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U.S. ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATION PROCEDURE

*Test Operation Procedure (TOP) 2-2-540 30 June 2008
DTIC AD No.

TESTING OF UNMANNED GROUND VEHICLE (UGV) SYSTEMS

*This TOP supersedes TOP 2-2-540, dated 20 June 2002

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1. SCOPE.

This TOP describes a systematic approach to safety and performance testing of Unmanned Ground Vehicles (UGVs). The objective is to ensure that the design of each UGV includes positive measures to enhance system safety, and that hazards which could reduce system safety are eliminated or controlled to an acceptable level of risk. This overarching document will point to other TOPs or International Test Operation Procedures (ITOPS) for more detailed explanation of specific test activities.

1.1 Purpose.

The purpose of this document is to provide a systematic approach to testing UGVs in order to ensure that the overall safety of the system is adequate and that the performance of the UGV meets with expectations. It describes activities necessary to ensure safety is designed into the system under test. This document provides uniform procedures for developing and implementing a test methodology of sufficient comprehensiveness to identify hazards of a system and to verify performance of the system meets with system requirements.

1.2 Applicability.

This document is appropriate for application to UGVs regardless of size, mode of operation, or type of weapon employed. This document applies to tethered, remote-controlled, tele-operated, and autonomous controlled ground vehicles. Robotic systems addressed in this TOP cover the full spectrum from throwable systems weighing approximately a quarter pound up to 70 ton vehicles and range in capabilities from pure remote control or tele-operated systems to fully intelligent and autonomous systems. Any capabilities not under on-board human control such as weapons firing or vehicle movement are also covered by this document.

1.3 Activities Addressed.

The information contained herein applies to any testing of robotic systems, whether simply obtaining a safety release or conducting a formal developmental test program for systems acquisition. As with any test program, tailoring of test procedures to the specific needs of the system and its intended use are encouraged. This document also applies to the experimentation and demonstration of robotic system capabilities. Although many sections of this document may not apply, all safety related sections still apply, as the safety of personnel and avoidance of damage to vehicles, equipment, and facilities near robotic systems must be assured.

1.4 Limitations.

a. This document is only for testing of UGVs. Methodologies for testing of Unmanned Aerial Vehicles (UAVs) or Unmanned Submersible Vehicles (USVs) are not covered in this document. This document does not apply to automated subsystems that do not directly affect people or objects outside of the vehicle such as automated internal weapon loading systems or automated tracking subsystems, nor to automated driver-assist functions that require full-time on-board driver attention to perform a task such as cruise control, anti-lock brake systems, or self-leveling systems.

b. This document is applicable to testing of multiple UGVs working in the vicinity of each other; however, testing of multiple UGVs working in cooperation is not addressed in this document.

1.5 Introduction to UGVs.

1.5.1 Need and Roles for UGVs.

UGVs are robotic platforms that are used as an extension of human capability. These robots are generally capable of operating outdoors and over a wide variety of terrain, functioning in place of humans. UGVs are generally used to complete tasks that are, from a human perspective, dull, dirty, or dangerous. Tasks such as reconnaissance, explosive ordnance disposal, mine clearing, and logistic resupply are typical examples of jobs suited for UGVs. Due to the wide range of tasks that can be accomplished with UGVs, there are necessarily a wide range of types of UGVs; however, the general principles for testing UGVs can be applied regardless of UGV type.

1.5.2 UGV Categories.

UGVs can be generally defined based on three categories: size, mode of operation, and weapon type.

a. Size

(1) MicroUGV: An unmanned ground vehicle weighing less than 10 lbs.

(2) SUGV: (Small Unmanned Ground Vehicle): An unmanned ground vehicle weighing less than 200 lbs.

(3) MUGV (Medium Unmanned Ground Vehicle): An unmanned ground vehicle weighing between 200 and 2,000 lbs.

