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Standard Practice for Evaluating Response Robot Logistics: System Configuration[1]

This standard is issued under the fixed designation E3132/E3132M; 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 system is capable of performing specific missions in unstructured and often hazardous environments. These missions decompose into elemental robot tasks that can be represented individually as standard test methods and practices. The associated test apparatuses and performance metrics provide a tangible language to communicate various mission requirements. They also enable repeatable testing to establish the reliability of robot capabilities.

ASTM International Committee E54 on Homeland Security Applications specifies standard test methods and practices for evaluating such robot capabilities. These standards facilitate comparisons across robot models or various configurations of a particular robot model. They support robot researchers, manufacturers, and user organizations in different ways. Researchers use the standards to understand mission requirements, encourage innovations, and demonstrate breakthrough capabilities. Manufacturers use the standards to evaluate design decisions, integrate emerging technologies, and harden systems. User organizations leverage the resulting robot capabilities data to guide purchasing decisions, align deployment objectives, and focus training with standard measures of operator proficiency. Associated usage guides describe how such standards can be applied to support these various objectives.

The overall suite of the standards addresses robotic critical subsystems, including maneuvering, mobility, dexterity, sensing, energy, communications, durability, proficiency, autonomy, logistics, safety, and terminology. This practice is part of the logistics test suite and addresses the issue of identifying robot system configuration.

1. Scope

1.1 This practice, as a part of the response robot logistics test suite, specifies the requirements of identifying and documenting the configuration of a robot system under test as well as the associated processes for doing it. The aspects to be included in such a configuration practice are the key dimensions and weights, the existent subsystems and key components, as well as the key timing requirements for setting up and maintaining the system.

1.2 This practice applies to ground, aerial, and aquatic response robot systems controlled remotely by an operator from a standoff distance appropriate for the intended missions. Such robot systems may further possess certain assistive features or autonomous behaviors.

1.3 *Performing Location*—This practice may be performed anywhere the specific apparatuses are implemented and environmental conditions are met.

1.4 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard. Both units are referenced to facilitate acquisition of materials internationally and minimize fabrication costs.

1.5 *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.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the*

[1] This practice 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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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

E2830 Test Method for Evaluating the Mobility Capabilities of Emergency Response Robots Using Towing Tasks: Grasped Sleds

E2854 Test Method for Evaluating Emergency Response Robot Capabilities: Radio Communication: Line-of-Sight Range

E2855 Test Method for Evaluating Emergency Response Robot Capabilities: Radio Communication: Non-Line-of-Sight Range

3. Terminology

3.1 The following terms are used in this practice and are defined in Terminology E2521: administrator or test administrator, operator, operator station, response robot or emergency response robot, teleoperation, test event or event, test form, test sponsor, test suite, and trial.

3.2 The following terms are used in this practice and are defined in the *ALFUS Framework Volume I*: autonomous, autonomy, levels of autonomy, human-robot interaction, operator control unit (OCU), and semi-autonomous.[3]

4. Summary of Practice

4.1 This practice specifies a way in which a robot system's configuration shall be identified and documented.

NOTE 1—The resulting information is intended to provide the users, who could be responders, law enforcement officials, and soldiers, a quick and overall perspective of their response robot systems and help them make decisions on procurement, deployment, or operator training.

4.2 The particular system configuration to be tested shall be comprehensively identified and uniquely named by using the make, model, and applicable configuration name as provided by the manufacturer. This identification process includes measuring the time required to bring the system to the operationally ready state, called setup time. The process, then, involves measuring and documenting the dimensions and weights of all the subsystem, components, and as-shipped packaging. These include the robot, OCU, and other sustainment and maintenance items such as power sources and spare parts. This identification process also lists subsystems, payloads, and items in the field-maintenance kit. These include tools and consumable items such as duct tape, cable ties, and other items. Documentation shall also include detailed photographs of all of the above as well as videos of routine maintenance tasks (for example, battery change). The system configuration shall remain the same for all relevant tests to enable direct comparison of performance and to identify capability trade-offs between different configurations. Any number of identified system configurations can be subjected to testing.

