SURFACE VEHICLE RECOMMENDED PRACTICE

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(R) Vehicle-Level Validation Test Procedures for V2V Safety Communications

RATIONALE

The first version of SAE J3161/1 described the minimum requirements for transmission of Vehicle-to-Vehicle (V2V) Basic Safety Message (BSM). Subsequent versions of SAE J3161/1 incorporated changes to improve performance of the LTE-V2X system. The new version of this document provides complementary test procedures and adjustments based on the improvements defined in the updated SAE J3161/1.

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1. SCOPE

This document provides vehicle-level data collection, data analysis, and data verification procedures that may be used to verify that an instrument under test (IUT) satisfies the vehicle-level requirements specified in SAE J3161/1. For the purposes of this report, “vehicle-level requirements” primarily consist of those requirements which can be verified external to the vehicle. The IUT for these procedures is a configured LTE-V2X vehicle-to-vehicle (V2V) device as defined in SAE J3161/1 and is installed on a vehicle of class 2, 3, 4, or 5. While the IUT is conceptually separated from the vehicle it is installed on, the tests outlined in this document are primarily vehicle level, so the terms “vehicle” and “IUT” can generally be considered interchangeable. Additionally, non-vehicle-level complementary tests, not included in this document, are required to verify that the entire set of requirements specified in SAE J3161/1 is satisfied.

NOTE 1: Aside from the vehicle-level data collection, data analysis, and data verification procedures that are in common between light vehicles and public safety vehicles, this document provides some vehicle-level data collection, data analysis, and data verification procedures which are exclusive for public safety vehicles (see Appendix A).

NOTE 2: The validation test procedures for RF TX signal strength in this document were derived from FHWA class 2 light vehicles that are testable on today’s automotive antenna test ranges. Note that FHWA class 3 to 5 vehicles are not testable with these procedures because they exceed the max weight or size to use today’s automotive test ranges and chambers.

This document also includes a Traceability Matrix to provide traceability between SAE J3161/1 sections and the test procedures. This can be used to ensure thoroughness of testing coverage. The traceability matrix in Section 7 correlates test procedures from this document with the sections in SAE J3161/1 being tested.

The SAE J3161/1 sections that are addressed in this document are indicated in Table 1. SAE J3161/1 major section numbers that are indicated as N/A do not contain any requirements (subsections may include requirements). Sections that are not in scope, such as standards profiles, are expected to be tested and verified as part of device-level certification, done prior to the vehicle-level testing described in this document.

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Table 1 - SAE J3161/1 sections currently in scope

SAE J3161/1 Section Number	SAE J3161/1 Section Title	Included in Scope (w/ Focus Primarily on Vehicle-Level Tests)
6.1	Standards Profiles	N/A
6.1.1	ETSI	N
6.1.2	IEEE 1609.2	N/A
6.1.2.1	IEEE 1609.2 Security Profile Identification	N
6.1.2.2	Sending	Y
6.1.2.3	Receiving	N
6.1.3	IEEE 1609.3	N
6.1.5	IEEE 1609.12	N
6.1.6	SAE J2735	Y
6.1.7	Regulatory	N
6.2	Positioning and Timing Requirements	N/A
6.2.1	Position Determination	Y
6.2.2	Wide Area Augmentation System	Y
6.2.3	Coordinate System and Reference	Y
6.2.4	System Time Coordination	Y
6.3	BSM Transmission Requirements on Channel *vChannelNumber*	N/A
6.3.1	BSM Contents	Y
6.3.2	Channel and Data Rate	N
6.3.3	Generation of the First BSM after System Device Startup and Generation Timing	Y
6.3.4	ProSe Per Packet Priority (PPPP) Settings	N
6.3.5	Minimum Transmission Criteria	Y
6.3.6	Data Element Accuracy	Y
6.3.7	Data Persistency	Y
6.3.8	BSM Scheduling and Congestion Control	Y
6.4	RF Performance Requirements	N/A
6.4.1	Minimum Tx RF Performance and Signal Strength	Y
6.4.2	Receiver Sensitivity	Y
6.5	Security and Privacy Requirements	N/A
6.5.1	Identification Randomization	Y
6.5.2	BSM Signing	Y
6.5.3	Identifier Change	Y
6.5.4	BSM Cryptographic Verification	N
6.5.5	Certificate Revocation	N
6.6	Security Management	N/A
6.6.1	Bootstrap: Initialization and Enrollment Processing	N
6.6.2	Certificate Loading	N
6.6.3	Certificate Storage	N
6.6.4	Certificate Revocation List Loading	N
6.6.5	Secure Hardware	N

1.1 Purpose

The purpose of this document is to provide a set of vehicle-level validation test and data verification procedures that may be run to confirm the over-the-air interoperability of an IUT which has been developed to meet the SAE J3161/1 requirements.

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2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 1-877-606-7323 (U.S. and Canada only) or 1-724-776-4970 (outside U.S. and Canada), www.sae.org.

SAE J2735	V2X Communications Message Set Dictionary
SAE J2945/1	On-Board System Requirements for V2V Safety Communications
SAE J3161/1	Onboard System Requirements for LTE-V2X V2V Safety Communications

2.1.2 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

IEEE 149-1979	IEEE Standard Test Procedures for Antennas
IEEE 1609.2-2022	IEEE Standard for Wireless Access in Vehicular Environments - Security Services for Applications and Management Messages (as amended by IEEE Std 1609.2aTM-2017 and IEEE Std 1609.2bTM-2019)
IEEE 1609.3-2020	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services
IEEE 1609.12-2019	IEEE Standard for Wireless Access in Vehicular Environments (WAVE) - Identifier Allocations
IEEE 1720-2012	IEEE Recommended Practice for Near-Field Antenna Measurement

2.2 Related Publications

Refer to SAE J3161/1 and SAE J2945/1A.

3. TERMS AND DEFINITIONS

In addition to the SAE J3161/1 definitions, for the purposes of this recommended practice, the following definitions also apply.