(4) LUGV (Large Unmanned Ground Vehicle): An unmanned ground vehicle weighing more than 2,000 lbs.

b. Mode of operation

(1) Tethered: A mode of control wherein the human operator controls the UGV through a direct, wired connection. An example of such connection would be a fiber optic cable. Typically a line of sight (LOS) must be maintained under tethered operation; however, under certain circumstances, a LOS isn't necessary (i.e., operation in tunnel, around corners, etc).

(2) Remote Controlled**:** A mode of control wherein the human operator must dedicate 100 percent of their attention to system operation without benefit of sensory feedback from the vehicle. A LOS must be maintained with the vehicle under remote control operation.

(3) Teleoperated: A mode of control wherein the human operator has control of the UGV through cues provided by video, audio and digital feedback. The human operator controls the UGV through a wireless connection transmitted over radio frequencies (RF). The human operator must dedicate 100 percent of their time to operating the UGV. A LOS does not necessarily need to be maintained under tele-operation.

(4) Autonomous: A mode of control wherein the UGV is self-sufficient. The human operator can program a mission for the UGV, but the UGV will execute the mission without any human interaction. There are varying levels of autonomy in regards to the level of human interaction with the UGV.

(5) Semi-autonomous: A UGV that has multiple modes of control occurring simultaneously to include at least one autonomously controlled function. The level of semi-autonomy can vary greatly from UGV to UGV and will tend to be used extensively on weaponized UGVs (i.e. a weaponized UGV equipped with an Autonomous Navigation and Obstacle Avoidance System, but with tele-operated, operator controlled weapon functions).

(6) Manned: A mode of control wherein the UGV is directly controlled by a human operator through the use of a steering wheel, etc.

c. Weapon type

(1) Weaponized, projectile: A UGV equipped with any device that launches a projectile (i.e., machine gun, smoke grenades, lane markers).

(2) Weaponized, non-projectile: A UGV equipped with any energetic device that can affect the area around the vehicle without launching a projectile (i.e., acoustic, laser, sonic devices)

(3) Weaponized, non-lethal projectile. A UGV equipped with a weapon or device that launches a non-lethal projectile (i.e., rubber bullets, pepper balls, netting, paint balls, etc.)

(4) Non-weaponized: A UGV not equipped with a weapon or device that affects the environment around the vehicle.

2. FACILITIES AND INSTRUMENTATION.

2.1 Test Facilities and Conditions.

a. Existing test facility types should be used when possible. It is necessary to consider all types of climatic and environmental conditions in a great variety of soil types. The tester should consider the effects of operating on primary roads, secondary roads, cross-country terrain, and the ability to operate in and around natural and man-made obstacles. The tester should also consider the effects of high and low temperature extremes, humidity, snow, freezing rain, sand, dust, vibration, and electromagnetic interference. Instrumentation and system operational equipment procedures for each facility should be created and may vary based on the type of equipment being tested.

b. Courses that are being used for UGV testing must be accurately digitally modeled in order to be used to verify the UGV cognitive abilities when applicable. This digital model will be used as the “control” that can be compared to the UGV’s perception in order to determine if there are variances between the UGV’s perception and what actually exists. These facilities must be accurately instrumented and calibrated to include RF and meteorological monitoring stations in order to accurately depict changing conditions of the course.

c. Dedicated UGV test courses should be equipped with complete video coverage of the entire course in order to record mishaps and incidents while also providing situational awareness to personnel monitoring the test from a safe location.

d. UGVs should be tested in facilities where there are no other experimental systems under test.

