INTERNATIONAL

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Standard Test Method for Evaluating ~~Emergency~~ Response Robot ~~Capabilities: Mobility: Confined Area Terrains:~~ Mobility Using Symmetric Stepfields Terrains[1]

This standard is issued under the fixed designation ~~E2828;~~E2828/E2828M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The robotics community needs ways to measure whether a particular robot is capable of performing specific missions in complex, unstructured, and often hazardous environments. These missions require various combinations of elemental robot capabilities. Each capability can be represented as a test method with an associated apparatus to provide tangible challenges for various mission requirements and performance metrics to communicate results. These test methods can then be combined and sequenced to evaluate essential robot capabilities and remote operator proficiencies necessary to successfully perform intended missions.

The ASTM International Standards Committee on Homeland Security Applications (E54) specifies these standard test methods to facilitate comparisons across different testing locations and dates for diverse robot sizes and configurations. These standards support robot researchers, manufacturers, and user organizations in different ways. Researchers use the standards to understand mission requirements, encourage innovation, and demonstrate break-through capabilities. Manufacturers use the standards to evaluate design decisions, integrate emerging technologies, and harden systems. Emergency responders and soldiers use them to guide purchasing decisions, align deployment expectations, and focus training with standard measures of operator proficiency. Associated usage guides describe how these standards can be applied to support various objectives.

Several suites of standards address these elemental capabilities including maneuvering, mobility, dexterity, sensing, energy, communications, durability, proficiency, autonomy, and logistics. This standard is part of the Mobility Suite of test methods.

1. Scope

1.1 ~~*Purpose:*~~ This test method is intended for remotely operated ground robots operating in complex, unstructured, and often hazardous environments. It specifies the apparatuses, procedures, and performance metrics necessary to measure the capability of a robot to traverse complex terrains in the form of symmetric stepfields. This test method is one of several related mobility tests that can be used to evaluate overall system capabilities.

~~1.1.1 The purpose of this test method, as a part of a suite of mobility test methods, is to quantitatively evaluate a teleoperated ground robot's (see Terminology E2521) capability of traversing complex terrain composed of symmetric stepfields in confined areas.~~

~~1.1.2 Robots shall possess a certain set of mobility capabilities, including negotiating complex terrains, to suit critical operations such as emergency responses. A part of the complexity is that the environments often pose constraints to robotic mobility to various degrees. This test method specifies apparatuses to standardize a confined areas terrain that is composed of symmetric stepfields and that notionally represents types of terrains containing extensive discontinuities, existent in emergency response and other environments. This test method also specifies procedures and metrics to standardize testing using the apparatus.~~

~~1.1.3 The test apparatuses are scalable to provide a range of lateral dimensions to constrain the robotic mobility during task performance. Fig. 1 shows three apparatus sizes to test robots intended for different emergency response scenarios.~~

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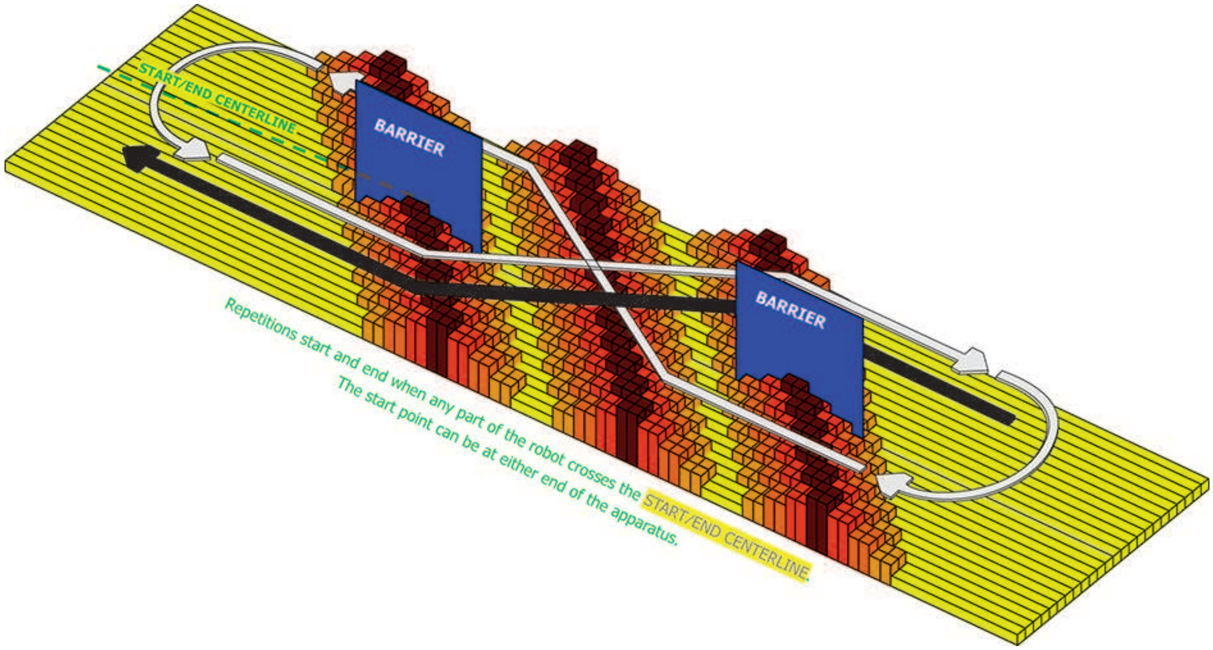

