane Keeping Assistance Systems (LKAS).

a. LKAS support the driver in keeping the vehicle within the current lane, using sensor technologies to detect traffic lane lines and actuators to influence lateral movement of the vehicle. The intent is to prevent unintentional lane departure. Systems do not perform automatic driving and the responsibility for safe vehicle operation remains with the driver. LKAS activation may be suppressed by the driver. Systems rely on visible lane markings and may not work well with faded, missing, or irregular lane markings, as well as sand, snow, or water covered roads. The LKAS may only activate above a predefined speed setting.

b. Table 22 outlines LKAS test procedures.

TABLE 22. LKAS TEST PROCEDURES

CLAUSE NO.	DESCRIPTION
4.2.7.1	Identify LKAS system activation states, suppression <sup>a</sup> conditions, system incapable <sup>b</sup> conditions, system inoperable <sup>c</sup> conditions, lane keeping actions, sensors, actuators, vehicle speed requirements and settings
4.2.7.2	Lane keeping test
4.2.7.3	Suppression tests
4.2.7.4	Inoperable/system incapable tests
4.2.7.5	Deactivation test

<sup>a</sup> Suppression is a system or driver feature intended to prevent lane keeping assistance if an intended lane departure is detected or assistance is not desired for a specific condition.

<sup>b</sup> System incapable is a state of the system in which it is unable to assist with lane keeping due to a temporary condition (e.g., no lanes are detected).

<sup>c</sup> System inoperable is a state of the system where the system is made inoperable by a component failure.

c. General Instructions.

(1) Unless the system specification or DTP provide other guidance, assess LKAS performance using the system requirements provided in ISO 11270 Clause 5.

(2) Conduct tests on a dry and level paved road test course, with sufficient space free of incidental visible road features indicative of the position of the test lane (i.e., pavement seams, curbs, and tracks or ruts left by previous vehicles). The road course consists of two lanes, with the primary test lane 3.66 m (12 ft) wide between the lane markings and runout lane sufficiently wide for safe vehicle runout.

(3) Road striping for tests shall include solid and dashed white lines for the right side of the subject vehicle and solid and dashed white and yellow lines for the left side of the subject vehicle. Striping width is 10.2 cm (4 in.) minimum and 15.2 cm (6 in.) maximum. Striping shall conform to the U.S. DOT FHWA MUTCD.

(4) The ambient conditions should be free of precipitation, between 0 °C and 35 °C (32 °F and 95 °F). The horizontal visibility range shall be greater than 1 km. Visibility is the distance at which the illuminance of a non-diffusive beam of white light with a color temperature of 2,700 K is decreased to 5 percent of its original light source illuminance.

(5) Prior to testing, ensure the LKAS sensors are clean and not covered by dust, soil, ice, or vehicle fluids.

(6) During testing, record the following vehicle CAN bus data channels (at a minimum when possible).

- (a) LKAS activation state or mode.
- (b) LKAS incapable state.
- (c) LKAS inoperable state.
- (d) LKAS suppression state.
- (e) LKAS faults.
- (f) LKAS lane keeping threshold setting.
- (g) Subject vehicle speed.

(7) Measure and record subject vehicle speed and position using RTK GPS. When using RTK GPS to determine vehicle position relative to lane boundaries, account for offsets between the antennae and the front, rear, and sides of the vehicles. Vehicle-mounted, time-stamped video camera data may also be used to determine vehicle position relative to lane boundaries.

(8) Measure subject vehicle longitudinal and lateral velocity using a 2-axis optical sensor and vehicle yaw rate. Measure lateral acceleration using an IMU.

4.2.7.1 Identify LKAS Activation States, Suppression Conditions, System Incapable Conditions, System Inoperable Conditions, Lane Keeping Actions, Sensors, Warnings, Displays, Vehicle Speed Requirements and Settings.

Prior to testing, using system documentation, requirements documents, the DTP, system training, and inspection:

- a. Identify the LKAS activation states, incapable conditions (e.g., lack of lane markers) and responses, inoperable conditions (e.g., component failures) and responses, response to lack of one lane marker, and suppression conditions (e.g., turn signal usage and braking).
- b. Identify the means necessary to activate the LKAS (e.g., continuous activation, manual switch activation, and SV speed activation). Include whether the LKAS system requires driver-state feedback for activation (e.g., hands on the steering wheel) and document corresponding system responses and warnings.
- c. Identify lane keeping actions (e.g., steering or braking).
- d. Identify threshold-action settings, if settings are driver adjustable, and the means to adjust the settings (if available).

e. Document the sensors used by the LKAS (e.g., optical cameras, steering torque, or haptic sensors on steering wheel). Indicate the location of the sensors on the vehicle.

f. Document the displays available for driver interaction with the LKAS system. Include any diagnostics (self-tests), system status and reaction to failure indicators or warnings. Include photographs, as appropriate.

