INTERNATIONAL

Designation: ~~E2802 – 11 (Reapproved 2020)~~ E2802/E2802M – 21

Standard Test Method for Evaluating ~~Emergency~~ Response Robot ~~Capabilities: Mobility: Confined Area Obstacles: Hurdles~~Mobility Using Variable Hurdle Obstacles[1]

This standard is issued under the fixed designation ~~E2802;~~E2802/E2802M; 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 negotiate an obstacle in the form of hurdles. 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 vertical obstacles in confined areas.~~

[1] This test method is under the jurisdiction of ASTM Committee E54 on Homeland Security Applications and is the direct responsibility of Subcommittee E54.09 on Response Robots.

Current edition approved ~~Jan. 1, 2020~~March 1, 2021. Published ~~January 2020~~March 2021. Originally approved in 2011. Last previous edition approved in ~~2011~~2020 as ~~E2802 – 11.~~E2802 – 11 (2020). DOI: ~~10.1520/E2802-11R20.~~10.1520/E2802_E2802M-21.

1.1.2 Robots shall possess a certain set of mobility capabilities, including negotiating obstacles, to suit critical operations such as emergency responses. A vertical step with an unknown edge condition is a type of obstacle that exists in emergency response and other environments. These environments often pose constraints to robotic mobility to various degrees. This test method specifies apparatuses, procedures, and metrics to standardize this obstacle for testing.

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.

1.1.4 Emergency response ground robots shall be able to handle many types of obstacles and terrain complexities. 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 hurdle test method is a part of the mobility test suite. 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 mobility test suite quantifies elemental mobility capabilities necessary for ground robots intended for emergency response applications. As such, users 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. These 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 most functionality, so an onboard camera and remote operator

A

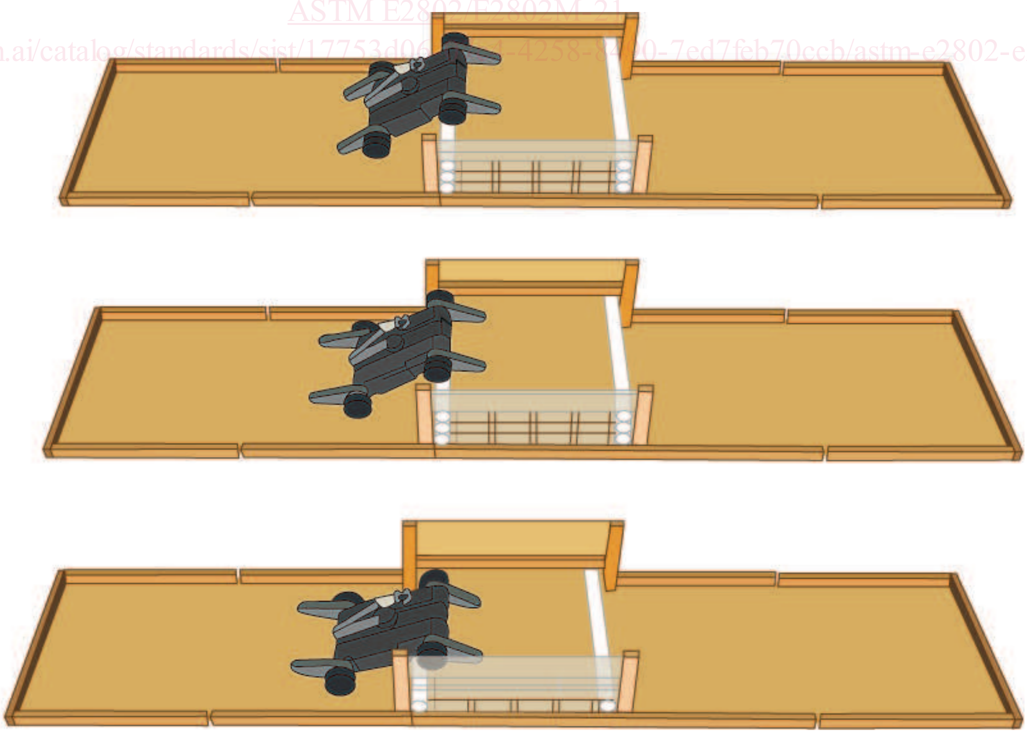

FIG. 1 Mobility: Confined Area Obstacles: Hurdles Apparatuses(A) View of the Variable Hurdle Obstacle Shown Heights: 20 cm [8 in.], 30 cm [12 in.], 40 cm [16 in.]

display are typically required. This test method can be used to evaluate assistive or autonomous behaviors intended to improve the effectiveness or efficiency of remotely operated systems.