FIG. 1 ~~Mobility: Confined Area Terrains: Symmetric Stepfields Apparatuses~~Overview of the Symmetric Stepfield Terrain Apparatus

~~1.1.4 Emergency response ground robots shall be able to handle many types of obstacles and terrains. The required mobility capabilities include traversing gaps, hurdles, stairs, slopes, various types of floor surfaces or terrains, and confined passageways. Yet additional mobility requirements include sustained speeds and towing capabilities. Standard test methods are required to evaluate whether candidate robots meet these requirements.~~

~~1.1.5 ASTM Task Group E54.08.01 on Robotics specifies a mobility test suite, which consists of a set of test methods for evaluating these mobility capability requirements. This confined area terrain with symmetric stepfields is a part of the mobility test suite. Fig. 2 shows examples of other confined area terrains, along with the traversing paths. The apparatuses associated with the test methods challenge specific robot capabilities in repeatable ways to facilitate comparison of different robot models as well as particular configurations of similar robot models.~~

~~1.1.6 The test methods quantify elemental mobility capabilities necessary for ground robot intended for emergency response applications. As such, users of this standard can use either the entire suite or a subset based on their particular performance requirements. Users are also allowed to weight particular test methods or particular metrics within a test method differently based on their specific performance requirements. The testing results should collectively represent an emergency response ground robot's overall mobility performance as required. This performance data can be used to guide procurement specifications and acceptance testing for robots intended for emergency response applications.~~

~~NOTE 1—Additional test methods within the suite are anticipated to be developed to address additional or advanced robotic mobility capability requirements, including newly identified requirements and even for new application domains.~~

1.2 The robotic system includes a remote operator in control of all functionality, so an onboard camera and remote operator display are typically required. Assistive features or autonomous behaviors that improve the effectiveness or efficiency of the overall system are encouraged.

1.3 Different user communities can set their own thresholds of acceptable performance within this test method for various mission requirements.

1.4 *Performing Location*—This test method ~~shall~~may be performed ~~in a testing laboratory or the field where the specified apparatus~~anywhere the specified apparatuses and environmental conditions ~~are implemented.~~ can be implemented.

1.5 *Units*—The ~~values stated in SI units are to be regarded as the standard. The values given in parentheses are not precise mathematical conversions to inch-pound units. They are close approximate equivalents for the purpose of specifying material dimensions or quantities that are readily available to avoid excessive fabrication costs of test apparatuses while maintaining repeatability and reproducibility of the test method results. These values given in parentheses are provided for information only and are not considered standard.~~International System of Units (SI Units) and U.S. Customary Units (Imperial Units) are used throughout this document. They are not mathematical conversions. Rather, they are approximate equivalents in each system of units to enable use of readily available materials in different countries. This avoids excessive purchasing and fabrication costs. The differences between the stated dimensions in each system of units are insignificant for the purposes of comparing test method results, so each system of units is separately considered standard within this test method.

