Designation: E2802/E2802M – 21$^{\varepsilon 1}$

Standard Test Method for Evaluating Response Robot Mobility Using Variable Hurdle Obstacles[1]

This standard is issued under the fixed designation 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.

ε[1] NOTE—Editorial corrections were made to Table 1 in May 2021.

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 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.

1.2 The robotic system includes a remote operator in control of most functionality, so an onboard camera and remote operator 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 may be performed anywhere the specified apparatuses and environmental conditions can be implemented.

1.5 *Units*—The 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] 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.

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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:*

NIST Special Publication 1011-I-2.0 Autonomy Levels for Unmanned Systems (ALFUS) Framework, Volume 1: Terminology, Version 2.04 [3]

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

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

3. Terminology

3.1 *Definitions*—The following terms are used in this test method and are defined in Terminology E2521: *abstain*, *administrator* or *test administrator*, *emergency response robot* or *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 of Terms Specific to This Standard:*

3.3.1 *pallet, n*—a stackable unit with an *Oriented Strand Board* (OSB) top surface or similar material sized to fit inside a subfloor.

3.3.2 *subfloor, n*—an 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.

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.

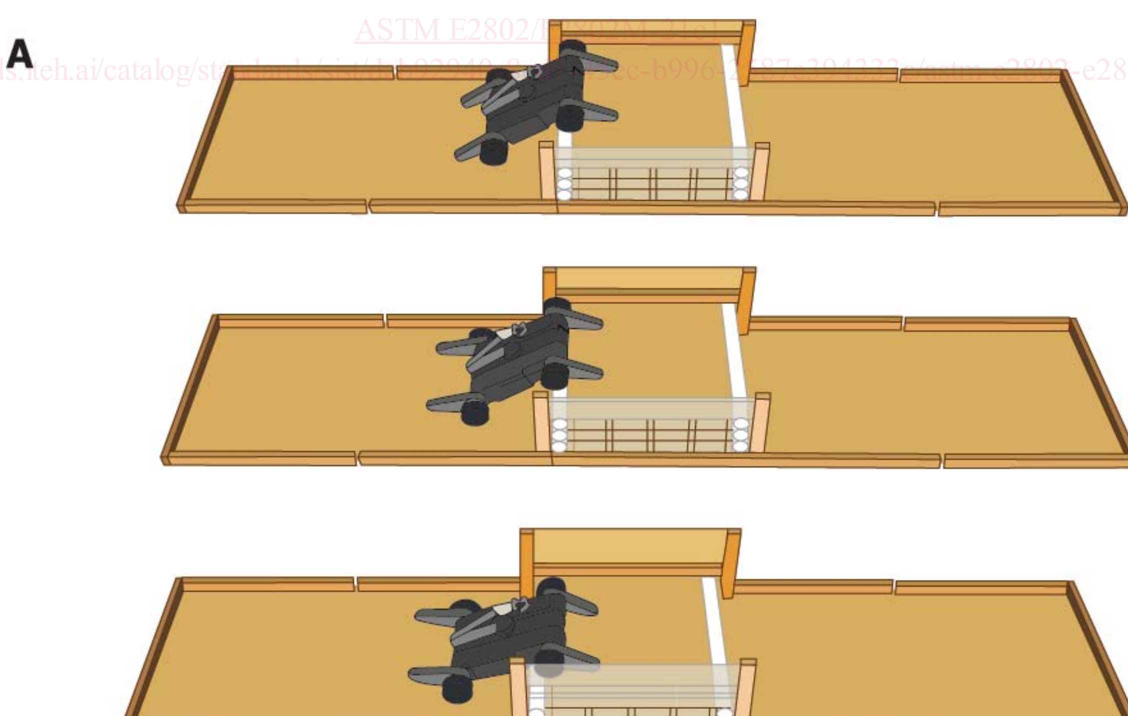

FIG. 1 (A) View of the Variable Hurdle Obstacle
Shown Heights: 20 cm [8 in.], 30 cm [12 in.], 40 cm [16 in.]