5. Significance and Use

5.1 These basic requirements for response robots that help enhance the safety and effectiveness of responders or soldiers include: the robots are designed to be remotely operated from safe standoff distances, deployable at operational tempos, capable of operating in complex environments, sufficiently hardened against harsh environments, reliable and field serviceable, durable or cost-effectively disposable, and equipped with operational safeguards.

5.2 This practice aligns user expectations with actual capabilities to understand the inherent trade-offs in deployable systems at any given cost. For example, a design issue of the number of batteries to be packed on a robot could affect the desired weight, endurance, or cost. Appropriate levels of understanding can help ensure that requirement specifications are articulated within the limit of current capabilities.

5.3 This practice provides a tangible representation of essential robot capabilities with quantifiable measures of performance. It facilitates communication among communities of robot users and manufacturers. As such, this practice can be used to help:

5.3.1 Inspire technical innovation and guide developers toward implementing the combinations of capabilities necessary to perform essential mission tasks.

5.3.2 Measure and compare essential robot capabilities. This practice can help establish the reliability of the system to perform specified tasks, highlight break-through capabilities, and encourage hardening of developmental systems.

5.3.3 Inform purchasing decisions, conduct acceptance testing, and align deployment objectives with statistically significant robot capabilities data captured through repeated testing and comparison of quantitative results.

5.3.4 Focus operator training and measure proficiency as a repeatable practice task that exercises actuators, sensors, and operator interfaces. The practice can help capture and compare quantitative scores even within uncontrolled environmental variables and, in turn, help develop, maintain, measure, and track very perishable skills over time and enable comparisons across squads, regions, or national averages.

5.4 Although this practice is scoped for homeland security applications, it could be much more wildly applicable. However, it shall be the responsibilities of the respective practitioners to verify the extents of applicability of this practice to their domains.

6. Apparatus

6.1 As illustrated in Fig. 1, two walls and a floor of a neutral color and entirely marked with a 20 cm [8 in.] grid shall be used to provide a full and consistent background scale for

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

NOTE 1—The robot just fits within this booth; a larger booth would be necessary for any larger robot.

FIG. 1 Example of a Standard Environment in which a Robot May be Photographed for Documentation

photographing the robot system under test. Such walls are typically made of commercially available oriented strand board (OSB) or perforated hardboards.

6.1.1 The walls shall be large enough such that all parts of the object being photographed are covered.

6.1.2 Photographs shall be taken with a good quality digital still camera. A digital single-lens reflex or mirrorless large sensor camera is highly recommended.

6.1.3 To reduce perspective and optical distortion, photographs should be taken with as long a lens (or as "zoomed-in") as is practical within the confines of the available space.

6.1.4 It is recommended that studio strobe (flash) equipment be used to allow smaller apertures (increasing depth of field to ensure that the whole robot is in focus), reduce image noise, and provide better image clarity. Lighting should be soft (diffuse) rather than direct. This may be achieved by placing white sheeting across the ceiling and two open sides and positioning the strobes so that their light is reflected off the sheets rather than directed at the equipment being photographed.

6.1.5 As many video cameras as needed shall be used to document the entireties of the required operations, as specified in Section 8.

6.2 Commercially made weight scales and tape measures that are accurate to at least the tenth digit shall be used for the measurements as specified in Section 8.

6.3 Timing devices, such as stopwatches, shall be available to measure the lengths of time of required operations. The documented time may be verified by observing the corresponding video(s).

7. Hazards

7.1 Besides 1.5, which addresses common safety and health concerns, users of this practice shall also address equipment preservation as well as additional, specific safety concerns. In addition, environmental conditions, such as high or low temperatures and excessive moisture may also be stressful and cause damages to robot components or unexpected robot behaviors.

7.2 Identify all the emergency stop button(s) on the robot chassis and the OCU before operating or interacting with the robot.

7.3 While the robot is active and the emergency stop button is disengaged, avoid:

7.3.1 the areas directly in front of and behind the robot,

7.3.2 the reachable radius of the robot's manipulator, as equipped, and

7.3.3 touching the robot other than to engage the emergency stop button.

8. Procedure

8.1 *Identification Scope:*

8.1.1 The comprehensive configuration of a robot system that shall be identified and documented includes the robot, its OCU, and all the applicable subsystems or major components, accessories, and payload.

8.1.1.1 Keywords are recommended to be used for the documentation purposes. Such a practice facilitates identification of common characteristics among different robot systems and helps maintain consistent terminology.