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 shallmay be performed in a testing laboratory or the field where the specified apparatusanywhere the specified apparatuses and environmental conditions are 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 (a.k.a. SI Units) and U.S. Customary Units (a.k.a. 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. 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.

1.6 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

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 *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 1: Terminology, Version 2.04 [3]

ALFUS Framework Volume INIST Special Publication 1011-II-1.0 : Terminology, Version 2.0Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume I:3[3]

3. Terminology

3.1 *Definitions*—The following terms are used in this test method and are defined in Terminology E2521: *listsabstain, administrator* additionalor *definitions relevanttest administrator, to thisemergency response robot* testor *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 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.*

3.3 *Definitions: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 http://www.fema.gov/emergency/nrf/

[3] 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. Practices within the test apparatus prior to testing should allow for establishing the applicability of the test method for the given robot.

3.3.1 *administrator,pallet, 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 ita stackable unit with an *properly; and theOriented Strand Board* administrator shall call the operator to start and end the test and record the performance data and any notable observations during the test.(OSB) top surface or similar material sized to fit inside a subfloor.

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 for gaining 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: rapidly deployable; remotely operable 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—*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. 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, and task execution problems, such as excessive deviation from a specified path or failure to recognize a target.

3.2.5 *flat-floor terrain element—*flat surface with overall dimensions of 1.2 by 1.2-cm (4 by 4-ft) that is elevated by using 10 by 10-cm (4 by 4 in.) posts to form a 10 cm (4 in.) thick pallet. The material used to build these elements shall be strong enough to enable the participating robots to execute the tasks.

3.2.5.1 *Discussion—*
The material that is typically used to build these elements, oriented strand board (OSB) is a commonly available construction material. The frictional characteristics of OSB resemble that of dust covered concrete and other human-improved flooring surfaces often encountered in emergency responses.

3.2.6 *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.

3.2.6.1 *Discussion—*
No precise size and weight ranges are specified for this term. The test apparatus specifies the confined areas in which to perform the tasks. Such constraints limit the overall sizes of robots to those considered applicable to emergency response operations.

3.2.7 *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 from the test.

3.2.7.1 *Discussion—*
An operator is typically an emergency responder in emergency response situations.

3.2.8 *operator station, n—*apparatus for hosting the operator and her/his operator control unit (OCU, see ALFUS Framework Volume I: Terminology) to teleoperate (see Terminology E2521) the robot; the operator station shall be positioned in such a manner so as to insulate the operator from the sights and sounds generated at the test apparatuses.

~~3.2.9 *repetition, n*—robot's completion of the task as specified in the test method and readiness for repeating the same task when required.~~

~~3.2.9.1 *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 test performance to a certain degree of statistical significance as specified by the testing sponsor.~~

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

3.3.2 ~~*test sponsor,*~~ *subfloor, n*—an ~~organization or individual that commissions a particular test event and receives the corresponding test results.~~ underlayment of OSB or similar material with dimensional lumber borders used to affix multiple subfloors to one another and can contain apparatus elements such as terrains or obstacles.

~~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.~~

4. Summary of Test Method

4.1 This test method is performed by a remote operator that cannot see or hear the robot within the test apparatus. The robot traverses through a defined area to negotiate the variable hurdle obstacle with or without walls for confinement (see Fig. 1). This test method requires the robot to overcome challenges such as pitch, roll, traction, and control of variable chassis shape and articulators.

4.2 The ~~task for this test method, vertical obstacle traversing, is defined as the entire robot traversing from the starting flat-floor terrain element to the ending flat-floor terrain element and back. See~~ robot traverses a path as shown in Fig. 1. The ~~test~~robot starts ~~at the 10 cm (4 in.) height, the lowest height. As the evaluation proceeds, the task shall be performed on the increased obstacle heights as specified in Section~~on the A-side of the apparatus, crosses to the B-side into the nearest approach area, traverses over the variable hurdle obstacle to the exit area on the opposite end of the apparatus, and then ~~6.~~crosses to the A-side to complete each repetition. All repetitions alternate directions through the apparatus.

4.3 The robot traverses the path in one of two operationally-relevant driving orientations: *unrestricted* or *forward/reverse*.*Unrestricted* allows the robot to traverse the path in any driving orientation throughout the test. *Forward/reverse* requires the robot to alternate between forward and reverse driving orientations for subsequent repetitions throughout the test. Resulting data from the two driving orientations are not comparable to one another.