2.2 Instrumentation.

a. A wide range of instrumentation must be available to measure the performance of the components, subsystems, sensors, algorithmic processes, and telemetric links, and to capture required data. This data will be used not only to verify the performance and safety of the vehicle, but also to validate system models which can then be used to create larger data sets to complement physical testing. Therefore, when designing the instrumentation package for the system under test, data required to validate system models must considered.

b. In general, instrumentation will continue to be used in traditional physical test roles to gather pertinent component level data using accelerometers, thermocouples and the like.

c. Additional instrumentation requirements must be considered when testing UGVs. UGVs will rely extensively on sensors to provide information regarding the environment in which the UGV is operating. Data instrumentation packages must be able to pull information from the sensors prior to manipulation of that information by the UGV algorithmic processes as well as processed information such as the perception map, decisions about the map, and planned actions.

d. In order to understand how the UGV uses the sensor information it receives to make decisions, data log files of the UGVs algorithmic process will be recorded. This information can be used to understand why and how the UGV made its decisions. This information also will be used to validate system models and will allow for test repeatability that would not normally be available without this information.

e. Following execution of the UGVs algorithmic processes, there will be outputs to the vehicle subsystems generally based on the UGVs "worldmap" or perception of its environment. Data instrumentation packages must be used to capture this perception and outputs to the system in order to determine the accuracy of the UGVs perception and the correctness of its response.

f. Generally, UGVs will export their view of the world to an external controller or System of Systems. Testers must have access to the same vehicle-created worldmaps that are being used by system developers. Data instrumentation packages should be used to capture information as it's sent from the UGV, and as it's received by the external controller, in order to determine if there is degradation in information quality caused by or occurring during the information transfer.

g. A redundant emergency stop (E-stop) with an independent power supply will be installed on each UGV.

h. A strobe light, which will activate when the UGV engages in remote or autonomous operations, will be installed.

i. The use of three dimensional (3D) viewers and system models may be needed to monitor vehicle states and projected path or weapon footprints for safety purposes.

j. Real Time and Near Real Time Analysis Displays. Testers need access to information to ensure the safety of all test personnel, to protect the test article as much as possible, and to ensure that the test unfolds as planned. Examples may include temperature profiles of critical components, comparisons of true and perceived world maps, vehicle planned paths, the states of weapons and payloads, actual and predicted data link quality, and other information as determined by the test director.

k. For Micro UGVs, SUGVs, and small MUGVs, the data acquisition/instrumentation package must be small enough so as to not affect the performance of the UGV under test.

2.3 Modeling and Simulation.

a. Data Link Prediction. Testers may use RF propagation prediction tools for some systems to predict the areas where the data link may be marginal or unacceptable for the test article and E-Stop systems. This information helps the tester maintain positive control of the UGV at all times and to ensure that a valid test is conducted.

b. 3D Models. As a part of test planning, testers may use 3D models of the vehicle and the test area to ensure that the vehicle is properly presented with challenges. Avenues of approach may be adjusted accordingly during the test planning process to achieve test objectives. These models may also be used during test execution to support monitoring UGV performance. This is especially important in areas of difficult terrain or where obscurants are present.

3. REQUIRED TEST CONDITIONS.

3.1 Test Item Configuration.

a. The item should be tested at system, subsystem, and component levels. Each discreet, identifiable component or subsystem should be tested and measured for overall contribution to the system. Sufficient testing should be conducted to demonstrate that the operator, software, vehicle platform, control unit, and mechanical operating devices and applications can work effectively together. Knowledge of software versions is critical to successful conduct of developmental testing. The test instrumentation suite should be selected based on the objective of the test and the data required. Individual components should be instrumented when required.

b. For a UGV, the main components addressed for system level testing are referred to in this document as the human operator, vehicle platform, software, operator control unit (OCU), Mobile Base Unit (MBU) or vehicle control unit (VCU), RF links, video links, tethered links, mechanical operating devices, and the application hardware.

(1) The human operator controls the platform either remotely with an RF or tethered link or programs commands for autonomous operation.

(2) Software is used as artificial intelligence to control functions and coordinate the activities of other components.

(3) The vehicle platform provides mobility.

(4) The OCU is the remote work station for the human operator that enables remote control of selected driving and associated functions.