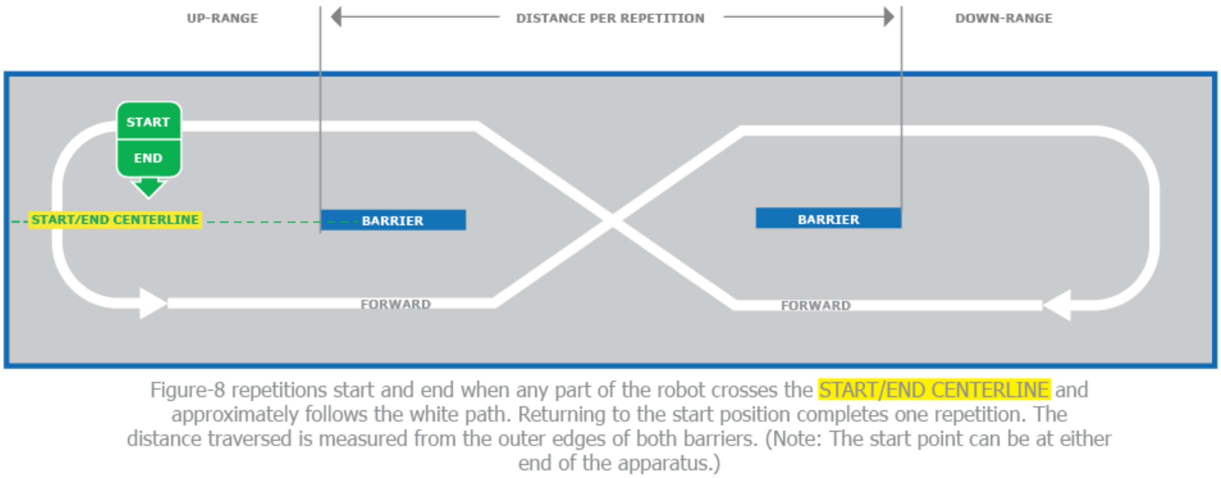

FIG. 2 ~~Three Confined Area Terrain Apparatuses in the Mobility Test Suite with Increasing Complexity: The Continuous Pitch/Roll Ramps Terrain Is Shown on the Left; The Crossing Pitch/Roll Ramps Terrain Is Shown at the Center; The Symmetric Stepfields Terrain Is Shown on the Right~~Top View Showing the Figure-8 Path (Forward) Defined by the Barriers

~~1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*~~

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1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E2521 Terminology for Evaluating Response Robot Capabilities

~~E2592 Practice for Evaluating Response Robot Capabilities: Logistics: Packaging for Urban Search and Rescue Task Force Equipment Caches~~

2.2 ~~*Additional Documents:*~~*Other Standards:*

National Response Framework U.S. Department of Homeland Security[3]

NIST Special Publication 1011-I-2.0 Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume I: Terminology, Version 2.04[4]

3. Terminology

3.1 *Definitions*—The following terms are used in this test method and are defined in Terminology E2521: ~~*lists*~~*abstain, administrator* ~~additional~~or ~~*definitions relevant*~~*test administrator,* ~~*to this*~~*emergency response robot* ~~test~~or ~~*method.*~~*response robot,fault condition,operator,operator station,remote control,repetition,robot,teleoperation,test event* or *event,test form,test sponsor,test suite,testing target* or *target,testing task* or *task,* and *trial* or *test trial.*

~~3.2 *Definitions of Terms Specific to This Standard:*~~

~~3.2.1 *abstain, v*—prior to starting a particular test method, the robot manufacturer or designated operator shall choose to enter the test or abstain. Any abstention shall be granted before the test begins. The test form shall be clearly marked as such, indicating that the manufacturer acknowledges the omission of the performance data while the test method was available at the test time.~~

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Federal Emergency Management Agency (FEMA), P.O. Box 10055, Hyattsville, MD 20782-8055, http://www.fema.gov.

[4] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

~~3.2.1.1 *Discussion*—~~

Abstentions may occur when the robot configuration is neither designed nor equipped to perform the tasks as specified in the test method. Practice within the test apparatus prior to testing should allow for establishing the applicability of the test method for the given robot.

3.2.2 *administrator, n*—person who conducts the test—The administrator shall ensure the readiness of the apparatus, the test form, and any required measuring devices such as stopwatch and light meter; the administrator shall ensure that the specified or required environmental conditions are met; the administrator shall notify the operator when the safety belay is available and ensure that the operator has either decided not to use it or assigned a person to handle it properly; and the administrator shall call the operator to start and end the test and record the performance data and any notable observations during the test.