NOTE 2—For example, the keywords "wheels" and "tracks" should be used as much as applicable to specify the locomotion mechanism.

8.1.2 All the manual adjustments and settings available to onboard subsystems or components shall be determined and set as such and shall remain the same throughout the entire set of the identified tests. Any further such adjustment(s) during testing constitutes a new testing configuration for the robot system.

8.1.2.1 Such specific settings and manual adjustment(s) and the processes of making them shall be documented in text, photos, or videos, or combinations thereof.

8.1.3 For US&R types of deployments, Practice E2592 standardizes procedures for identifying the volume and weight of cache packaging, robot system setup time, as well as tool requirements. Therefore, Practice E2592 shall be followed and the applicable, covered aspects shall not be repeated in this configuration process.

8.2 *System Configuration Identification and Setup Processes:*

NOTE 3—The purpose of this step is only to identify and document an overall perspective of a robot subsystem. When required, specific subsystem or component test methods are either available or being specified for testing their respective capabilities.

8.2.1 All the applicable subsystems shall be identified, documented, and verified to be functional. The associated setting up and maintenance procedures shall be identified, videotaped, photographs, and their respective lengths of time measured.

NOTE 4—Video recording and photographs help robot users understand and follow the processes.

8.2.1.1 Tables and pictures shall be used, in sufficient amounts, for every step within this process. Each picture shall have a descriptive caption that enables identification(s) of the subject subsystem or component(s), or both. The associated key characteristics shall also be marked on the respective pictures. Pictures shall also be used to enable identifications of the locations of the subsystems or components, or both, on the chassis or OCU. See Fig. 2 for an example.

NOTE 5—Schematic diagrams could also be added to help illustrate the respective features, such as specific dimensions.

8.2.2 *Packaging*—Identify and list all the packaging cases for the robot system:

8.2.2.1 Include a picture for each of the identified cases. See Fig. 3 for an example.

8.2.2.2 The documentation table shall include the information of the type, model, dimensions, and weight of each of the identified cases. See Table 1 for an example.

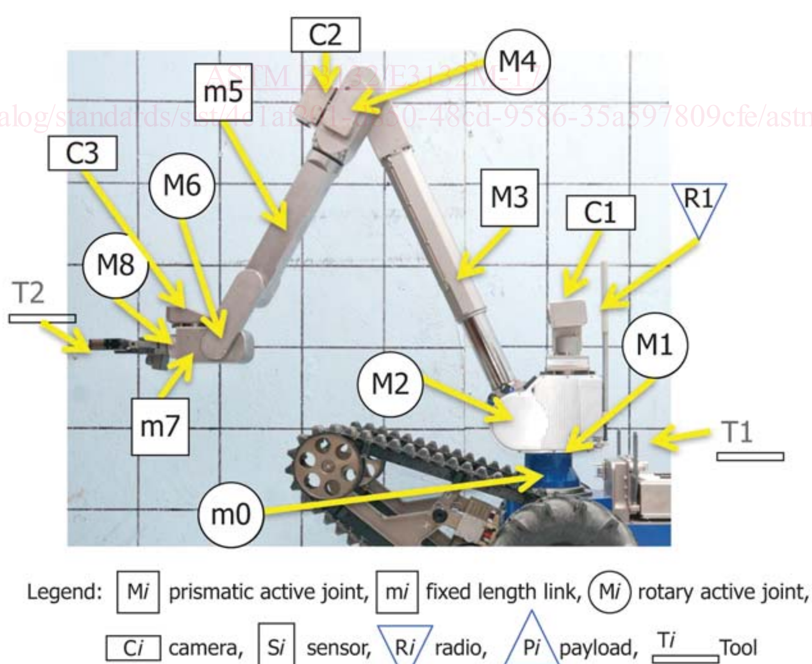
8.2.3 *Setup Time*—Measure the elapsed time—the time needed between when the robot system, while in its transportation packaging, is completely unloaded on the ground to when the system has been fully assembled and all the subsystem functions have been verified as functional.

8.2.3.1 Robot systems might arrive with various levels of readiness, from needing to be unpacked and assembled to being fully functional. Any application of 8.1.3 also affects the setup time. Any comparison of such setup time lengths shall take these differences into consideration.