(5) The MBU or VCU interface between the OCU and the mechanical operating devices on the UGV. RF, video and tethered links establish communication between the UGV and the command vehicle.

(6) The application hardware is the means to perform the specified task of the UGV.

3.2 Test Planning.

a. Test planning should be initiated early in the acquisition process in order to yield the most cost effective approach to decision risk mitigation. Component and subsystem level testing should be conducted throughout the development of the system. Each version must demonstrate effective support/operation of the system. The level of testing should be carefully considered. System level testing should be conducted whenever an operational system is available. Performance of the individual components should be determined during system level testing to confirm design goals. All subsystems and components should be individually qualified prior to integration into the system. Software is a critical component that must be rigorously tested.

b. Testing should be conducted to demonstrate that the logistics concept is adequate. Issues in the areas of maintenance, transportation, and storage must be addressed along with availability, accuracy, and comprehensibility. A logistics demonstration should be conducted with the system and representative soldiers who will perform maintenance on the system. Transportability testing is required to support the Military Traffic Management Center Transportability certificate.

c. Test planning should address the following:

(1) Purpose of testing.

(2) Test objectives.

(3) Test criteria.

(4) Test method.

(5) Data required.

(6) Data analysis techniques.

d. Criteria for each subtest data topic will be defined based on applicable contractual specifications and military requirements documents. Where the criteria are not clearly specified, criteria will be developed from the relevant ITOP, TOP, MIL-STD, federal statute, or other controlling document. Development of criteria should consider the logistics concept, employment concept, intended application, novel technologies, and threat environment as appropriate. Failures and successes should be defined to provide for a clear understanding of relevant conclusions for certain subtest data topics (i.e., reliability, performance, climatic suitability, electromagnetic interference, and safety).

e. Data requirements and analytical techniques necessary to address objectives and criteria will be established. It should be established which data requirements will be satisfied through physical test, and data sheets for each subtest data topic should be designed.

f. Appropriate test procedures for each subtest topic relative to objectives, criteria, and data requirements should be selected.

g. As a tool to audit, change, or summarize the test program, it is desirable to layout all events and data requirements in matrix format. As applicable, the test matrix should have a cell for each test objective, criteria, component, subsystem, system test event, item configuration, data requirement, and analytical technique. Multiple matrices, each of which is linked, may be required. Identify any unique resources necessary to conduct subtests.

h. How modeling and simulation will be used to answer test objectives should be identified within the detailed test plan.

3.3 Frequency Allocation.

a. The UGV Test Director is responsible for requesting frequency assignments from the local frequency manager in the proposed area of deployment. The local frequency manager receiving the frequency assignment application will process it through established channels to request appropriate national and/or international approval. The disposition of the frequency assignment request will be channeled back to the user. The request may be approved, disapproved in total, or approved in part with operating limitations. The information presented in Appendix A of this document must be provided by the test proponent in order to submit the appropriate frequency allocation request form.

b. This information must be provided by the test proponent no less than 120 days prior to the start of testing in order to ensure approvals are obtained within the desired schedule. This information must be provided for each transmitter and receiver.

3.4 Supporting Documents.

a. In order to properly assess the safety, performance and reliability of a UGV, a detailed documentation review must be conducted. This documentation review provides a more thorough understanding of UGV characteristics and in some instances can reduce the amount of physical testing required and can assist in reducing the assigned risk assessment code reported in safety releases. The documentation review is required in order to ensure that proper safety protocols are emplaced prior to initiation of testing. The following documents should be included in the test item data package; it is preferable that these documents be provided as early as possible prior to the start of testing. A documentation review checklist is presented in Appendix B.

(1) Safety Assessment Report (SAR) - Required Document - The SAR is a formal, comprehensive safety report that summarizes the safety data that has been collected and evaluated during the life cycle of an item. It expresses the considered judgment of the contractor or developing agency regarding the hazard potential of the item and any actions or precautions that are recommended to minimize these hazards and to reduce the exposure of personnel and equipment to them. In addition, US Army Center for Health Promotion and Preventive Medicine (CHPPM) certifications must be provided for lasers, and Material Safety Data Sheets (MSDS) must be provided for batteries, fuels, etc.