4.4 There are three apparatus configurations: *open*,*rectangular confinement*, and *square confinement*. In the *open* configuration, no walls are used around the approach/exit areas. The open configuration is representative of operating in unobstructed areas. The *rectangular confinement* and *square confinement* configurations use walls around the approach/exit areas. The walls are used to define the robot's path and are representative of operating in a confined environment. The square configuration has half of the available area as the rectangular configuration.

4.5 ~~The robot's vertical obstacle traversing capability is defined as the highest elevation that the robot is able to traverse. 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 are required.~~*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.

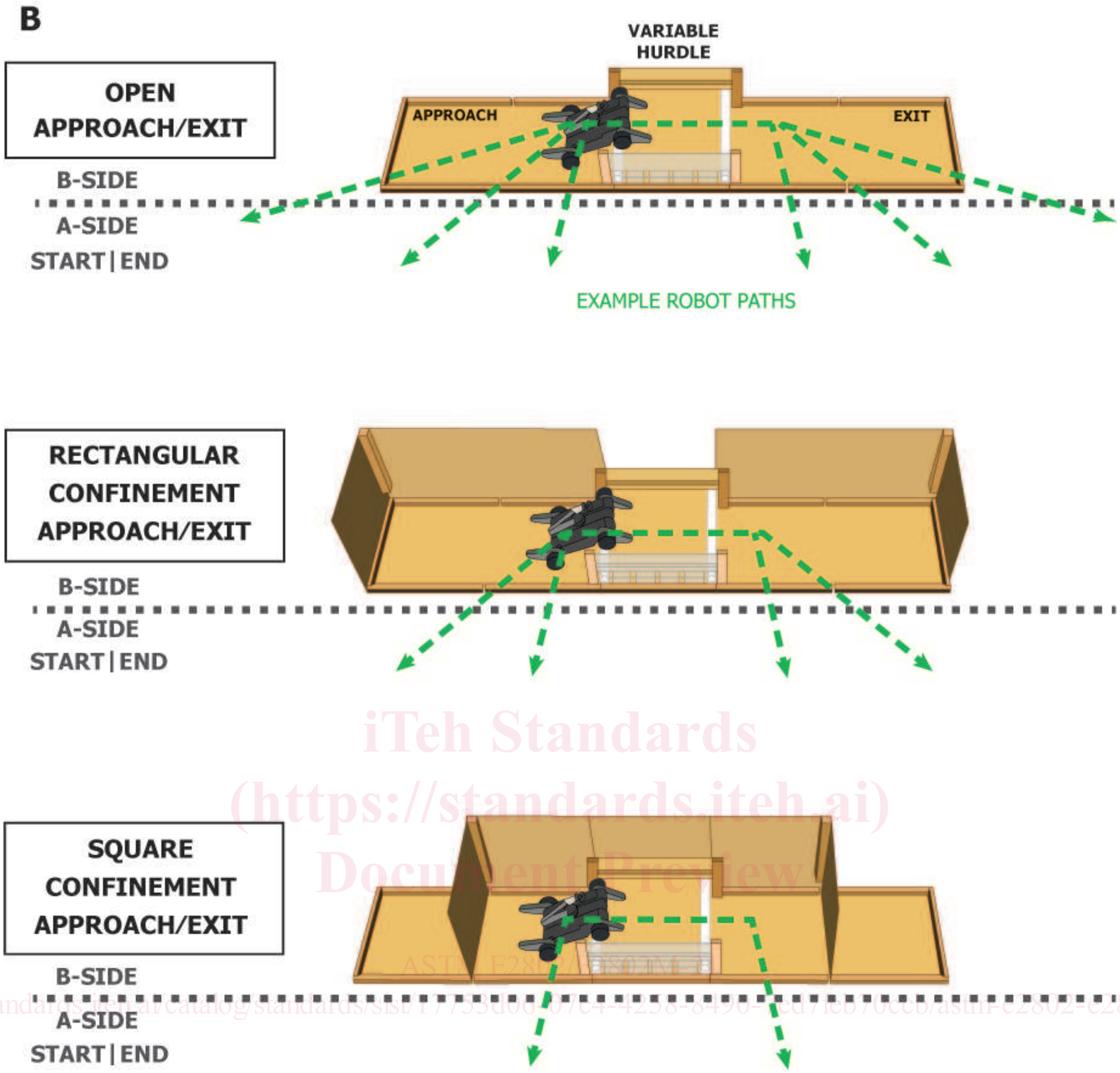

FIG. ~~2~~1 ~~Mobility: Confined Area Obstacles: Hurdles Apparatus (Perspective Views)~~(B) View of a Test Apparatus showing the Open, Rectangular Confinement, and Square Confinement Approach/Exit Areas; and Example Robot Traversal Paths *(continued)*

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

~~4.3 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 as to insulate the operator from the sights and sounds generated at the test apparatuses.~~

4.6 ~~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 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.~~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 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.