3.2.3 *emergency response robot, or response robot, n*—a robot deployed to perform operational tasks in an emergency response situation.

3.2.3.1 *Discussion*—

A response robot is a deployable device intended to perform operational tasks at operational tempos during emergency responses. It is designed to serve as an extension of the operator forgaining improved remote situational awareness and for projecting her/his intent through the equipped capabilities. It is designed to reduce risk to the operator while improving effectiveness and efficiency of the mission. The desired features of a response robot include: rapid deployment; remote operation from an appropriate standoff distance; mobility in complex environments; sufficiently hardened against harsh environments; reliable and field serviceable; durable or cost effectively disposable, or both; and equipped with operational safeguards.

3.2.4 *fault condition, n*—during the performance of the task(s) as specified by the test method, a certain condition may occur that renders the task execution to be failed and such a condition is called a fault condition. Fault conditions result in a loss of credit for the partially completed repetition. The test time continues until the operator determines that she/he can not continue and notifies the administrator. The administrator shall, then, pause the test time and add a time-stamped note on the test form indicating the reason for the fault condition.

3.2.4.1 *Discussion*—

Fault conditions include robotic system malfunction such as de-tracking, task execution problems, and excessive deviation from a specified path or uncontrolled behaviors and other safety violations which require administrative intervention.

3.2.5 *human-scale, adj*—used to indicate that the objects, terrains, or tasks specified in this test method are in a scale consistent with the environments and structures typically negotiated by humans, although possibly compromised or collapsed enough to limit human access. Also, that the response robots considered in this context are in a volumetric and weight scale appropriate for operation within these environments.

3.2.5.1 *Discussion*—

No precise size and weight ranges are specified for this term. The test apparatus constrains the environment in which the tasks are performed. Such constraints, in turn, limit the types of robots to be considered applicable to emergency response operations.

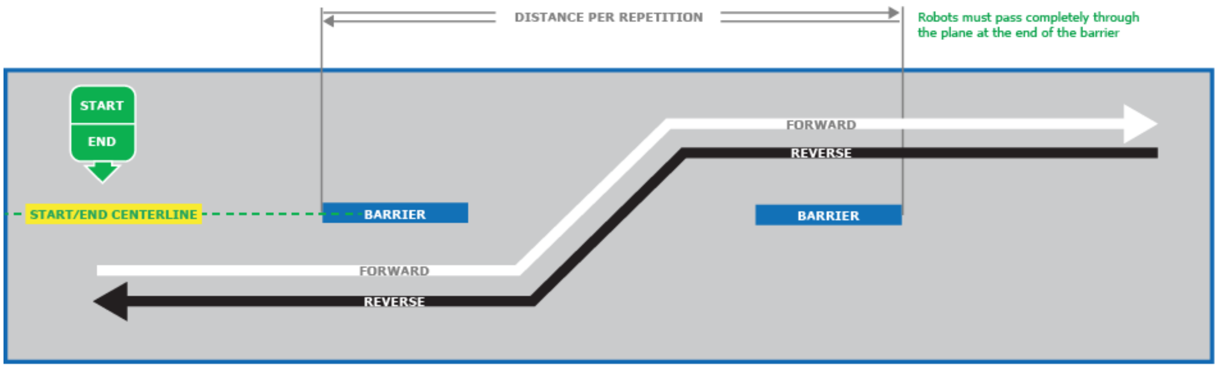
3.2.6 *operator, n*—person who controls the robot to perform the tasks as specified in the test method; she/he shall ensure the readiness of all the applicable subsystems of the robot; she/he through a designated second shall be responsible for the use of a safety belay; and she/he shall also determine whether to abstain the test.

3.2.7 *operator station, n*—apparatus for hosting the operator and her/his operator control unit (OCU, see NIST Special Publication 1011-I-2.0) to teleoperate (see Terminology E2521) the robot; the operator station shall be positioned in such a manner as to insulate the operator from the sights and sounds generated at the test apparatuses.

3.2.8 *repetition, n*—robot's completion of the task as specified in the test method and readiness for repeating the same task when required.