3.1 COLLECTED DATA REPOSITORY

A digital storage location(s) which contains the data collected from executing a test procedure.

3.2 CONFORMANCE REPORT

A report provided by the manufacturer of the IUT/vehicle which contains the compliance status for a select set of SAE J3161/1 requirements that are in the purview of the manufacturer to confirm compliance.

3.3 REFERENCE UNIT

A device which provides a known signal, message, or message content.

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3.4 REMOTE VEHICLE

Refer to SAE J3161/1.

3.5 RUN

Execution steps of a test procedure.

3.6 SETUP

Preparation steps of a test procedure.

3.7 TEST DATA AND ANALYSIS RESULTS REPOSITORY

A digital storage location(s) which contains the data from the collected data repository and the results produced from processing this data.

3.8 TEST FACILITY

A site or sites that offer the requisite driving areas and equipment for performing the vehicle-level validation test procedures contained in this report.

4. ABBREVIATIONS AND ACRONYMS

The abbreviations and acronyms cited below are terms used in this recommended practice.

ASN.1	Abstract Syntax Notation One
AUT	Antenna Under Test
AVD	Aftermarket V2X Device
BSM	Basic Safety Message
CFR	Code of Federal Regulations
CLoss	Cable and Connector Loss
CW	Continuous Wave
ETSI	European Telecommunication Standards Institute
FCC	Federal Communications Commission
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GUI	Graphical User Interface
HDOP	Horizontal Dilution of Precision
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
IUT	Instrument Under Test

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ITU	International Telecommunication Union
LTE	Long Term Evolution
OBU	Onboard Unit
OER	Octet Encoding Rules
PER	Packet Error Ratio
PPPP	ProSe Per Packet Priority
RF	Radio Frequency
RP	Radiated Power
RV	Remote Vehicle
SPS	Semi-Persistent Scheduling
3D	Three-Dimensional
Tx	Transmit
2D	Two-Dimensional
UDP	User Datagram Protocol
UPER	Unaligned Packed Encoding Rules
UTC	Coordinated Universal Time
VSWR	Voltage Standing Wave Ratio
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Everything
WAAS	Wide Area Augmentation System
WAVE	Wireless Access in Vehicular Environments
WGS-84	World Geodetic System 1984
WSM	WAVE Short Message

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5. TEST PROCEDURE STRUCTURE

5.1 Overview

Two categories of test procedures are provided in this report. The first consists of a set of procedures that primarily rely on the transmitted basic safety messages (BSMs) for data analysis and requirements validation. The second consists of a set of procedures to test and validate the radio frequency (RF) performance requirements. These test procedures have been developed with the following goals in mind:

- To the extent possible, the procedures should be tool agnostic.
- The procedures should be designed for an installed and configured deployment-ready device.
- The procedures should be designed such that tampering with hardware, firmware, or software is prohibited.

NOTE 1: Given the nature of the RF testing, some of the RF test procedures may require direct access to the IUT. It would be up to the certifying test organization and/or test facility to work with the manufacturer regarding this.

NOTE 2: The IUT can be a factory integrated Onboard Unit (OBU) or an Aftermarket V2X Device (AVD).

These test procedures are structured such that the tests can be run in a serial manner or in parallel. The data and logs captured during the vehicle-level testing can be processed by data analysis tools that output verification results for assembly into a test report.

Data collection procedures are provided to clearly describe and sequence the steps needed to operate the IUT and V2X vehicle during data collection. These procedures are listed in 5.3. A high-level data analysis procedure describes how to analyze the data collected in order to generate compliance tables as shown in 5.4. Note that the parameter settings for parameters identified in italicized text in the test procedures (e.g., *vChannelNumber*) are contained in SAE J3161/1.

5.2 Test Systems and Tools Suite

The following test procedures assume that a suite of approved and validated test systems and tools are utilized to support the data collection and analysis processes. An illustration of the test systems and tools suite is provided in Figure 1 and is followed by Table 2, which provides a high-level description of the systems and tools. Depending on the test center, a particular “system” or “tool” may be one test apparatus, or many, consisting of a collection of hardware and software components which support the execution of various scripts and programs. Or some of the “systems” or “tools” could be combined into a single system or tool. They are separated this way to highlight the key components; however, the procedures in this report are not binding on which is used; rather, it would be up to the certifying test organization and/or test facility to determine. The key capabilities for these test systems and tools are included in Appendix B. A potential use case diagram utilizing these systems and tools is illustrated in Appendix E.

NOTE: The RF systems and tools are not included in Figure 1 as a good representation of these are provided in the various figures contained in the RF data collection procedure of 5.3.4 and 5.3.4.2.