~~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.~~

4.7 ~~The test sponsor has the authority to select the size of the lateral clearance 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.~~ There are three metrics to consider when calculating the results of a test trial. They should be considered in the following order of importance: completeness score, reliability, and efficiency. The results from open, rectangular confinement, and square confinement configurations are not comparable because they represent different difficulties and clearances.

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 negotiate the specified types of obstacles and thus provide emergency responders sufficiently high levels of confidence to determine the applicability of the robot.~~

~~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.~~

5.1 This test ~~apparatus is 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, stairwells, and urban sidewalks; minimum lateral clearance of 0.6 m (2 ft) for robots expected to operate within environments such as dwellings and workspaces, buses and airplanes, and semi-collapsed structures; minimum lateral clearance of less than 0.6 m (2 ft) with a minimum vertical clearance adjustable from 0.6 m (2 ft) to 10 cm (4 in.) for robots expected to deploy through breeches and operate within sub-human size confined spaces voids in collapsed structures.~~method is part of an overall suite of related test methods that provide repeatable measures of robotic system mobility and remote operator proficiency. The variable hurdle obstacle as described challenges robotic system locomotion, suspension systems to maintain traction, rollover tendencies, self-righting (if necessary), chassis shape variability (if available), and remote situational awareness by the operator. As such, the variable hurdle obstacle can be used to represent obstacles in the environment, such as railroad tracks, curbs, and debris.

5.2 The scale of the apparatus can vary to provide different constraints representative of typical obstacle spacing in the intended deployment environment. For example, the three configurations can be representative of repeatable complexity for unobstructed obstacles (open configuration), relatively open parking lots with spaces between cars (rectangular confinement configuration), or within bus, train, or plane aisles, or dwellings with hallways and doorways (square confinement configuration).

5.3 The test apparatuses are low cost and easy to fabricate so they can be widely replicated. The procedure is also simple to conduct. This eases comparisons across various testing locations and dates to determine best-in-class systems and operators.

5.4 *Evaluation*—This test method can be used in a controlled environment to measure baseline capabilities. The variable hurdle obstacle can also be embedded into operational training scenarios to measure degradation due to uncontrolled variables in lighting, weather, radio communications, GPS accuracy, etc.

5.5 *Procurement*—This test method can be used to identify inherent capability trade-offs in systems, make informed purchasing decisions, and verify performance during acceptance testing. This aligns requirement specifications and user expectations with existing capability limits.

5.6 *Training*—This test method can be used to focus operator training as a repeatable practice task or as an embedded task within training scenarios. The resulting measures of remote operator proficiency enable tracking of perishable skills over time, along with comparisons of performance across squads, regions, or national averages.

5.7 *Innovation—*~~The standard apparatus is specified to be easily fabricated to facilitate self-evaluation by robot developers and provide practice tasks for emergency responders that exercise robot actuators, sensors, and operator interfaces. The standard apparatus can also be used to support operator training and establish operator proficiency.~~This test method can be used to inspire technical innovation, demonstrate break-through capabilities, and measure the reliability of systems performing specific tasks within an overall mission sequence. Combining or sequencing multiple test methods can guide manufacturers toward implementing the combinations of capabilities necessary to perform essential mission tasks.

~~5.5 Although the test method was developed first for emergency response robots, it may be applicable to other operational domains.~~

6. Apparatus

6.1 ~~These test apparatuses are fabricated from stacks of flat-floor terrain elements placed side by side to form a step (~~The equipment required to perform this test method includes pallets, subfloors, pipes, walls (only for rectangular confinement and square confinement configurations), and a timer. The~~Fig. 2~~ ~~and~~ apparatus consists of subfloors, walls, and the variable hurdle obstacle (see Fig. ~~3~~2). The ~~elevated stack can be increased from~~main apparatus dimension to consider is the minimum clearance width (W) for the robot. The minimum clearance width should be chosen to represent the intended deployment environment or based on the size of the robot, or both. The minimum clearance width is typically set to 120 cm [4 ft], 60 cm [2 ft], or 30 cm [1