8.2.3.2 The time spent on required manual adjustment(s) shall be included as a part of the setup time.

8.2.3.3 When errors occur during the process, correct them while leaving the timer running, note the errors, time of occurrences, and actions taken. Continue the setup process when possible until when either the robot system is ready or the process can no longer continue.

8.2.3.4 The test sponsor may choose to average the setup time among multiple test trials or among multiple operators' time results. Such choices shall be noted. The test sponsor could ask for this configuration identification process to be repeated when significant errors or anomalies occurred during the process and rendered the total time unrepresentative.



NOTE 1—The notations are for illustration purposes and users are free to choose their own.

FIG. 2 Key Subsystem and Component Identification

NOTE 1—All items in the system as they arrived on site for testing. They are staged in the photo booth with metered backdrop (20 cm [8 in.]). The chassis for the Remotely Operated Vehicle (ROV) under test is sitting on top of its packaging to show the correspondence. Each of the packages is clearly marked with a respective identification number, name, weight, type, and model.

FIG. 3 Packages

TABLE 1 Packaging Case Illustration

NOTE 1—Use as many tables as applicable.

<Number>	<Content>		
Type	<xxxxx>		
Model	<yyyyyyy>		
Weight		______kg	______lb
Length		______cm	______in.
Width		______cm	______in.
Height		______cm	______in.

TABLE 2 Mobility Configuration Illustration

Identifier	Type (Wheel/Track/ Legged)	Drive Control (Independent/ Synchronized)	Actuation (Fixed/Indexed/ Actuated)
Left track	Wheel	Independent	Fixed
Right track	Wheel	Independent	Fixed
Front left flipper	Track	Independent	Actuated
Front right flipper	Track	Independent	Actuated
Rear left flipper	Track	Synchronized	Indexed
Rear right flipper	Track	Synchronized	Indexed

8.2.4 *System Dimensions and Weight:*

8.2.4.1 All the linear dimensions, lengths, widths, heights, and weights of the robot, OCU, and associated equipment shall be individually measured and documented, including the information of:

(1) Configuration weight as tested for the robot, its battery, and its OCU.

(2) Base Dimensions, the length, width, and height of the robot, OCU, OCU screen, radio, battery, controller, and the reaches of its manipulator in the directions of forward, side, vertical, and diagonal.

(3) The degrees of freedom of the applicable subsystem(s)/component(s): end-effector or gripper, weapon, manipulator, etc.

8.2.5 *Safety Features*—This section shall have images showing the safety features of the systems and their locations on the chassis and OCU. Examples include emergency stop (E-Stop) buttons, warnings for pinch hazards, propeller guards, loss communication behavior, etc. Each picture shall have a descriptive caption that enables identification of the feature and its location on the chassis or OCU.

8.2.6 *Mobility*—All the mobility mechanisms, such as wheels, tracks, and flippers, shall be identified and verified as functional. See Table 2 for an example.

8.2.7 *Cameras*—Identify and document the following information:

8.2.7.1 Identifier or name of the camera as provided by the manufacturer.

8.2.7.2 Detection type:

(1) "EO" for electro-optical,

(2) "IR" for infra-red,

(3) "Thermal," or

(4) "Other."

8.2.7.3 Image type:

(1) "Color" for color,

(2) "BW" for black and white,

(3) "IR" for infra-red.

8.2.7.4 Field of View (degrees).

8.2.7.5 Zoom:

(1) "None"

(2) "Optical"

(3) "Digital"

8.2.7.6 See Table 3 for an example. Note the magnification power, such as 10×, as applicable and when known.

8.2.8 *Sensors*—Identify, verify, and document all the applicable onboard sensors except for the camera(s), including their respective capabilities. Such sensors include, but are not limited to, for the purposes of:

TABLE 3 Camera Configuration Illustration

Identifier	Type	Image	FOV	Zoom
Front Driving	EO	Color	90	None
Rear Driving	EO	BW	90	None
Elbow				Digital, 10×
Wrist				None
End-Effector				Digital, 4×
Thermal	Thermal	BW	40	None

8.2.8.1 Mobility/navigation, such as sensors for pitch, roll, range, and GPS.

8.2.8.2 Handling chemical, biological, radioactive, nuclear, or explosive (CBRNE) or search and rescue (might employ thermal or other types of sensors) tasks.