#### 4.2.7.2 Lane Keeping Test.

Conduct lane keeping test events on a two-lane roadway with the primary test lane marked as listed in Table 15 and nominally 3.7 m (12 ft) wide. The adjacent test lane, in the direction of lane departure, shall be at least 3.7 m wide. Test sections should be sufficiently long to encompass the lane departure events with consistent markings.

a. Procedure on a Straight.

(1) Apply one of the Table 15 lane marking scenarios and conduct the test procedure described in ISO 11270 Clause 6.5.2.

(2) Repeat testing for each of the Table 15 lane marking scenarios.

b. Procedure on a Curve.

(1) Apply one of the Table 15 right turn lane marking scenarios and conduct the test procedure described in ISO 11270 Clause 6.5.3. The subject vehicle shall begin the maneuver from the inside lane of the curve.

(2) Repeat testing for one of the Table 15 left turn lane marking scenarios.

#### 4.2.7.3 Suppression Tests.

Repeat one right and one left lane departure procedure on a straight scenario from paragraph 4.2.7.2 with the turn signal engaged for the appropriate lane departure direction and any other conditions known to cause warning suppression (e.g., brakes applied or hazard lights on). Observe and record LKAS system behavior.

#### 4.2.7.4 Inoperable/System Incapable Warning Tests.

a. Response to a Component Failure (System Inoperable).

(1) Cause a component failure, such as rendering a sensor temporarily inoperable causing a loss of camera signal, disconnecting a communication line, causing a loss of subject vehicle GPS signal, or any other failure appropriate for the LKAS system technology used.

(2) With the LKAS system engaged, record any warning signals, fault indications, or system status presented to the driver. Engagement may require operating the vehicle above the defined minimum speed.

(3) Undo the component failure. Repeat step in paragraph 4.2.7.4.a(2). Observe if the warning signal or fault indication clears. An ignition cycle may be required to clear the fault warning or signal.

b. Response to an External Loss of Input (System Incapable).

(1) Operate the subject vehicle with the LKAS system engaged in an environment where the external indication of lane position is not present (e.g., no lane markers present or GPS signal shadowed).

(2) Repeat one right and one left lane departure procedure on a straight scenario from paragraph 4.2.7.2. Observe and record LKAS system behavior.

#### 4.2.7.5 Deactivation Test.

a. For subject vehicles equipped with means to deactivate the LKAS system, turn the LKAS system off with the engine running. Observe and record system status signals.

b. Turn the ignition switch off and wait between 10 and 60 seconds. Restart the vehicle. Observe and record system status signals.

#### 4.2.8 Rear Automatic Braking (or Reverse Automatic Braking) Systems.

RAB is a driver assist technology similar to BUW, except that vehicle brakes are applied automatically if a rear collision with a stationary object is imminent. To evaluate RAB, apply the test procedures prescribed in paragraph 4.2.1, but continue backup maneuvers until subject vehicle brakes are applied. Evaluate warning signal timing, brake timing and collision effectiveness as a complete system. If RAB is required in system specifications to respond to rearward cross traffic, apply the procedures prescribed in paragraph 4.2.3 to include subject vehicle brake application. For rearward cross traffic testing, a guided soft target shall be used.

#### 4.2.9 ESC/ABS/TCS.

ESC, ABS, and TCS automotive stability enhancement systems are defined and described in SAE J2564, Automotive Stability Enhancement Systems. Refer to TOP 02-2-718A for electronic stability control test procedure guidance. Refer to SAE J2536 and SAE J46 for ABS test procedures. Test procedures for TCS have historically not been standardized, possibly because of control variations (e.g., engine versus brake control), terrain usage variations (e.g., pavement, gravel, wet roads, snow, and ice), and less relevance to overall system safety compared to ESC and ABS. Performance tests for TCS should be individually tailored to specific requirements provided in the DTP.

## 5. DATA REQUIRED.

The following data are required for all ADAS test procedures provided in this TOP.