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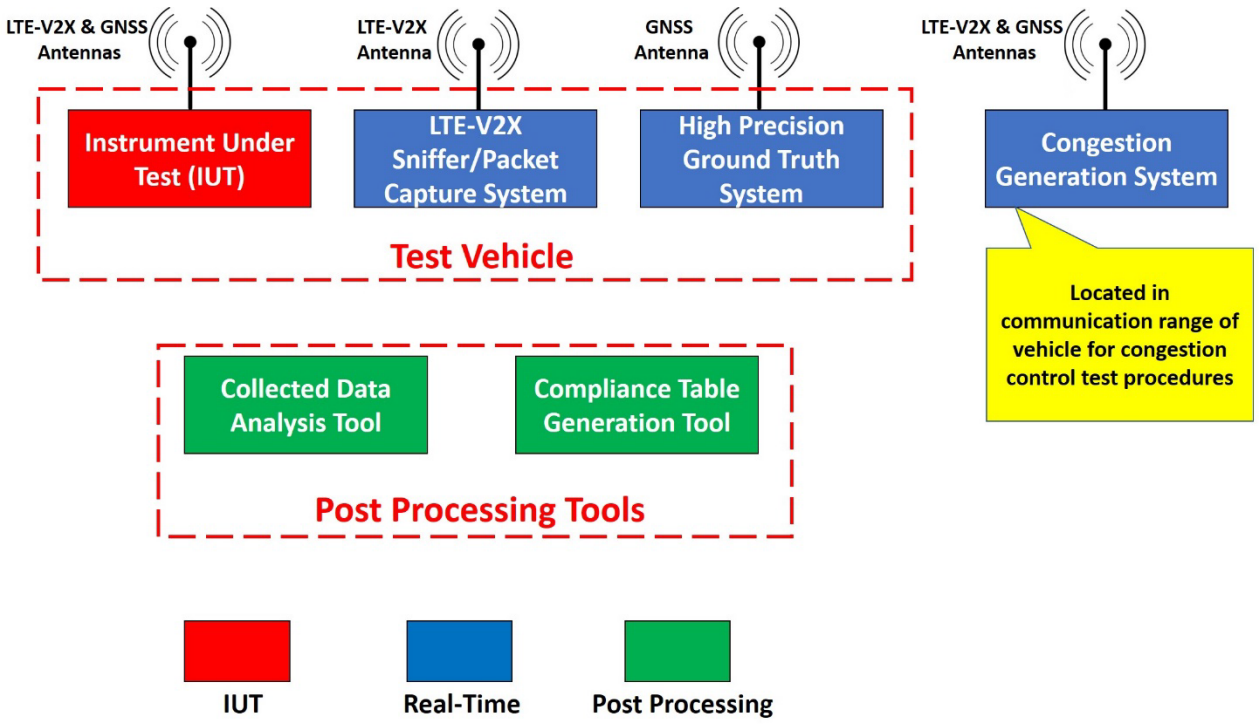


Figure 1 - Test systems and tools suite overview

Table 2 - Test systems and tools suite descriptions

Test Systems/Tools	Description	In Test Vehicle?	Tool Type
LTE-V2X Sniffer/Packet Capture System	A system that is compliant with the relevant ETSI specifications and IEEE standards (1609.x) such that it can capture sidelink LTE-V2X (mode 4) packets on *vChannelNumber* and timestamp and log each packet with the corresponding UTC time it was received. See Table B1 for the key capabilities.	Y	Real time
High Precision Ground Truth System	A system that can be placed on a moving vehicle to capture high precision, UTC timestamped, position, and motion data. See Table B2 for the key capabilities.	Y	Real time
Congestion Generation System	A system located within communication range of the test vehicle which is representative of multiple transmitting RVs and capable of creating repeatable congestion scenarios for validating the congestion control. See Table B3 for the key capabilities.	Optional	Real time
Collected Data Analysis Tool	A tool that can process individual or sets of data collected by the LTE-V2X sniffer/packet capture system and high precision ground truth system. It can: 1. Parse and decode the messages that are contained in the captured packets. 2. Verify the message content against message set constraints defined by the SAE J2735 messages, data frames, and data elements definitions in conjunction with the SAE J3161/1 requirements. 3. Verify performance requirements that are related to vehicle motion (e.g., positioning accuracy, heading, speed, path history, path prediction, and event flags). 4. Verify performance requirements that are related to congestion control (e.g., transmit interval). 5. Verify performance requirements that are related to security and privacy (e.g., randomization, certificate signature present, certificate changing). 6. Has the capability to process sets of data (e.g., all packets captured during a test session) or individual packets. This tool may also provide an analysis report as well as anomalies identified. See Table B4 for the key capabilities.	N	Post processing
Compliance Table Generation Tool	A tool that can process the test results provided by the collected data analysis tool to produce and populate a set of compliance tables for the nonmanufacturer supplied test data requirements. See Table B5 for the key capabilities.	N	Post processing
Power Meter and Sensor	Measurement sensor used to accurately measure output power at the antenna connector of a radio.	N	Real time
Transmit Coverage Test Facility	Environment used to execute transmit coverage tests. See Table C1 for the key capabilities.	N	Real time

Before testing can begin, the test tools must be properly calibrated and adjusted, according to the manufacturer or test lab procedures, to ensure accurate measurements. The calibration process may differ from system to system.

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5.3 Data Collection Procedures

Prior to execution of the data collection procedures, the following should be obtained from the device manufacturer:

a. A report which contains the test status of all requirements that are marked with “D” in the “DC Procedure” column of the compliance verification tables contained in Section 6.

b. A list of permissible data elements/data frames in SAE J3161/1 that are not supported (refer to 6.3.5 in SAE J3161/1).

c. If (1) maintaining the heading below *vHeadLatchThresh* with the required accuracy is supported, or (2) latching of the heading is supported. Refer to SAE J3161/1 requirements [6.3.6-V2V-BSMTX-DATAACC-022] and [6.3.6-V2V-BSMTX-DATAACC-023].

It is important to note that the data collection procedure requires IUT to be security enabled and have appropriate security certificates as a deployed certified V2X system.

A list of data collection procedures (performed in no specific order) is given in Table 3 and is detailed in the following subsections.