(2) Preliminary Hazard Assessment (PHA) - Required Document - Broad hazard-screening tool that includes a review of the work that will be performed in a facility and identifies the hazards associated with the work and the facility. The results of the PHA are used to determine the need for additional, more detailed hazard analysis, serve as a precursor documenting that further analysis is deemed necessary, and serve as a baseline hazard analysis where further analysis is not indicated.

(3) Software Requirements Specification (SRS) – Required Document - Complete description of the behavior of the system to be developed. It includes a set of use cases that describe all of the interactions that the users will have with the software. Use cases are also known as functional requirements. In addition to use cases, the SRS also contains nonfunctional (or supplementary) requirements. Non-functional requirements are requirements which impose constraints on the design or implementation (such as performance requirements, quality standards, or design constraints).

(4) Capabilities Requirements Document (CRD) /Operational Requirements Document (ORD) - Required Document - Describes the overall mission area, the type of system proposed and the anticipated operational and support concepts in sufficient detail for program and logistics support planning and includes a brief summary of the mission need. If the mission need was not documented prior to preparation of the CRD/ORD, the process that investigated alternatives for satisfying the mission need and developing the operational requirements is explained.

(5) Performance Specification/System Specification/Purchase Description - Required Document - Communicates the user's requirements to the manufacturer. These documents translate operational requirements into more technical language that tells the manufacturer: 1) what will be considered an acceptable product, and 2) how it will be determined if the product is acceptable.

(6) Security Classification Guide - Required Document - A documentary form of classification guidance issued by an original classification authority that identifies the elements of information regarding a specific subject that must be classified and establishes the level and duration of classification for each such element.

b. Programmatic documents that were developed for the system, or those preexisting documents that apply, should be used to identify test criteria. These documents define the mission scenarios, climatic conditions, operational, and electromagnetic environments in which the item must operate. Documents that should be used to establish test criteria include:

(1) Operational Mode Summary/Mission Profile.

(2) Operational Requirements Document/Capabilities Requirements Document.

(3) Purchase Description/Performance Specification/System Specification.

(4) Military Regulations, Standards and other controlling directives.

(5) Federal Statutes.

(6) Test Directives.

c. The following documents are desired if they are available:

(1) Developer Software Functional Qualification Test Plans and Reports.

(2) Component Level Test Plans and Reports.

(3) System Operator Manuals.

(4) System Maintenance and Repair Manuals.

(5) Software Trouble/Problem Reports.

(6) System Safety - Critical Software Requirements.

(7) Software Traceability Analysis.

(8) Data Tap Locations and Interface Definitions.

(9) Software Design/Development Documents.

(10) Message Protocols/Definitions.

(11) Programmatic Environmental, Safety, and Health Evaluation.

(12) Configuration Management Plan.

(13) Interface Control Document.

(14) Operational Mode Summary/Mission Profile.

3.5 Test Controls.

Test controls are listed for each subtest data topic in accordance with the applicable ITOP, TOP or military standard (MIL-STD).

3.6 Safety.

a. Historically, UGVs have a high incidence of uncontrolled movement caused by various means including RF interference, mechanical failures, software design issues, etc. Given this historical precedent, additional precautions must be taken with regard to tester safety that would not normally be required for a manned vehicle test. The safety of individual components and subsystems must be demonstrated prior to conducting a system level test. All components must be safe or the hazards controlled to an acceptable level.

b. Additionally, a complete safety and health hazard analysis should be made throughout the course of the test. During the initial inspections and maintenance, observations should be made through visual examination and functional checks for compliance in design to assure personnel safety. During the course of testing, any potential hazard observed during operations or maintenance actions must be recorded. All scheduled subtests should be considered in the overall safety and health assessment.

c. A complete and detailed analysis of system software, software development documents, and software test results must be conducted prior to the start of actual physical testing.