- a. SV identification: manufacturer, type, registration number, serial number.
- b. SV odometer mileage.
- c. SV payload and weight distribution.
- d. SV center of gravity location.
- e. SV central tire inflation system and active suspension settings.
- f. SV drivetrain settings (e.g., 4 x 2 mode).
- g. Test course location, environmental conditions, test dates and time of day.
- h. Subject, target, and forward vehicles used.
- i. ADAS software and hardware version numbers.
- j. Subject, target, and forward vehicle RTK, GPS positions, locations of GPS antennae on vehicles, and gap clearances, as appropriate.
- k. Subject, target, and forward vehicle velocities (longitudinal and lateral), accelerations (longitudinal and lateral), and angular rates, as appropriate.
- l. Relevant CAN data for the specific ADAS under test.
- m. Video, audio, and accelerometer data, as appropriate.
- n. Descriptions of visual, audible, haptic indications and warnings, including target or forward vehicle detected and collision warnings.
- o. ADAS control hierarchy when multiple systems are present.
- p. Verification of brake light function during automatic braking.
- q. Observed anomalies, false warnings, and unsafe conditions.

### 5.1 Adaptive Cruise Control Systems.

- a. Descriptions of control modes, sensors, controls, displays, and settings listed in paragraph 4.1.1.

- b. ACC driver settings (i.e., set speed, gap time, gap clearance).
- c. ACC states during test events.
- d. Descriptions of verified means available for the driver to manually to change from ACC *Active* to *Standby* or *Off* states functioned as expected.
- e. Observations of *Active Speed* control functionality, set speed regulation, and conformance to  $v_{\text{set, low}}$  ( $v_{\text{low}}$ ) and  $v_{\text{set, max}}$ . Report statistical data on set speed performance.
- f. Observations of *Active Speed* control *Resume* feature functionality (if provided). Report the average acceleration value during resume instances.
- g. Observations of ACC set speed (+) and (–) feature functionality (if provided).
- h. Maximum allowed lateral acceleration in curves,  $a_{\text{lateral, max}}$ .
- i. Observations of *Active Following* control functionality, including regulation of subject vehicle gap clearance and time settings, conformance to  $v_{\text{set, low}}$  ( $v_{\text{low}}$ ) and  $v_{\text{set, max}}$ , and acceleration and deceleration performance. Report statistical data as appropriate.
- j. Observations of *Hold* and the so-called “Go” transition functionality.
- k. Target detection range distances  $d_0$ ,  $d_1$ , and  $d_{\text{max}}$ .
- l. Target discrimination performance for the test events described in paragraph 4.1.3.2.
- m. Observations of the brake overuse feature functionality (if provided). Report brake temperature, number of braking snubs, average deceleration, and ambient temperature.

## 5.2 Active Safety Systems.

### 5.2.1 BUW Systems.

- a. Descriptions of control modes, sensors, controls, displays, and settings listed in paragraph 4.2.1.1.
- b. Azimuth and elevation grid coverage dimensions (see Figure 5) and coverage ratio, indicating prewarning, main warning, and collision warning zones.
- c. Speed range.
- d. Detection distance and accuracy.
- e. Detection and warning latency.

- f. Observations of sensor fault self-test behavior.

#### 5.2.2 BSM Systems.

- a. Descriptions of BSM system type, activation criteria, states, sensors, warnings, displays, and settings listed in paragraph 4.2.2.1.
- b. Success and failure observations performing the test trials listed in ISO 17387 Tables 5, 6, and 7.
- c. Warning activation and termination times.

#### 5.2.3 CTA Systems.

- a. Descriptions of CTA forward and reverse functionality, activation criteria, states, sensors, warnings, displays, and settings listed in paragraph 4.2.3.1.
- b. Pre-test distances L, DY, and BZ.
- c. Distances DX and DY and angle a, for each test trial at warning activation and deactivation times.
- d. Warning success or failure for each test trial.

#### 5.2.4 LDW Systems.

- a. Descriptions of LDW system activation states, suppression conditions, system incapable conditions, system inoperable conditions, sensors, warnings, displays, vehicle speed requirements and settings listed in paragraph 4.2.4.1.
- b. LDW driver settings.
- c. Subject vehicle lateral velocity and yaw rate.
- d. Vehicle position relative to the lane boundaries when the LDW system indicated a lane departure and when the driver was warned.
- e. Warning success and failure for each test trial.
- f. Observations of suppression effectiveness.
- g. System response to component failure, external loss of input, and deactivation tests.