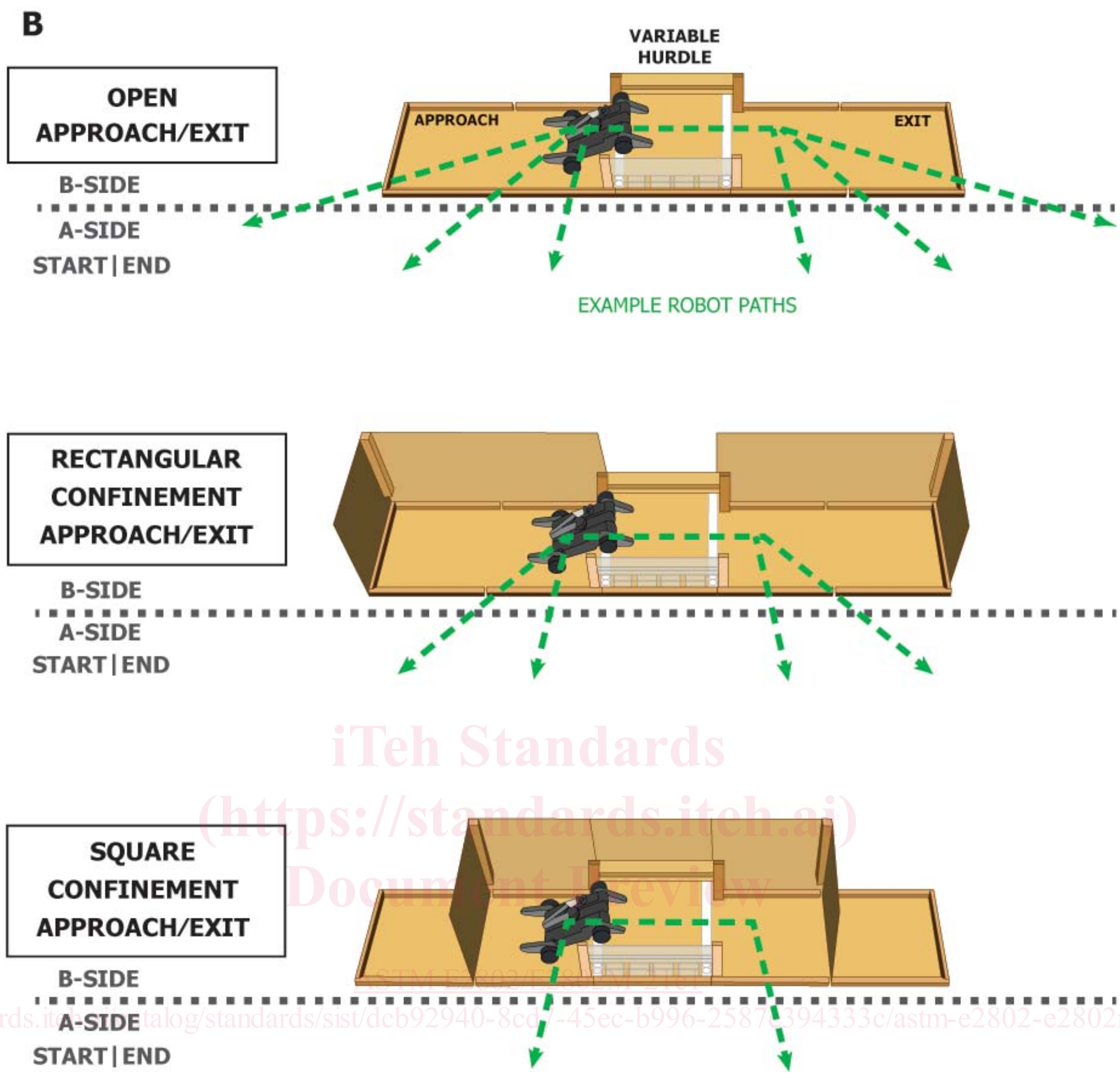

FIG. 1 (B) View of a Test Apparatus showing the Open, Rectangular Confinement, and Square Confinement Approach/Exit Areas; and Example Robot Traversal Paths *(continued)*

4.2 The robot traverses a path as shown in Fig. 1. The robot starts 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 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 *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.

4.6 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.

4.7 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 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. 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*—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.