(1) Early involvement by testers in system software development is required in order to validate the capabilities, robustness, and safety features of the software. A thorough understanding of the contractor's software development process, hazard analysis, software test results, and software trouble reports will lead to an accurate assessment of the residual risk inherent in the system's software controls and processes.

(2) Clear, accurate documentation of software version updates/revisions and of regression testing of software version updates/revisions is required during all phases of testing.

d. Specific tests to determine the mechanical, software, and operating safety of the entire system can be completed only after all component subsystem testing has been completed or adequate provisions have been taken to prevent any accidental injury or damage.

e. The concept of a UGV locates the operator away from the platform; therefore, control must be maintained when the telemetric link between the remote operator and the vehicle is lost, an unanticipated event occurs, or an unsafe condition exists. As a minimum, the system must demonstrate the ability to safely stop when any uncontrolled event or unsafe condition occurs. All emergency and fail-safe systems must be tested, and their reliability must be determined.

f. In situations during testing when safety related decisions must be made, the well being of personnel, buildings, and vehicles should be placed above that of the test item.

g. The number of personnel in the test area shall be limited to those test critical personnel necessary to accomplish the test mission safely and efficiently. Observers and spectators shall remain outside of the hazardous operating zone of the system at all times until the system is rendered safe and verified to be safe to approach.

h. Prior to shipping the test item, or transporting it between local test sites, a safety assessment must be performed. Specific items to be considered include loading and unloading procedures and transportability characteristics of the test item. UGVs will not be permitted access to test agency roadways, and therefore a plan must be in place to transition the test item from test site to test site.

i. Until the safety envelope has been determined by operating the item near the maximum safe limit, a thorough understanding of what the operator/maintainer has to do with, on, in, and around an item is unknown and critical hazards could exist. This is especially true of software controlled systems, where unpredictable and unsafe responses may result from computer failure, maintenance interlocks, power failures, and power-up tests (DA PAM 73-1[1**], para 6-63).

j. The tester should identify the software components that control safety-related functions and give them special attention. Software safety activities should be initiated on that component and continued through the requirements, design, code analyses, and testing phases. The tester also might identify the need for a more formal evaluation of software safety, based on the probability that the software might cause or fail to prevent failures in a safety-critical system component (DA PAM 73-1, para Q-26.b).

k. Although remote operators may be highly trained before using a system, training is not a sufficient preventive measure or work-around in most cases for safety related issues. Products of safety related testing include documentation of: conditions in which the system can and cannot be safely operated; and the propensity for the total system to enter unsafe operating conditions.

[**] Superscript numbers correspond to those in Appendix C, References

l. A Safety Release indicates a system is safe for use and maintenance and describes the specific hazards of the system, operational limits, and required precautions (DA PAM 73-1, Paragraph 6-64.b). The Safety Release will have a specific start and end date, and is only valid for a specific time period or event. A Safety Confirmation indicates if specific safety requirements are met, includes a risk assessment for hazards not adequately controlled, lists technical or operational limitations or precautions, and highlights safety problems that require further investigation (DA PAM 73-1, Paragraph 6-65). The Safety Confirmation indicates the system is ready for fielding, has a specific start date, and is valid indefinitely. The scope of testing to obtain a safety release and confirmation is dependent on a number of factors to include:

(1) Objectives of the test, demonstration, or experiment.

(2) Intended use of the robotic system.

(3) Types of payloads, attachments, or weapons associated with the system.

(4) Modes of control.

(5) Relative positions of people with respect to the system (spectators, casualties, remote operators, warfighters on the ground, manned vehicles, etc.).