Table 3 - Data collection procedures

Procedure	Purpose
Procedure #1: Stationary Vehicle Data Collection - Base Functionality (DC-BASE)	Collect data pertaining to baseline behaviors and BSM structure for a stationary vehicle.
Procedure #2: Stationary Vehicle Data Collection - Power On (DC-PWR)	Collect BSMs transmitted immediately after IUT startup.
Procedure #3: Moving Vehicle Data Collection - Hard-Braking Behavior (DC-EVNT)	Collect data that will be used to verify the hard-braking event flag is set appropriately in the BSM during a hard-braking event.
Procedure #4: Moving Vehicle Data Collection - Data Accuracy (DC-ACCU)	Collect BSMs transmitted by the IUT from a moving vehicle. The collected data will be used to determine compliance with data element accuracy requirements.
Procedure #5: Moving Vehicle Data Collection - Persistence and Low-Speed Operation (DC-LSPD)	Collect data pertaining to IUT data persistence and low-speed behavior by selectively causing the heading of the vehicle to latch and unlatch in different directions.
Procedure #6: Moving Vehicle Data Collection - Controlled Deceleration and Acceleration (DC-CDA)	Collect data pertaining to IUT deceleration and acceleration.
Procedure #7: Moving Vehicle Data Collection - Security and Privacy Data Collection (DC-SECPRIV)	Collect data pertaining to security and privacy requirements.
Procedure #8: Moving Vehicle Data Collection - Path Prediction (DC-PATHPRED)	Collect data pertaining to IUT path prediction.
Procedure #9: Stationary Vehicle Data Collection - Congestion Control - Option 1 (DC-SVCC-1)	Validate congestion control Option 1 for stationary vehicle data collection.
Procedure #10: Stationary Vehicle Data Collection - Congestion Control - Option 2 - Tx Interval and SPS Periodicity (DC-SVCC-2A)	Validate congestion control Option 2 (verifying Tx interval and SPS resource reservation interval) for stationary vehicle data collection.
Procedure #11: Stationary Vehicle Data Collection - Congestion Control - Option 2 - Hysteresis (DC-SVCC-2B)	Validate congestion control Option 2 (verifying hysteresis) for stationary vehicle data collection.
Procedure #12: Stationary Vehicle Data Collection - Congestion Control - Option 2 - Tx Interval Update Delay (DC-SVCC-2C)	Validate congestion control Option 2 (verifying Tx interval update delay) for stationary vehicle data collection.
Procedure #13: Moving Vehicle Data Collection - Congestion Control EVNT (DC-MVCC-EVNT)	Validate congestion control for moving vehicle data collection (critical events).
Procedure #14: Moving Vehicle Data Collection - Congestion Control Dynamic (DC-MVCC-DYN)	Validate congestion control for moving vehicle data collection (vehicle dynamics).
Procedure #15: Tx Signal Strength Data Collection (DC-DTC)	Compute the Tx signal strength by measuring different components of the transmitter.
Procedure #15-a: Cable Loss Data Collection (DC-DTC)	Measure the cable and connector loss between the radio and the antenna.
Procedure #15-b: Maximum Conducted Power Data Collection (DC-DTC)	Measure the maximum conducted power.
Procedure #15-c: Antenna Gain Data Collection (DC-DTC)	Measure the antenna gain around the antenna.
Procedure #16: Receiver Sensitivity (DC-DRS)	Measure the IUT receiver sensitivity.
Procedure #17: Stationary Vehicle Data Collection - Public Safety Vehicle (DC-BASE-PSV)	Collect data pertaining to data frames and elements that support public safety vehicles engaged in an emergency response (see Section A.1).

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5.3.1 Stationary Vehicle Data Collection

5.3.1.1 Stationary Vehicle Test Configuration

This data collection environment shall be a vehicle at a location where global navigation satellite system (GNSS) including at least a global positioning system (GPS) signals are available indoors (repeated) or outside in open-sky conditions. The vehicle will be analyzed in this environment to determine minimum functionality prior to further testing. This functionality includes proper transmission of SAE J3161/1-compliant BSMs. Further testing will be performed for requirements that do not require a moving vehicle, such as identifier (ID) randomization, device startup, and device shutdown.

5.3.1.2 Stationary Vehicle Data Collection Procedures

The stationary vehicle test procedures are Procedure #1: DC-BASE (see Table 4) and Procedure #2: DC-PWR (see Table 5).

NOTE: The following procedures use the LTE-V2X sniffer/packet capture system and collected data analysis tool to capture and decode/interpret BSMs transmitted by the IUT. Testers should verify that BSMs are being captured and decoded prior to running the collection procedures.

Table 4 - Procedure #1, stationary vehicle data collection - base functionality

Procedure #1: DC-BASE	**Est. Time: 10 minutes**
Purpose	Collect data pertaining to baseline behaviors and BSM structure for a stationary vehicle. This test does not require a specific kind of track.
1. Setup	Ensure IUT is operating where GNSS, including GPS, signals are available or in open-sky conditions.
2. Setup	Enable the LTE-V2X sniffer/packet capture system.
3. Run	Turn the IUT on to enable BSM transmissions.
4. Run	If available from vehicle interface to provide vehicle information to use in V2X BSM transmission, activate the following indicator lights one at a time, allowing at least 5 seconds between enabling and disabling each indicator and noting the time of each activation/deactivation. - Low beam headlights - High beam headlights - Left turn signal - Right turn signal - Hazard lights - Fog lights - Parking lights
5. Run	While the vehicle is stationary and in park, press the brake pedal down then release the brake pedal five times, allowing at least 5 seconds between each cycle. For manual transmissions, perform the procedure while in neutral.
6. Run	Hold the vehicle in brake and cycle through the transmission states of the vehicle in the following sequence, allowing at least 5 seconds between each transmission state. - Park - Reverse - Neutral - Drive
7. Run	Verify the collected data is complete and save the collected data from the LTE-V2X sniffer/packet capture system to the collected data repository.

Table 5 - Procedure #2, stationary vehicle data collection - power on

Procedure #2: DC-PWR	**Est. Time: 20 minutes**
Purpose	Collect BSMs transmitted immediately after IUT startup. This test does not require a specific kind of track.
1. Setup	Ensure IUT is operating where GNSS, including GPS, signals are available or in open-sky conditions.
2. Setup	Enable the LTE-V2X sniffer/packet capture system and keep the sniffer/packet capture system running throughout the course of the procedure.
3. Run	Apply the power and turn the IUT on to enable BSM transmissions.
4. Run	Wait for the IUT to start transmitting BSMs. Note that GNSS must be acquired to start transmitting BSMs.
5. Run	Turn the IUT off and wait for the IUT to complete shutdown. Note that the exact time differs between devices and must be provided by the manufacturer ahead of time.
6. Run	Repeat for five cycles minimum.
7. Run	Verify the collected data is complete and save the collected data from the LTE-V2X sniffer/packet capture system to the collected data repository.

Note: This data collection procedure is recommended to be done at the end and after the other data collection procedures.