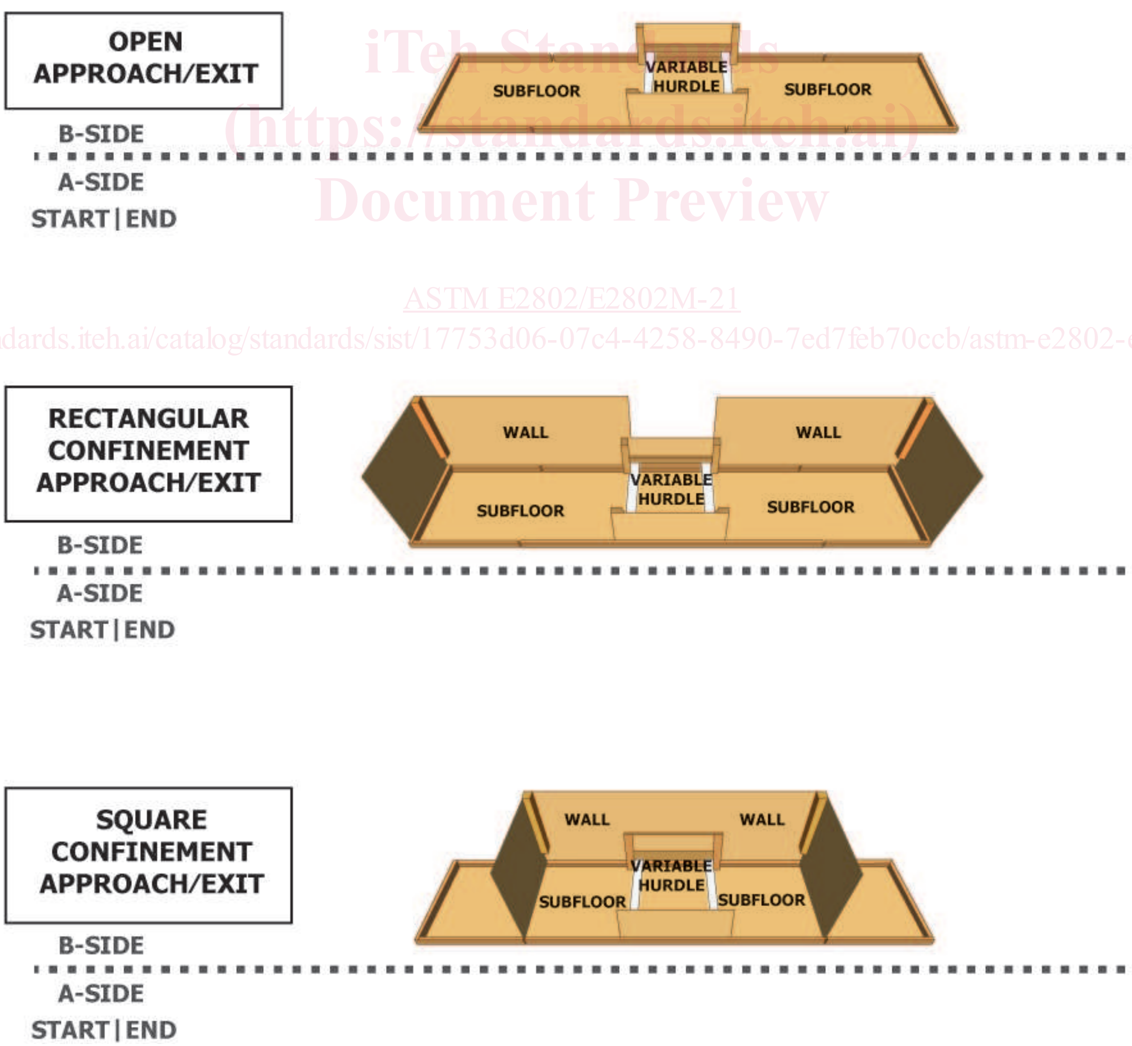

FIG. ~~3~~2 ~~Mobility: Confined Area Obstacles: Hurdles Apparatus (Projection Views)~~View of a Test Apparatus with Labeled Components ft] to efficiently use available construction materials, although other apparatus sizes can be used (see Fig. 3~~10 to 100 cm (4 to 40 in.) in 10-cm (4-in.) increments. Plastic pipes with a diameter of 10 cm (4 in.) are stacked along the vertical surfaces of traversing~~). All apparatus dimensions scale proportionally with the minimum clearance width (see Fig. 4~~to reduce the edge traction. The plastic pipes are constrained against the elevated pallets but are free to only rotate. The stacks of flat-floor terrain elements are surrounded with containment walls. A safety rope belay shall be provided, although it is the operator's option and responsibility to attach, route, and handle it such that the robot can be secured when needed.~~). For example, the width of the variable hurdle obstacle apparatus is 1W, and the length of the variable hurdle obstacle apparatus is either 3W (square confinement configuration) or 5W (rectangular confinement and open configurations). Resulting data from a specific minimum clearance width of the apparatus is not comparable to data from other apparatuses with different minimum clearance widths.