6. Apparatus

6.1 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 apparatus consists of subfloors, walls, and the variable hurdle obstacle (see Fig. 2). The 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 ft] to efficiently use available construction materials, although other apparatus sizes can be used (see Fig. 3). All apparatus dimensions scale proportionally with the minimum clearance width (see Fig. 4). 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 variable hurdle obstacle is constructed of multiple 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). 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 and Fig. 5).

6.4 *Subfloor*—The 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).

6.5 *Walls to Confine the Robot Path*—The walls placed within the rectangular confinement and square confinement

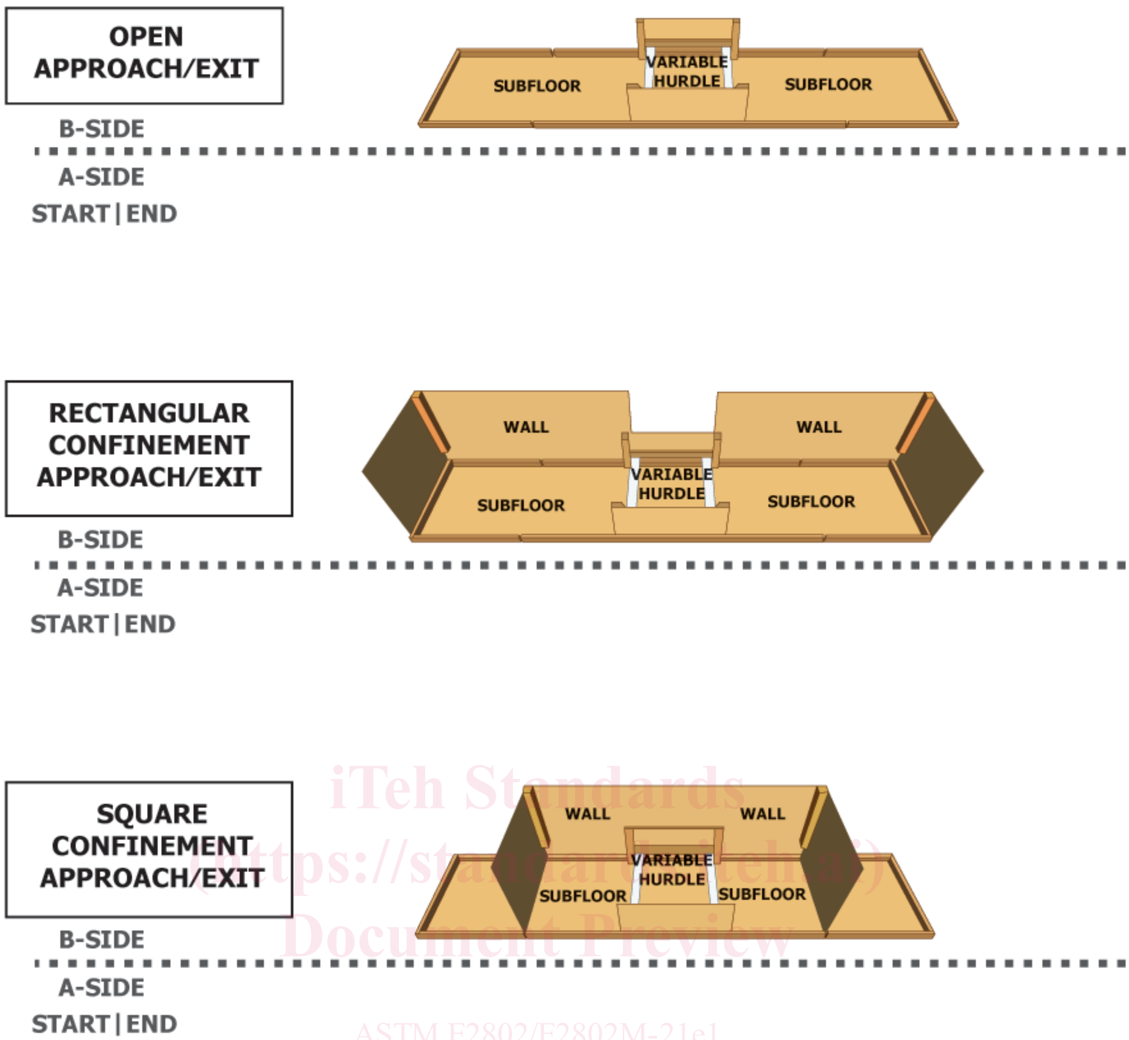

FIG. 2 View of a Test Apparatus with Labeled Components

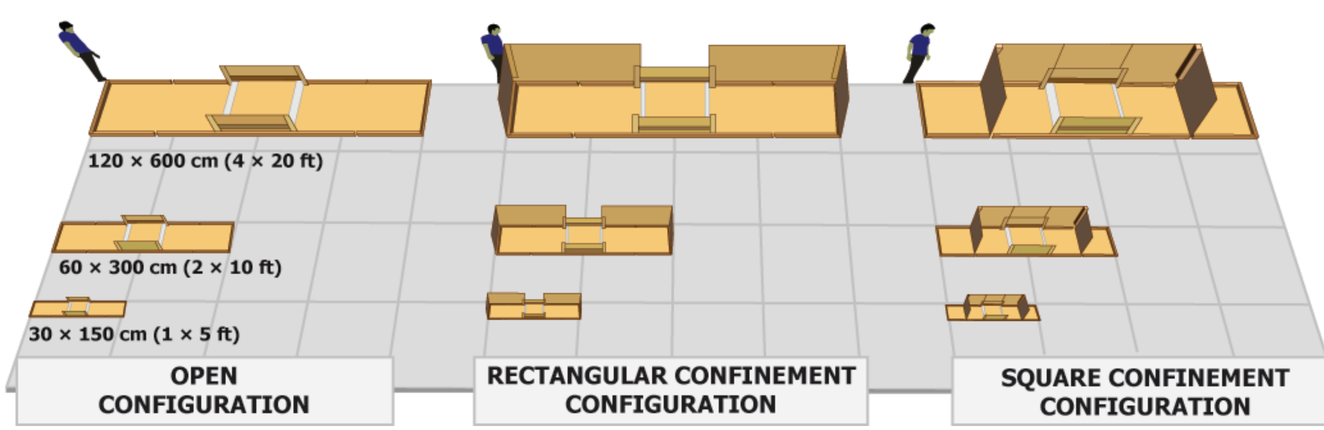

FIG. 3 Testing Apparatus is Scalable to Represent Different Environments

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.