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5.3.2 Moving Vehicle Data Collection

5.3.2.1 Moving Vehicle Test Configuration

As described in SAE J3161/1, vehicles can use many forms of augmentation to accurately determine their position and vehicle dynamics. Therefore, a practical set of steps is used to collect the data to test the IUT's conformance to the requirements for BSM contents such as speed, acceleration, heading, position, path prediction, path history, and event flags.

These steps should be conducted in a test area that satisfies the open-sky and flat road conditions as specified in SAE J3161/1. Additionally, this area must be safe and able to handle vehicle speeds up to at least 100 km/h, with enough room to allow deceleration to trigger a hard-braking event. The vehicle needs to be in operational safety condition, including braking and tire conditions, to perform these drive tests before collecting data. An example of this environment is shown in Figure 2. It should be stressed that only data collection is addressed in this configuration. The SAE J3161/1 requirements will be verified upon analysis of the recorded data.



Figure 2 - 1.75-mile test track example with 1/2-mile straightaways

5.3.2.2 Moving Vehicle Data Collection Procedures

Procedures #3 through #7 are the moving test procedures and are outlined in the following tables and figures.

NOTE: The following procedures use the LTE-V2X sniffer/packet capture system and collected data analysis tool to capture and decode/interpret BSMs transmitted by the IUT. Testers should verify that BSMs are being captured and decoded prior to running the data collection procedures.

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Table 6 - Procedure #3, moving vehicle data collection - hard-braking behavior

Procedure #3: DC-EVNT	**Est. Time: 10 minutes**
Purpose	Collect data that will be used to verify the hard-braking event flag is set appropriately in the BSM during a hard-braking event. This data collection procedure only requires a straightaway route long enough and no surrounding vehicles to accommodate a hard-braking event.
1. Setup	Verify the high precision ground truth system is calibrated and operational.
2. Setup	Enable the LTE-V2X sniffer/packet capture system.
3. Run	Enable the high precision ground truth system.
4. Run	Turn the IUT on to enable transmissions.
5. Run	Accelerate to 60 km/h ± 5 km/h, then apply sufficient braking to produce a deceleration in excess of >0.4 g at Point 1 (according to Figure 3) to trigger a hard-braking event.
6. Run	Accelerate to 60 km/h ± 5 km/h, then apply sufficient braking to produce a deceleration in excess of >0.4 g at Point 2 (according to Figure 3) to trigger a hard-braking event. Note: It is preferable to capture brake events in multiple directions.
7. Run	Verify the collected data is complete and save the collected data from the LTE-V2X sniffer/packet capture system and high precision ground truth system to the collected data repository.

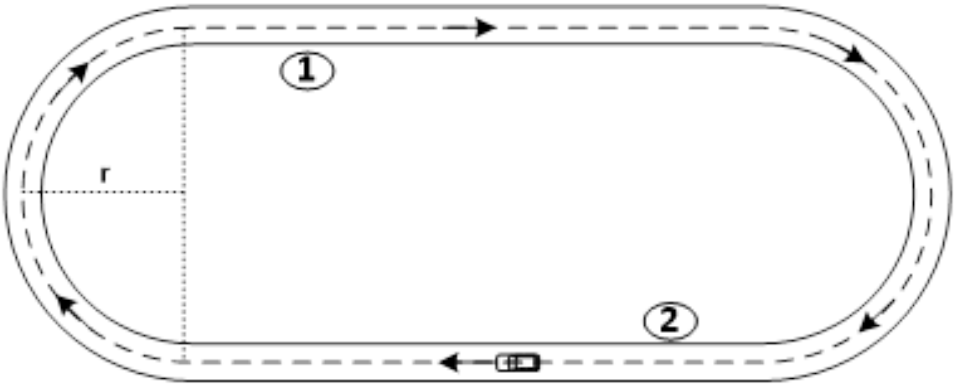


Figure 3 - Route example for hard-braking data collection

Table 7 - Procedure #4, moving vehicle data collection - data accuracy

Procedure #4: DC-ACCU	**Est. Time: 25 minutes**
Purpose	Collect BSMs transmitted by the IUT from a moving vehicle. The collected data will be used to determine compliance with data element accuracy requirements. This test can be run on a drive route with straightaways, curves, and turns to provide typical driving behavior and duration to determine location accuracy.
1. Setup	Verify that the high precision ground truth system is installed, calibrated, and operational.
2. Setup	Enable the LTE-V2X sniffer/packet capture system.
3. Setup	Enable the high precision ground truth system.
4. Setup	Turn the IUT on to enable transmissions.
5. Run	Drive vehicle at a speed 10 to 15 km/h below *vHeadingSpeedThresh* (refer to SAE J3161/1) on the course for at least 3 km. If possible, it is preferable to ensure that multiple left and right turns are taken. In the case of an oval test track, the vehicle should follow paths of at least 3 km each, if possible, in both clockwise and counterclockwise directions (shown in Figures 4 and 5). Both left/right and/or clockwise/counterclockwise directions are desired in order to verify that the path history and path prediction results are obtained regardless of direction/yaw rate.
6. Run	Drive vehicle at a speed >60 km/h on the course for at least 3 km. If possible, it is preferable to ensure that multiple left and right turns are taken. In the case of an oval test track, the vehicle should follow paths of at least 3 km each, if possible, in both clockwise and counterclockwise directions (shown in Figures 4 and 5). Both left/right and/or clockwise/counterclockwise directions are desired in order to verify that the path history and path prediction results are obtained regardless of direction/yaw rate.
7. Run	Verify the collected data is complete and save the collected data from the LTE-V2X sniffer/packet capture system and high precision ground truth system to the collected data repository.