6.2 The apparatus consists of two symmetrical approach/exit areas on either side of a variable hurdle obstacle. There are three configurations of the apparatus: open, rectangular confinement, and square confinement (see Fig. 3). The selection of apparatus configuration should correspond to intended deployment environment. The open configuration does not use walls in the approach areas on either side of the variable hurdle obstacle, allowing for unobstructed robot movement. The approach areas in the rectangular confinement configuration measure 2W by 1W and are bounded by walls taller than the robot to obstruct robot movement. The approach areas in the square confinement configuration measure 1W by 1W and are bounded by walls taller than the robot to further obstruct robot movement. Resulting data from a specific configuration of the apparatus is not comparable to data from other apparatuses with different configurations.

6.3 *Pallet and Pipe*—The ~~test apparatuses specify three lateral clearances (~~variable hurdle obstacle is constructed of multiple~~Figs. 1-3), which are 2.4 m (8 ft), 1.2 m (4 ft), or 0.6 m (2 ft) wide, to be determined by the test sponsor. All three scales~~ pallets which are made of OSB or similar material, dimensional lumber, and pipes on both ends. The thickness of the pallet and the outer diameter of the pipe are relative to the scale of the apparatus (see Table 1~~have 2.4 m (8 ft) long launch and landing areas as their default setting. The apparatuses shall be strong enough to allow the participating robots to execute~~). The pallet is fabricated to fit within the rails of the subfloor. The ground dimension of the hurdle is set to 1W and the overall height of the variable hurdle obstacle (H) is adjustable by stacking multiple pallets and pipes (see Fig. 1 ~~the~~and Fig. 5~~testing tasks.~~).

6.4 *Subfloor*—The ~~test sponsor has the authority to implement further confined launch and landing areas, which are square to match the selected lateral clearance. Removable containment walls shall be placed accordingly.~~subfloor's surface is constructed of OSB or similar material and rails are dimensional lumber that surround the border of the subfloor. Each subfloor is 2W by 1W. A gap in the rails halfway along the side measuring 2W will allow containment wall to be inserted (see Fig. 6).

~~NOTE 3—The material that is typically used to build this test apparatus, OSB, is a commonly available construction material. The frictional characteristics of OSB resemble that of dust covered concrete floors and other improved flooring surfaces often encountered in emergency responses~~

6.5 *Walls to Confine the Robot Path*—The walls placed within the rectangular confinement and square confinement configurations provide physical and visual guidance for the remote robot operator to traverse the variable hurdle obstacle (see Fig. 7). The walls can be made from any solid material and must be taller than the highest point of the robot throughout the test. This ensures that all parts of the robot remain contained within the designated area defined by the walls. The walls should be sturdy and easily repaired or replaced.

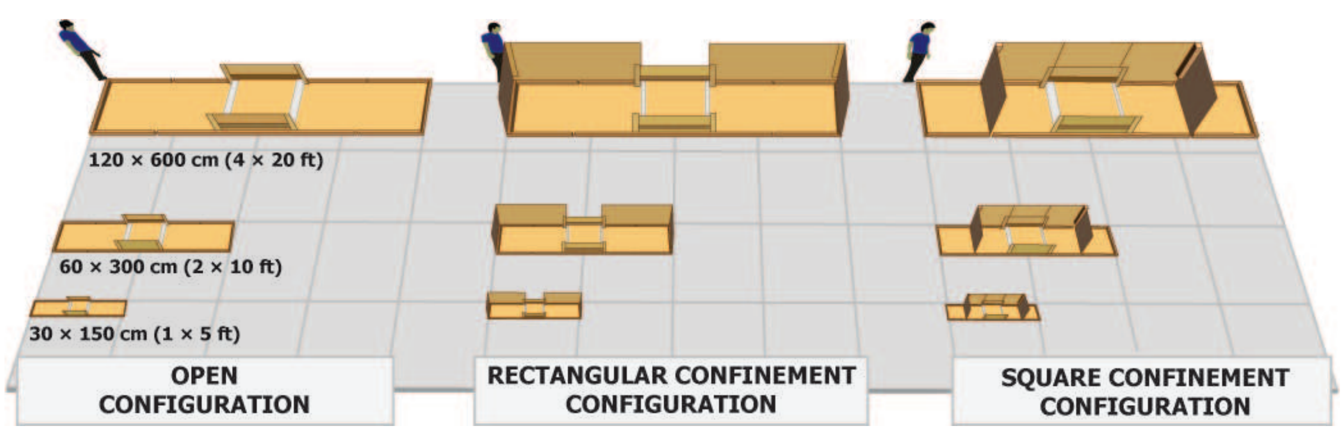

FIG. 4~~3~~ Testing ~~Form Implementation~~Apparatus is Scalable to Represent Different Environments