8.2.9 *Power*—Identify and document the power source(s), battery or otherwise, in terms of the type(s) and the number(s) of units to be used and respective capacity rating(s), including expected operating times. The associated and applicable components, such as charger(s), release(s), cover(s), and backup unit(s) shall be included.

8.2.10 *Radio Communication, As Equipped:*

8.2.10.1 Identify and document power level(s), frequency range(s), antenna type(s), and protocol for transmitting the control, video, or audio signals;

8.2.10.2 See Table 4 for an example.

8.2.11 *Tether Communication, As Equipped*—Identify and document power level delivered to the robot, total length, signal availabilities for control, video or audio or both, media type such as fiber or copper, spool diameter and weight when fully loaded, and illumination.

8.2.12 *Manipulator, As Equipped*—Identify, measure, and document the reaches of the applicable manipulator in the directions of forward, side, vertical, and diagonal, and degrees of freedom. See Table 5 for an example.

8.2.13 *Payload*—Identify and document the applicable payloads, including their purposes, the reaches in the directions of forward, side, vertical, and diagonal, and the degrees of freedom as applicable.

8.2.14 *Tools*—Identify and document the applicable tools. See Table 6 for an example.

8.2.15 All the applicable:

8.2.15.1 Ports for data, power, and others;

8.2.15.2 Operational indicators;

8.2.15.3 Mounting points for all of these components; and

TABLE 4 Radio Communication Configuration Illustration

Robot Systems	Frequency (MHz)	Power (mW)	Antenna Gain (dB)	Antenna Type (Omni/ Directional)	
Control					
Video					
Audio Tx					
Audio Rx					
OCU Systems	**Frequency (MHz)**	**Power (mW)**	**Antenna Gain (dB)**	**Antenna Type (Omni/ Directional)**	**Protocol (Analog/ Digital)**
Control					
Video					
Audio Tx					
Audio Rx					

TABLE 5 Manipulator Configuration Illustration

NOTE 1—Multiple lines could be used for a link/joint having multiple degrees of freedom.

Link/ Joint ID	Prismatic: Length in cm [in.]		Revolute (rotational): degree		Control: A: Active P: Passive M: Manual	Name	Note
	Min.	Max.	Min.	Max.			
m0	n/a	n/a	n/a	n/a			
M1	n/a	n/a					
M2			n/a	n/a			
M3							
...							

TABLE 6 Tools Configuration Illustration

After completed testing, list all tools in kit and used:	
Name	Quantity
Wrench	1
Duct Tape	1 roll

8.2.15.4 Carrying handles and tie-down points for the robot.

8.2.16 *Maintenance Procedures and Time:*

8.2.16.1 Videos to capture procedure, tools, and timing of typical maintenance:

(1) Track change

(2) Battery change

(3) Camera location change

(4) Charging the batteries

(5) Stowing and unstowing all the articulated components

8.2.16.2 Also list all the tools required to service, repair, and adjust the robot in the field.

NOTE 6—Figs. 4-6 illustrate a set of test forms that could serve an alternative for the documentation purposes.

8.3 *Photograph:*

8.3.1 Photographs and video recordings shall be sufficiently used to document the entire configuration identification process.

8.3.1.1 Close-up views shall include key steps or settings. Examples include, but are not limited to, proper ways to clean an onboard camera lens or control a particular robot function. Wide-angle views shall include the entirety of the robot system under test. Examples include, but are not limited to, when the system is in its as-shipped packaging, when the manipulator is in its full extension, etc.

8.3.2 To avoid variations in exposure and white balance, the existent manual settings for the photographing camera(s) shall be determined and fixed. When multiple robot systems are to be photographed for an event, it is recommended that a single set of settings be used for the consistency purposes.

8.3.3 The robot, OCU, all the included tools or equipment or both, and the applicable packaging shall be photographed, individually as well as collectively.

8.3.4 When certain spare robotic parts are normally carried during a deployment, the parts are recommended to be photographed and documented as well.

8.3.5 For a photograph of a robot in its entirety, all the subsystems shall be installed and are at their respective ready statuses or default positions or both. For example, when a robot