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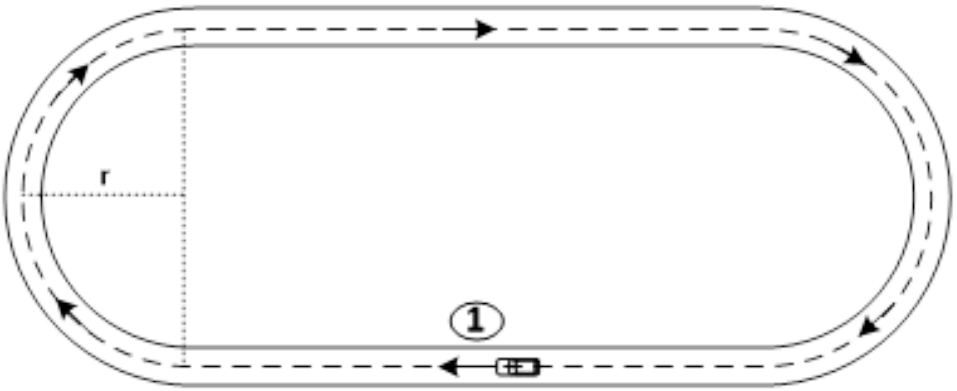


Figure 4 - Clockwise moving data collection

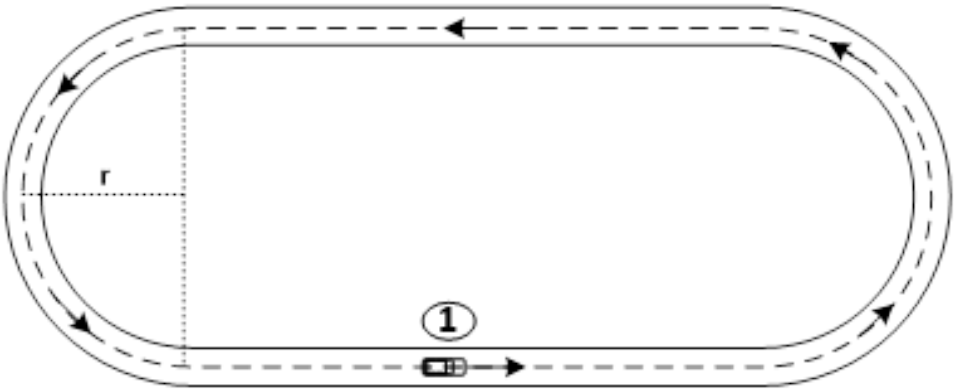


Figure 5 - Counterclockwise moving data collection

Table 8 - Procedure #5, moving vehicle data collection - persistence and low-speed operation

Procedure #5: DC-LSPD	**Est. Time: 15 minutes**
Purpose	Collect data pertaining to IUT data persistence and low-speed behavior by selectively causing the heading of the vehicle to latch and unlatch in different directions. This test requires the track detailed in Figure 6.
1. Setup	Verify that the high precision ground truth system is installed, calibrated, and operational.
2. Setup	Setup cones (or mark reference points) to create the configuration shown in Figure 6.
3. Setup	Enable the LTE-V2X sniffer/packet capture system.
4. Setup	Enable the high precision ground truth system.
5. Setup	Turn the IUT on to enable transmissions.
6. Run	Beginning at position 1 as shown in Figure 6, drive to position 3 at 20 km/h ± 5 km/h passing between positions 2 and 6.
7. Run	At position 3, decelerate and keep the speed below 1.11 m/s (4 km/h) (*vHeadLatchThresh per SAE J3161/1*) to induce heading latch prior to the curve.
8. Run	At position 5, accelerate above 1.39 m/s (5 km/h) (*vHeadUnlatchThresh* per SAE J3161/1) to allow the heading to unlatch.
9. Run	At position 7, decelerate and keep the speed below 1.11 m/s (4 km/h) (*vHeadLatchThresh*) to induce heading latch prior to the curve.
10. Run	At position 1, accelerate above 1.39 m/s (5 km/h) (*vHeadUnlatchThresh*) to allow the heading to unlatch.
11. Run	Repeat steps 6 to 10 two more times to gather data for three complete cycles around the configuration.
12. Run	Verify the collected data is complete and save the collected data from the LTE-V2X sniffer/packet capture system and high precision ground truth system to the collected data repository.

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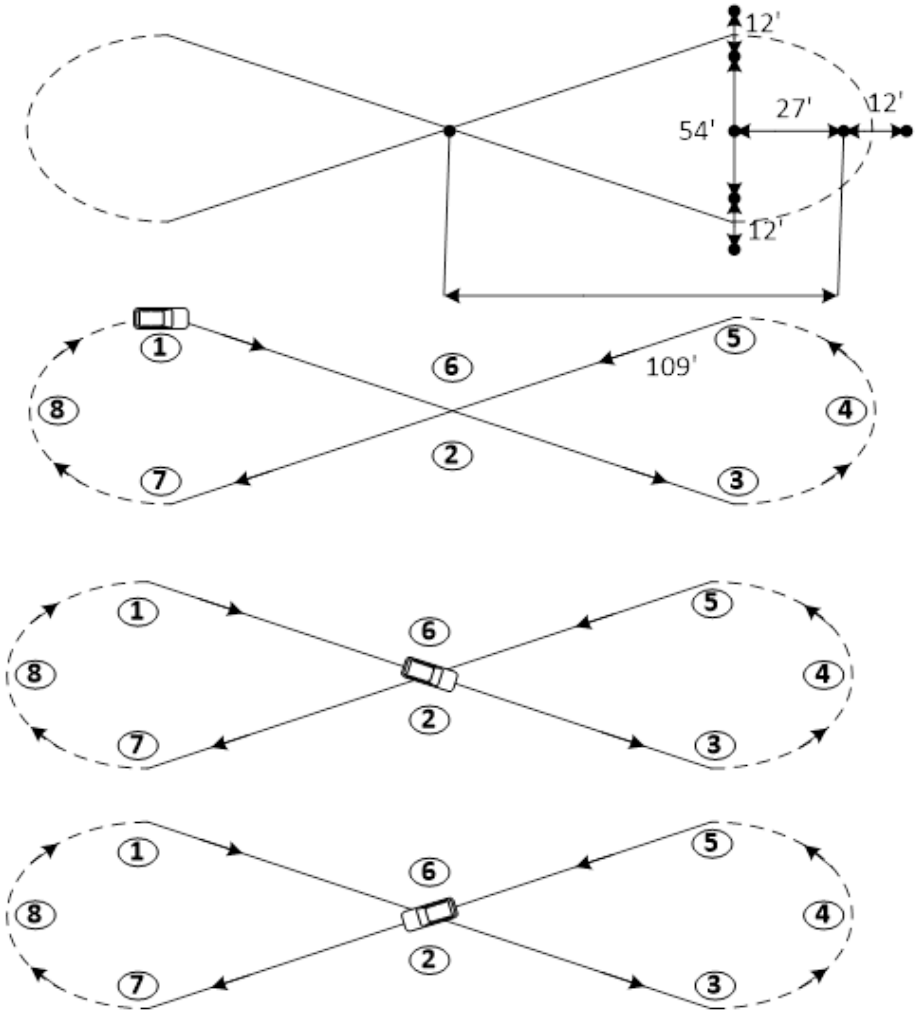