3.2.8.1 *Discussion*—

In a traversing task, the entire mobility mechanism shall be behind the START point before the traverse and shall pass the END point to complete a repetition. A test method can specify returning to the START point to complete the task. Multiple repetitions, performed in the same test condition, may be used to establish the robot performance of a particular test method to a certain degree of statistical significance as specified by the testing sponsor.



Zig-Zag repetitions start and end when any part of the robot crosses the START/END CENTERLINE and approximately follows the white and black paths. Each repetition completes alternating forward and reverse turns past the ends of the barriers. The distance traversed is measured from one end of the apparatus to the other. The traversal length of the robot beyond the barriers is disregarded because of various size robots. (Note: The start point can be at either end of the apparatus.)

FIG. 3 ~~Mobility: Confined Area Terrains: Symmetric Stepfield Apparatuses (Perspective View)~~Top View Showing the Zig-Zag Path (Forward/Reverse) Defined by the Barriers

~~3.2.9 *stepfield terrain element, n*—discontinuous terrain type using 10- by 10-cm (4- by 4-in.) posts with heights of 10, 20, 30, 40, and 50 cm (4, 8, 12, 16, and 20 in.); the posts are arranged in specified topologies, which, in turn, dictate the levels of complexity of the resulting terrain. The material used to build these elements shall be strong enough to enable the participating robots to execute the tasks.~~

~~3.2.10 *test event or event, n*—a set of testing activities that are planned and organized by the test sponsor and to be held at the designated test site(s).~~

~~3.2.11 *test form, n*—form corresponding to a test method that contains fields for recording the testing results and the associated information.~~

~~3.2.12 *test sponsor, n*—an organization or individual that commissions a particular test event and receives the corresponding test results.~~

~~3.2.13 *test suite, n*—designed collection of test methods that are used, collectively, to evaluate the performance of a robot's particular subsystem or functionality, including mobility, manipulation, sensors, energy/power, communications, human-robot interaction (HRI), logistics, safety, and aerial or aquatic maneuvering.~~

~~3.2.14 *testing task, or task, n*—a set of activities specified in a test method for testing robots and the operators to perform in order for the performance to be evaluated according to the corresponding metric(s). A test method may specify multiple tasks.~~

3.2 The following terms are used in this test method and are defined in ALFUS Framework Volume I:3: *autonomous*,*autonomy*, *level of autonomy*,*operator control unit (OCU)*, and *semi-autonomous*.

4. Summary of Test Method

4.1 This test method is performed by a remote operator controlling the robot out of sight and sound of robot within the test apparatus. The robot follows one of two defined paths in the specified terrain requiring the robot to overcome challenges including pitch, roll, traction, and turning on uneven surfaces within open or confined spaces.

4.2 *The Figure-8 Path (forward)* is a continuous forward path through the terrain with alternating left and right turns to avoid barriers. It can be used to demonstrate terrain traversal over long distances within a relatively small apparatus. The continuous traverse is shown as the white path (see Fig. 1 and Fig. 2).

4.3 *The Zig-Zag Path (forward/reverse)* ~~The task for this test method, symmetric stepfield terrain traversing, is defined as the robot traversing from the START point along the specified path which ends back at the START point, thus enabling continuous repetitions. The default path shall be a figure-eight, also known as a continuous "S," around two pylons installed in the test course as described in Section~~ is an end-to-end path that requires forward and reverse traversal through the terrain with alternating left and right turns to avoid barriers. This can be used to demonstrate traversal of the terrain within confined spaces. The down-range traverse, shown as the white path, is performed in a forward orientation and the up-range traverse, shown as ~~6. The START and END points are the same, located beside the first pylon upon entering~~the black path, is performed in reverse (see Fig. 1 ~~the gate. See~~ and Fig. 3 ~~for an illustration.~~).

4.4 The ~~robot's traversing capability of this type of terrain is defined as the robot's ability to complete the task and the associated effective speed. Further, the test sponsor can specify the statistical reliability and confidence levels of such a capability and, thus, dictate the number of successful task performance repetitions that is required. In such a case, the average effective speed shall be~~

used, instead, as the robot's capability.robot starts on one side or the other of a lane full of fabricated symmetric stepfield terrain at a chosen scale. The robot follows either the figure-8 path (forward) or the zig-zag path (forward/reverse) between the two barriers. The figure-8 path (forward) repetition is completed when the robot crosses the start/end centerline of the lane without a fault after approximately following the white path. The zig-zag path (forward/reverse) repetition is completed when the robot crosses the start/end centerline without a fault after approximately following the white and black paths.