### 5.2.5 FVCWS.

- a. Descriptions of FVCWS and FDW system classification, capabilities, features, and limitations listed in paragraph 4.2.5.1.
- b. SV full-effort brake effectiveness test results, including initial speed, stopping distance, and average deceleration ( $A_{SV}$ ) for each braking test speed.
- c. FDW and FVCWS driver settings.
- d. Detection range.
- e. Subject-to-target vehicle relative speed.
- f. Observed  $A_{TV}$  values and  $X_{c\_min\_Warning}$  calculations.
- g. Clearance gap between subject and target vehicle when warnings occurred.
- h. Clearance gap comparison between CAN distance to forward vehicle signal and RTK GPS data.
- i. Overhead target heights.
- j. Lateral, longitudinal, and overhead target discrimination performance.
- k. System response to inoperable warning and deactivation tests..

### 5.2.6 FVCMS.

- a. Descriptions of FVCMS system classification, capabilities, features, and limitations listed in paragraph 4.2.6.1.
- b. SV full-effort brake effectiveness test results, including initial speed, stopping distance, and average deceleration ( $A_{SV}$ ) for each braking test speed.
- c. FVCMS driver settings.
- d. Detection range.
- e. Subject-to-target vehicle relative speed.
- f. Observed  $A_{TV}$  values and  $X_{c\_min\_Warning}$  calculations.
- g. Clearance gap between subject and target vehicle when warnings and mitigation braking occurred, identifying warning types and if SRB or DBS was utilized.

- h. Clearance gap comparison between CAN distance to forward vehicle signal and RTK GPS data.
- i. Identify instances of collision with relative speeds between subject and target vehicles at the time of collision.
- j. Overhead target heights.
- k. Lateral, longitudinal, and overhead target discrimination performance.
- l. System response to inoperable warning and deactivation tests.

#### 5.2.7 LKAS.

- a. Descriptions of activation states, suppression conditions, system incapable conditions, system inoperable conditions, lane keeping actions, sensors, warnings, displays, vehicle speed requirements and settings listed in paragraph 4.2.7.1.
- b. LKAS driver settings.
- c. Subject vehicle lateral velocity and yaw rate.
- d. Vehicle position relative to the lane boundaries when the LKAS system indicated a lane departure and when lane keeping occurred.
- e. Lane keeping success and failure for each test trial.
- f. Observations of suppression effectiveness.
- g. System response to component failure, external loss of input, and deactivation tests.

#### 5.2.8 RAB Systems.

- a. Descriptions of control modes, sensors, controls, displays, and settings listed in paragraph 4.2.1.1.
- b. Azimuth and elevation grid coverage dimensions (see Figure 5) and coverage ratio, indicating prewarning, main warning, and collision warning zones.
- c. Speed range.
- d. Detection distance and accuracy.
- e. Detection, warning, and braking timing and latency.
- f. Observations of sensor fault self-test behavior.

- g. Observations of collision avoidance effectiveness.

#### 5.2.9 ESC/ABS/TCS.

Provide data results as required in the relevant test standards listed in 4.2.9.

### 6. PRESENTATION OF DATA.

Much of the information gathered from the test procedures is observational, requiring narrative descriptions of results. When presenting objective data, use Tables, Charts, and plots, as appropriate.

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APPENDIX A. ABBREVIATIONS.

ABS	Anti-lock Braking System
ACC	Adaptive Cruise Control
ADAS	Advance Driver Assist Systems
AEB	Automatic Emergency Braking
ASTM	American Society for Testing and Materials
ATEC	U.S. Army Test and Evaluation Command
BSM	Blind Spot Monitoring
BUW	Back Up Warning
°C	degrees Celsius
CAN	Controller Area Network
CL	centerline
CIB	Collision Imminent Braking
cm	centimeter
CTA	Cross Traffic Alert
DBS	Dynamic Brake Support
DOF	degree of freedom
DOT	Department of Transportation
DTIC	Defense Technical Information Center
DTP	Detailed Test Plan
ERBA	Extended-Range Backing Aid Systems
ESC	Electronic Stability Control
°F	degrees Fahrenheit
FCAM	Forward Collision Avoidance and Mitigation
FDW	Following Distance Warning
FHWA	Federal Highway Administration
FMVSS	Federal Motor Vehicle Safety Standard
FSRA	Full Speed Range Adaptive
ft	feet
FVCM	Forward Vehicle Collision Mitigation
FVCMS	Forward Vehicle Collision Mitigation System
FVCW	Forward Vehicle Collision Warning
FVCWS	Forward Vehicle Collision Warning System
GPS	Global Positioning System
Hz	Hertz

APPENDIX A. ABBREVIATIONS.