Figure 6 - Modified figure eight moving data collection

Table 9 - Procedure #6, moving vehicle data collection - controlled deceleration and acceleration

Procedure #6: DC-CDA	**Est. Time: 20 minutes**
Purpose	Collect data pertaining to IUT deceleration and acceleration. This test recommends an oval test track that can produce lateral as well as longitudinal acceleration changes, but it can be done in drivable route producing lateral and longitudinal acceleration change as well.
1. Setup	Verify that the high precision ground truth system is installed, calibrated, and operational.
2. Setup	Enable the LTE-V2X sniffer/packet capture system.
3. Setup	Enable the high precision ground truth system.
4. Setup	Turn the IUT on to enable transmissions.
5. Run	Drive to position 1 as shown in Figure 7 at with a speed of 95 km/h ± 5 km/h.
6. Run	At position 1, decelerate slowly (~-0.3 g or less) to a complete stop at position 2.
7. Run	At position 2, accelerate slowly (~0.15 g) to 95 km/h ± 5 km/h at position 3.
8. Run	Drive to position 4 at a speed of 95 km/h ± 5 km/h.
9. Run	At position 4, decelerate slowly (~-0.3 g or less) to a complete stop at position 5.
10. Run	At position 5, accelerate slowly (~0.15 g) to 95 km/h ± 5 km/h at position 6.
11. Run	Repeat steps 5 to 10 for two more complete laps for a total of six acceleration runs and six deceleration runs.
12. Run	Verify the collected data is complete and save the collected data from the LTE-V2X sniffer/packet capture system and high precision ground truth system to the collected data repository.

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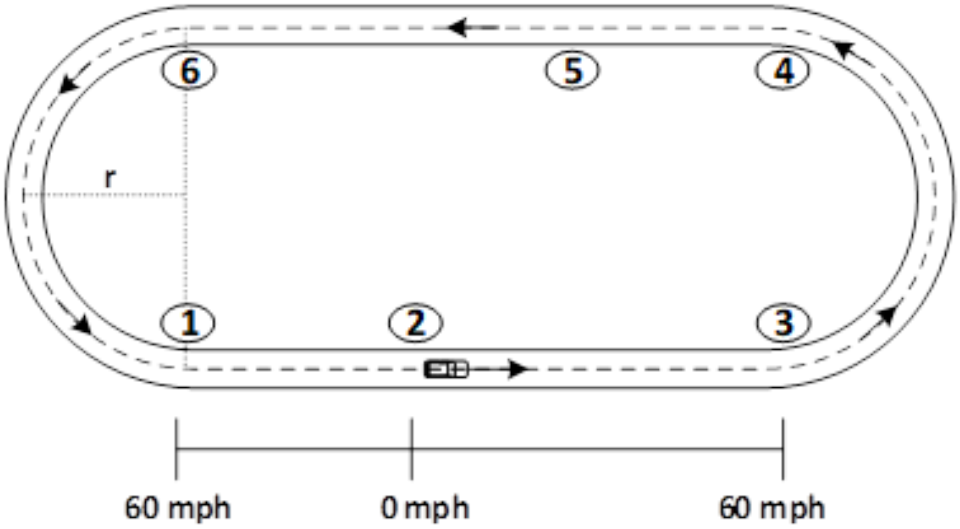


Figure 7 - Controlled deceleration and acceleration moving data collection

Table 10 - Procedure #7, moving vehicle data collection - security and privacy data collection

Procedure #7: DC-SECPRIV	**Est. Time: 35 minutes**
Purpose	Collect data pertaining to security and privacy.
1. Setup	Verify that the high precision ground truth system is installed, calibrated, and operational.
2. Setup	Determine a route that will span >2 km from start to turnaround as illustrated in Figure 8.
3. Setup	Position vehicle at position 1.
4. Setup	Enable the high precision ground truth system.
5. Setup	Enable LTE-V2X sniffer/packet capture system.
6. Run	At position 1, turn the IUT on to enable transmissions.
7. Run	Wait >5 minutes.
8. Run	Drive past position 2, located 2 km from position 1 measured point to point, to position 3, located >2.25 km from position 1 measured point to point, and stop.
9. Run	At position 3, turn vehicle around and drive to position 1, then continue to position 4, located 0.25 km past position 1 measured point to point.
10. Run	Wait 5 minutes.
11. Run	Verify the collected data is complete and save the collected data from the LTE-V2X sniffer/packet capture system and high precision ground truth system to the collected data repository.