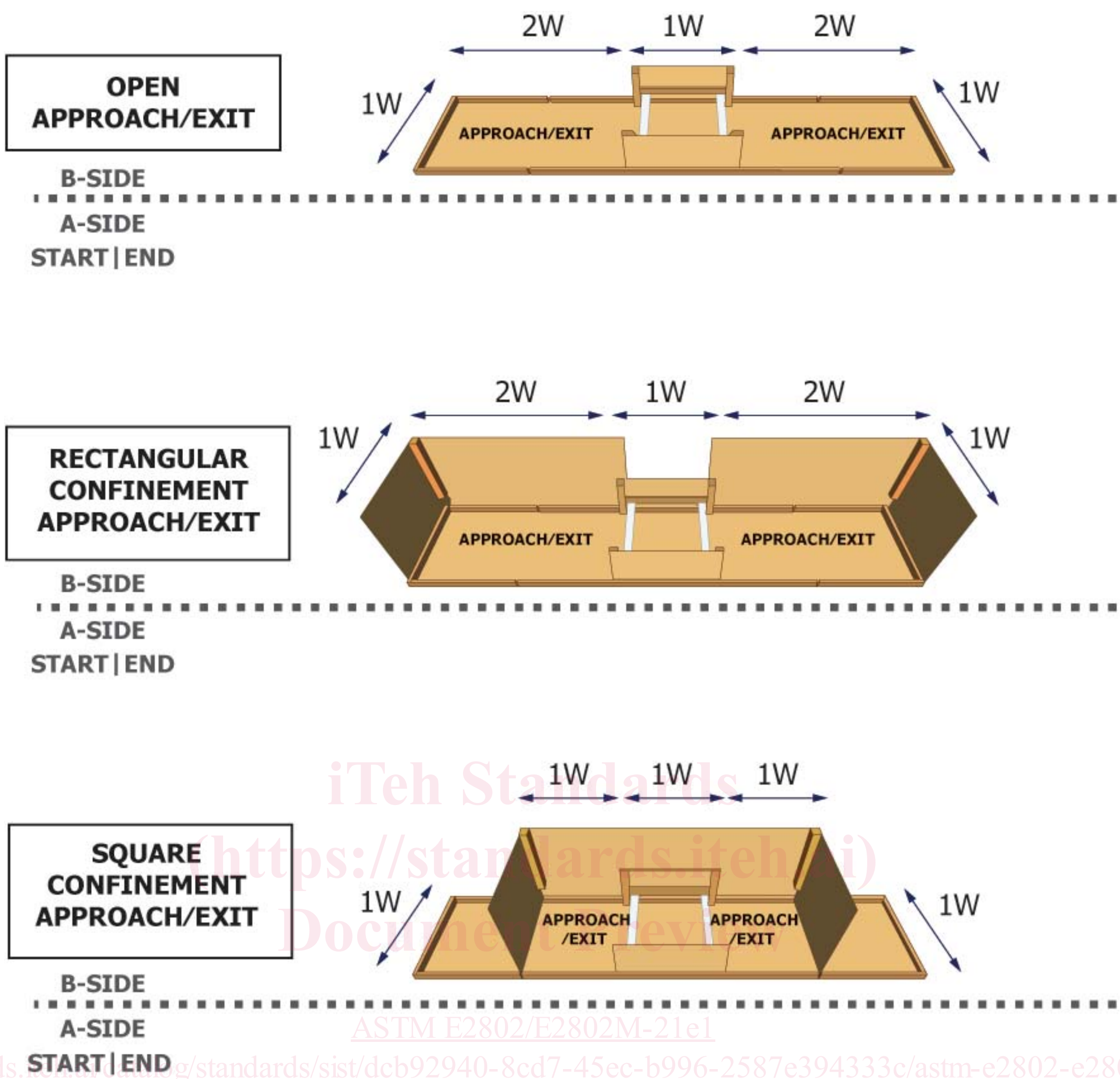

FIG. 4 Top View of a Test Apparatus showing the Dimensions and Labeled Open, Rectangular Confinement, and Square Confinement Approach/Exit Areas

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 [48 in.]†	10 cm [4 in.]	10 cm [4 in.]	H ± 12 mm [0.5 in.]
60 cm [24 in.]†	5 cm [2 in.]	5 cm [2 in.]	H ± 6 mm [0.25 in.]
30 cm [12 in.]†	2.5 cm [1 in.]	2.5 cm [1 in.]	H ± 3 mm [0.125 in.]

† Inch conversions editorially corrected.

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*—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).