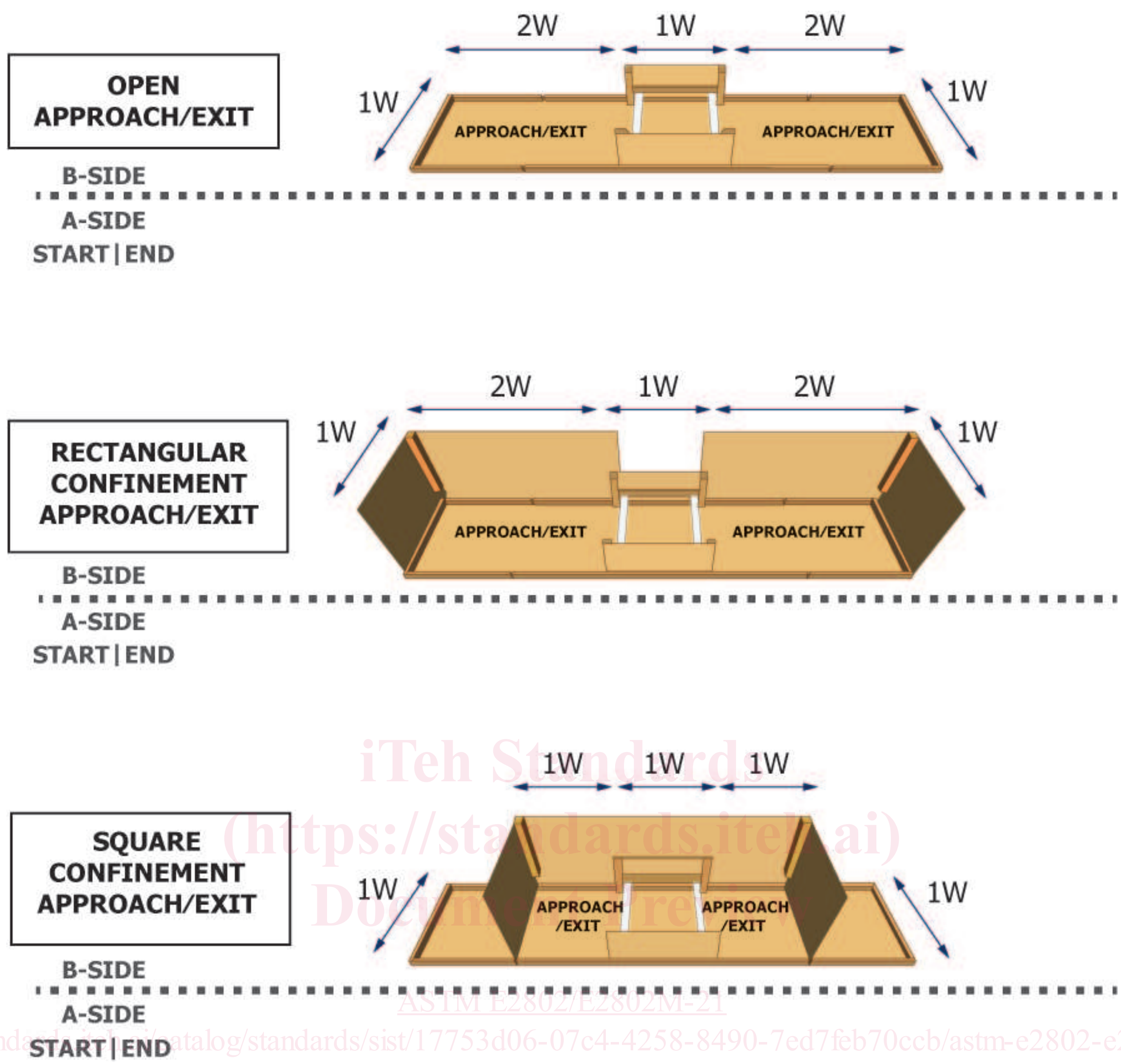

FIG. ~~5~~4 ~~Testing Result Information~~Top View of a Test Apparatus showing the Dimensions and Labeled Open, Rectangular Confinement, and Square Confinement Approach/Exit Areas

6.6 *Containment Structure*—This test method can be set up inside of a facility, outdoors in a parking lot, or inside of a shipping container. Note that at the 120 cm [48 in.] or larger scale, it is likely that only the rectangular confinement and square confinement configurations are possible when the test method is set up inside of a shipping container. All configurations smaller than 120 cm [48 in.] will fit inside of a shipping container.