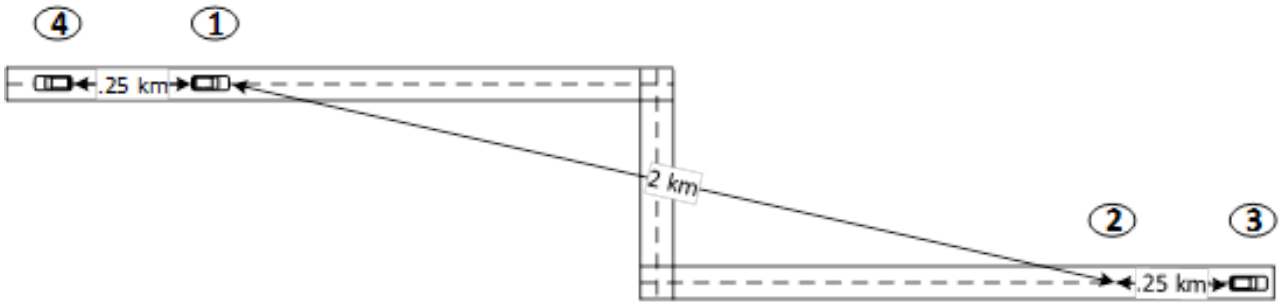


Figure 8 - Security and privacy data collection

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Table 11 - Procedure #8: moving vehicle data collection - path prediction data collection

Procedure #8: DC-PATHPRED	**Est. Time: 15 minutes**
Purpose	Collect data pertaining to IUT path prediction. This test requires a circular path with a constant radius of at least 80 m.
1. Setup	Verify that the high precision ground truth system is installed, calibrated, and operational.
2. Setup	Enable the LTE-V2X sniffer/packet capture system.
3. Setup	Enable the high precision ground truth system.
4. Setup	Turn the IUT on to enable transmissions.
5. Run	Drive to position 2 as shown in Figure 9 for surveying the entry point on the circular track. Set up cones around the spot.
6. Run	Drive to position 3 as shown in Figure 9 for surveying the exit point of the track. Set up cones around the spot.
7. Run	Drive to position 1 as shown in Figure 9 and drive toward the entry point cones at approximately 55 km/h. The path driven from position 1 to the entry point (position 2) must be along a straight line of a minimum distance of 100 m.
8. Run	After entering the circular track by driving through the entry point, complete at least two loops.
9. Run	Leave the circular track through the exit point by driving through the exit point at position 3 as shown in Figure 9.
10. Run	Steps 8 and 9 must be performed at constant speed.
11. Run	After exiting the path, stop the vehicle at point 4 as shown in Figure 9.
12. Run	Verify the collected data is complete and save the collected data from the LTE-V2X sniffer/packet capture system and high precision ground truth system to the collected data repository.

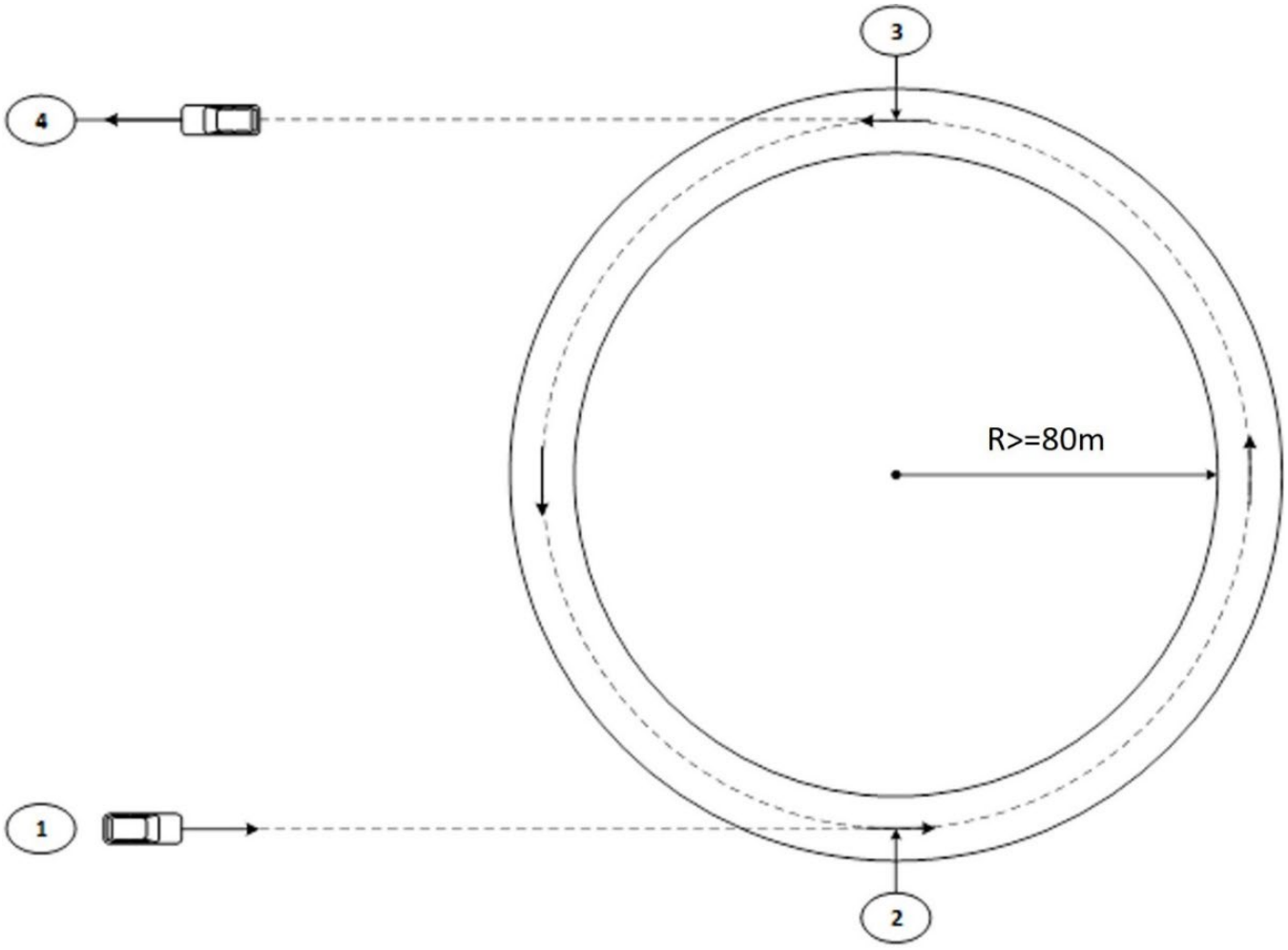


Figure 9 - Path prediction data collection

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