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,

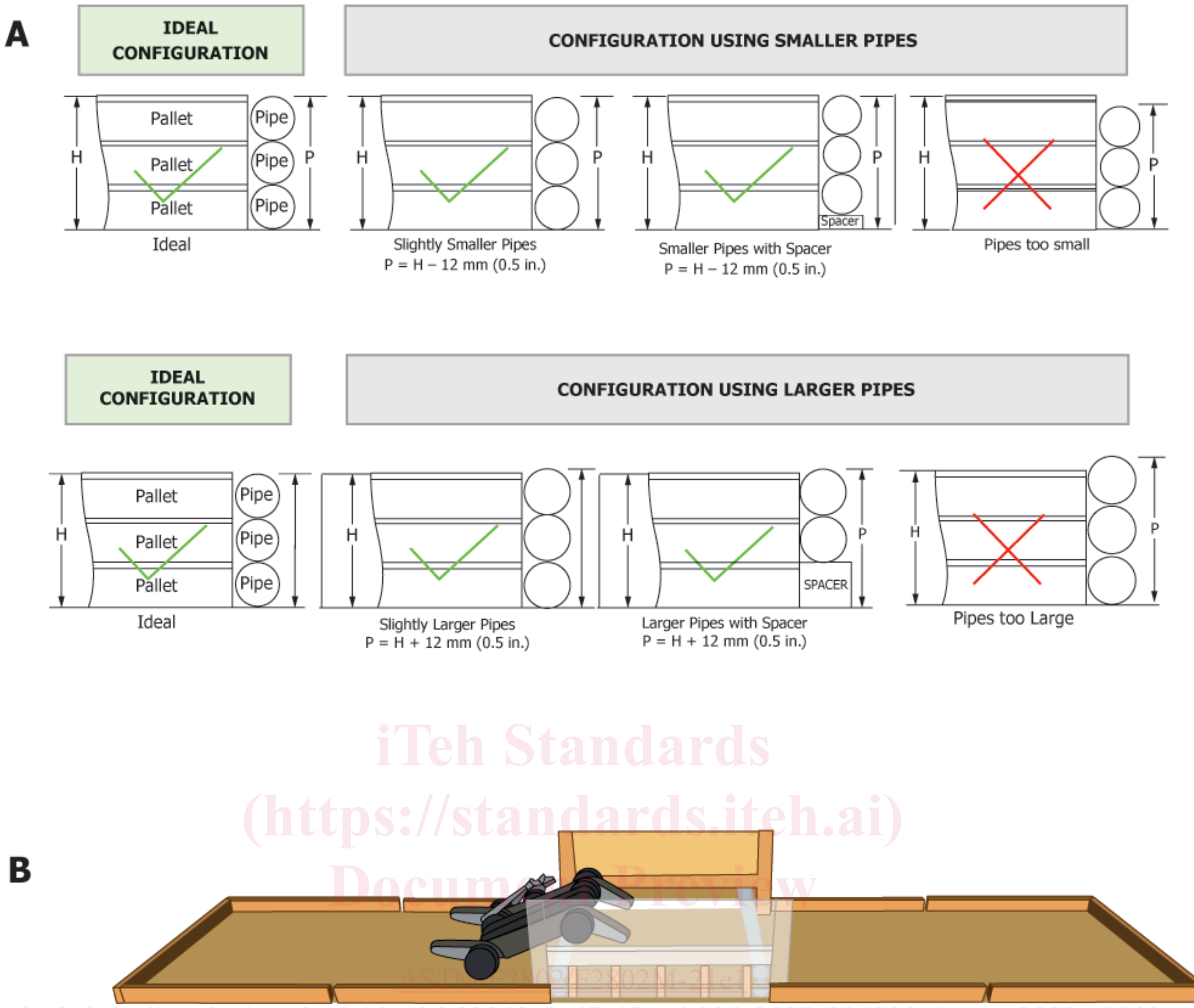

FIG. 5 (A) Configuration of Pipe Stacks
(B) Variable Hurdle Obstacle shown at Two Pallets High

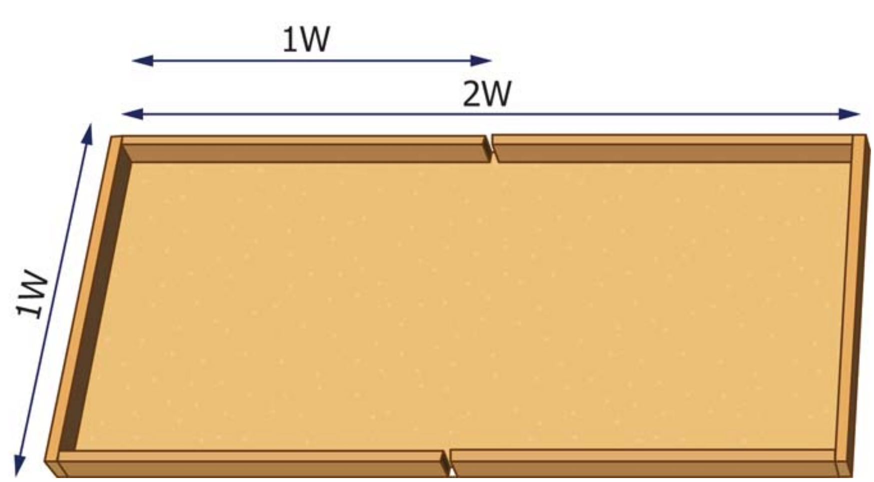

FIG. 6 Subfloor

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