IMU	inertial measurement unit
in.	inch
ISO	International Organization for Standardization
km/h	kilometers per hour
kPa	kilopascal
lb	pound
LCDAS	Lane Change Decision Aid Systems
LDW	Lane Departure Warning
LiDAR	Light Detection and Ranging
LKAS	Lane Keeping Assistance System
LSRA	Limited Speed Range Adaptive
m	meter
MALSO	Manoeuvring Aids for Low-Speed Operation
MB	mitigation braking
mm	millimeter
mph	miles per hour
MUTCD	Manual on Uniform Traffic Control Devices
N	Newton
PBC	Peak Braking Coefficient
psi	pounds per square inch
RAB	Rear Automatic Braking
RF	radio frequency
RTK	Real Time Kinematic
SAE	Society of Automotive Engineers International
SRB	speed reduction braking
SUT	System Under Test
SV	subject vehicle
TCS	Traction Control System
TOP	Test Operations Procedure
TV	target vehicle
3D	three-dimensional

APPENDIX B. REFERENCES.

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22. SAE International Surface Vehicle Recommended Practice J2536, Anti-lock Brake System (ABS) Road Test Evaluation Procedure for Trucks, Truck-trailers and Buses, November 2011.
23. SAE International Surface Vehicle Recommended Practice J46, Wheel-Slip Brake-Control System Road Test Code, October 1993.
24. International Standard ISO 19206-3, Road vehicles- Test devices for target vehicles, vulnerable road users and other objects, for assessment of active safety functions- Part 3: Requirements for passenger vehicle 3D targets, May 2021.
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29. Federal Highway Administration, Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD), 2009.
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31. ASTM International E1337, Standard Test Method for Determining Longitudinal Peak Braking Coefficient (PBC) of Paved Surfaces Using Standard Reference Tire Test, 2019.

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APPENDIX C. APPROVAL AUTHORITY.

CSTE-CI

22 August 2022

MEMORANDUM FOR

Commander, U.S. Army White Sands Missile Range  
Executive Director, U.S. Army Evaluation Center  
Commander, U.S. Army Operational Test Command  
Commander, U.S. Army Yuma Proving Ground  
Commander, U.S. Army Dugway Proving Ground  
Commanders, U.S. ATEC Test Centers  
Director, U.S. ATEC Tropic Regions Test Center  
Director, U.S. ATEC West Desert Test Center

SUBJECT: Test Operations Procedure 02-2-515 Advanced Driver Assistance Systems (ADAS)

1. Test Operations Procedure (TOP) 02-2-515 Advanced Driver Assistance Systems (ADAS), has been reviewed by the U.S. Army Test and Evaluation Command (ATEC) Test Centers, the U.S. Army Operational Test Command, and the U.S. Army Evaluation Center. All comments received during the formal coordination period have been adjudicated by the preparing agency.
2. Scope of the document. This TOP provides standardized tests for assessing the safety and performance of wheeled ground vehicles with Advanced Driver Assistance Systems. This TOP does not address driving automation, cooperative driving automation, or conventional cruise control unless conventional cruise control and adaptive cruise control are linked.
3. This document is approved for publication and has been posted to the Reference Library of the ATEC Vision Digital Library System (VDLS). The VDLS website can be accessed at <https://vdlis.atc.army.mil/>.
4. Comments, suggestions, or questions on this document should be addressed to U.S. Army Test and Evaluation Command (CSTE-CI), 6617 Aberdeen Boulevard-Third Floor, Aberdeen Proving Ground, MD 21005-5001; or e-mailed to [usarmy.apg.atec.mbx.atecstandards@mail.mil](mailto:usarmy.apg.atec.mbx.atecstandards@mail.mil).

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Policy and Standardization Division (CSTE-TM), U.S. Army Test and Evaluation Command, 2202 Aberdeen Boulevard, Aberdeen Proving Ground, Maryland 21005-5001. Technical information may be obtained from the preparing activity: Automotive Instrumentation Division (TEDT-AT-ADI), U.S. Army Aberdeen Test Center, 6943 Colleran Road, Aberdeen Proving Ground, MD 21005-5059. Additional copies can be requested through the following website: <http://www.atec.army.mil/publications/topsindex.aspx>, or through the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.