4.5 *Potential Faults Include:*

4.5.1 Any contact by the robot with the apparatus that requires adjustment or repair to return the apparatus to the initial condition;

4.5.2 Any visual, audible, or physical interaction that assists either the robot or the remote operator;

4.5.3 Leaving the apparatus during the trial.

4.6 Teleoperation shall be used from the operator station specified by the administrator to test the robots using an OCU provided by the operator. The operator station shall be positioned and implemented in such a manner so as to insulate the operator from the sights and sounds generated at the test apparatus.Test trials shall produce enough successful repetitions to demonstrate the reliability of the system capability or the remote operator proficiency. A complete trial of 10 to 30 repetitions in either one of the defined paths should take 10 to 30 min to complete. When measuring system capabilities, it is important to allow enough time to capture a complete trial with an expert operator. When measuring operator proficiency, it is important to limit the time of the trial so that novice and expert operators are similarly fatigued.

4.7 The operator is allowed to practice before the test. She/he is also allowed to abstain from the test before it is started. Once the test begins, there shall be no verbal communication between the operator and the administrator regarding the performance There are three metrics to consider when calculating the results of a test repetition other than instructions on when to start and notifications of faults and any safety related conditions. The operator shall have the full responsibility to determine whether and when the robot has completed a repetition and notify the administrator accordingly. However, it is the administrator's authority to judge the completeness of the repetition.trial. They should be considered in the following order of importance: completeness score, reliability, and efficiency. The results from the figure-8 path (forward) and the zig-zag path (forward/reverse) are not comparable because they measure different capabilities. The results from different scales of test apparatus are also not comparable because they represent different clearances and distances.

NOTE 2—Practice within the test apparatus could help establish the applicability of the robot for the given test method. It allows the operator to gain familiarity with the standard apparatus and environmental conditions. It also helps the test administrator to establish the initial apparatus setting for the test when applicable.

4.5 The test sponsor has the authority to select the size for the specified confined area apparatus. The test sponsor also has the authority to select the test methods that constitute the test event, to select one or more test site(s) at which the test methods are implemented, to determine the corresponding statistical reliability and confidence levels of the results for each of the test methods, and to establish the participation rules including the testing schedules and the test environmental conditions.

5. Significance and Use

5.1 A main purpose of using robots in emergency response operations is to enhance the safety and effectiveness of emergency responders operating in hazardous or inaccessible environments. The testing results of the candidate robot shall describe, in a statistically significant way, how reliably the robot is able to traverse the specified types of terrains and thus provide emergency responders sufficiently high levels of confidence to determine the applicability of the robot.This test method is part of an overall suite of related test methods that provide repeatable measures of robotic system mobility and remote operator proficiency. This symmetric stepfield terrain specifically challenges robotic system locomotion, suspension systems to maintain traction, rollover tendencies, self-righting in complex terrain (if necessary), chassis shape variability (if available), and remote situational awareness by the operator. As such, it can be used to represent modest outdoor terrain complexity or indoor debris within confined areas.

5.2 This test method addresses robot performance requirements expressed by emergency responders and representatives from other interested organizations. The performance data captured within this test method are indicative of the testing robot's capabilities. Having available a roster of successfully tested robots with associated performance data to guide procurement and deployment decisions for emergency responders is consistent with the guideline of "Governments at all levels have a responsibility to develop detailed, robust, all-hazards response plans" as stated in National Response Framework.The overall size of the terrain apparatus can vary to provide different constraints depending on the typical obstacle spacing of the intended deployment environment. For example, the terrain with containment walls can be sized to represent repeatable complexity within bus, train, or plane aisles; dwellings with hallways and doorways; relatively open parking lots with spaces between cars; or unobstructed terrains.

5.3 The test apparatuses are scalable to constrain robot maneuverability during task performance for a range of robot sizes in confined areas associated with emergency response operations. Variants of the apparatus provide minimum lateral clearance of 2.4 m (8 ft) for robots expected to operate around environments such as cluttered city streets, parking lots, and building lobbies; minimum lateral clearance of 1.2 m (4 ft) for robots expected to operate in and around environments such as large buildings,