6.7 *Other Devices*—~~Various test conditions such as apparatus surface types and conditions, including wetness and friction levels, temperature, types of lighting, smoke, humidity, and rain shall be facilitated when the test sponsor requires. For example, for a test run in the dark environment, a light meter shall be used to read 0.1 lux or less. The darkness shall be re-measured when the lighting condition might have changed. The actual readings of these conditions should be recorded on the test form.~~A timer is used to measure the elapsed time of the trial. It provides a deterministic indication of trial start and end times to minimize uncertainty. It can count-up or count-down but should have a settable duration in minutes. A stopwatch can also be used. A light meter is necessary if testing in lighted and dark environments. A lighted environment is considered >150 lx (typical lighting in indoor public spaces is approximately 100 lx to 500 lx) and a dark environment is considered <0.1 lx (a clear moonlit night is approximately 0.01 lx).

~~NOTE 4—The testing apparatus can be implemented in a standard International Standards Organization (ISO) shipping container in which some of the test conditions can be furnished. To achieve the specified darkness, turn off all the lighting sources inside and entirely cover the entrance with light-blocking drapes. The darkness is specified as 0.1 lux due to the implementation cost concerns for the apparatuses and due to the fact that robotic~~

TABLE 1 ~~Testing Results for Mobility: Confined Area Obstacles: Hurdles~~

Robot By Size	Weight (kg)	Length (cm)	Locomotion type	Successful A… Repetitions f…	
10 cm	20 cm	30 cm	40 cm	50 cm	
A	< 20	< 50	Skid steerwheels with 1 actuators	10	10
B	20–40	50–90	Skid steerwheels with 2 actuators	10	10
C	40–70	90–130	Skid steerwheels with 0 actuators	10	10
D	70–100	130–170	Skid steerwheels with 4 actuators	10	10

TABLE 1 Corresponding Height of the Hurdle Pallet and Pipes when used in Different Apparatus Scales

Apparatus Width (W)	Nominal Thickness of the Pallet using Dimensional Lumber	Nominal Outer Diameter of the Pipes	Pipe Stack Height (P) Tolerance
120 cm [96 in.]	10 cm [4 in.]	10 cm [4 in.]	H ± 12 mm [0.5 in.]
60 cm [48 in.]	5 cm [2 in.]	5 cm [2 in.]	H ± 6 mm [0.25 in.]
30 cm [24 in.]	2.5 cm [1 in.]	2.5 cm [1 in.]	H ± 3 mm [0.125 in.]

cameras are less sensitive than human eyes, such that any darkness below 0.1 lux would not make a difference in the cameras' functioning. It is recognized that the environments in real applications may be darker than the specified test condition.

6.5 A stopwatch shall be provided to measure the timing performance.

7. Hazards

7.1 Functional emergency stop systems are essential for safe remote or autonomous robot operation. The emergency stop on the operator control unit shall be clearly marked and accessible. The emergency stop on the robot chassis, if available, should also be marked. All personnel involved in testing shall familiarize themselves with the locations of all emergency stops prior to conducting trials.

7.2 Emergency stop systems shall be engaged prior to approaching a remotely operated robot. Constant communication is essential between the robot and the operator until the robot is safely within the test apparatus and people are either outside the apparatus or at a safe distance. The remote operator may not be aware that someone is interacting with the robot when they start to drive, actuate a manipulator, or move the robot in some other way. Avoid standing directly in front of the robot, behind the robot, or within reach of the manipulator arm unless the robot is completely deactivated.

7.3 Safety equipment such as a belay shall be used from a safe distance to prevent robot damage if necessary. Intervention by hand to try to stop a robot from falling or flipping over is to be prohibited. The belay shall be required for this. Any interaction with the robot, including tightening the belay to save the robot, is considered a fault for scoring purposes.

7.4 BesidesTest 1.4 that addresses the human safety and health concerns, users of the standard shall also address the equipment preservation concerns and human robot coexistence concerns. apparatuses that are intended to challenge robot mobility can be complex and unstable for humans. Proper footwear and other personal protective equipment shall be worn to mitigate risk. Caution is required when attending to a robot or carrying equipment within the apparatus.

NOTE 5—A test sponsor has the authority to decide the environmental conditions under which this test is to be conducted. Such conditions can be stressful not only to the humans but also to the robots, such as high or low temperatures, excessive moisture, and rough terrains that can damage the robotic components or cause unexpected robotic motions.

8. Calibration and Standardization

8.1 The robot configuration as tested shall be described in detail on the test form, including all subsystems and components and