(6) Functionality and reliability of the render safe system

(7) Contractor software development processes

(8) Analysis of contractor software test results and software trouble reports

m. Ensure that the necessary Risk Assessment is accomplished relative to the safety of the system prior to testing. This should include the following:

(1) All platform and application hardware will be investigated for safety prior to operating the vehicle in an unmanned mode.

(2) Prior to test initiation, a SAR, which includes a health hazard assessment of the UGV, must be submitted by the developer. Particular emphasis should be placed on radio frequency interference/hazards as well as the safety implication of embedded software controls.

(3) A detailed Failure Modes and Effects Analysis (FMEA) must be performed to evaluate the safety implications of the failure of the hardware and/or software. All hazards identified will be evaluated and categorized according to hazard severity and probability. Resolution of hazards may be addressed through design, procedures, or training. Hazards should be characterized by severity category and probability level in accordance with MIL-STD-882[2].

(a) Severity Categories. The severity categories as defined in MIL-STD-882 provide a qualitative measure of the worst credible mishap resulting from personnel error, environmental condition, design inadequacies, procedural deficiencies, or component failure or malfunction. Hazard categories are as follows:

1 Category I. Catastrophic hazard that could result in death or system loss.

2 Category II. Critical hazard that could result in severe injury, severe occupational illness, or major system damage.

3 Category III. Marginal hazard that could result in minor injury, minor occupational illness, or minor system damage.

4 Category IV. Negligible hazard that could result in less than minor injury, occupational illness, or system damage.

(b) Probability Levels. The probability levels rate the categories in terms of probability for occurrence per unit of time, events, population, items, or activity. These are as follows:

1 Level A. Frequent. The hazard would be likely to occur frequently for a specific individual item or be continuously experienced by the fleet or inventory.

2 Level B. Probable. The hazard would occur several times in the life of a specific individual item or would occur frequently for the fleet or inventory.

3 Level C. Occasional. The hazard is likely to occur some time in the life of a specific individual item or will occur several times for the fleet or inventory.

4 Level D. Remote. Unlikely, but possible, for the hazard to occur in the life of a specific individual item or unlikely, but reasonably expected, for the hazard to occur for the fleet or inventory.

5 Level E. Improbable. So unlikely that it could be assumed that the hazard may not occur for a specific individual item or the hazard is unlikely, but possible, to occur for the fleet or inventory.

(4) Assure that the proper training for the operation of the system is provided to the testers and operators. It is imperative that the emergency shut down procedures are emphasized in this training. An operator must be well trained in what to do should a problem occur.

(5) Upon receipt of the test item, select a suitable offloading site that provides positive controls to prevent injury or damage in the event of uncommanded movement.

(6) Wherever possible, conduct non-mobile tests where the UGV is prevented from moving (i.e., elevated on jack stands) prior to conducting tests on course. Tests on actual courses should not be attempted before a reasonable level of confidence has been achieved that the UGV will not have uncommanded movement. Instrumentation should be used to simulate various environments in a static setting. An example would be using attenuators to reduce RF signal strength in order to determine if there is uncommanded movement of the UGV when receiving a weak RF signal.

(7) When determining the safety characteristics of a tethered UGV, conduct the test in an area where there is a physical barrier (i.e., Jersey walls) between the UGV operator and the UGV. The physical barrier must be substantial enough to prevent the UGV from entering the area around the operator in the event of uncommanded movement. Once sufficient confidence has been achieved as to the reliability of the tethered controller, the barriers may no longer be necessary. The safety characteristics of the tethered controller must be determined prior to operating a tethered UGV around personnel or into and out of shops and work areas.

(8) The UGV must be outfitted with an independent emergency shutdown. This E-stop device must be separate from the onboard computers and is provided as backup to the integrated emergency shutdown device. The backup system must be capable of performing emergency shutdown of the UGV on command from an independent observer. This feature must be completely independent of the OCU and VCU and any onboard computers that are part of the UGV command and control system. This independent emergency shutdown system should be capable of being operated by an occupant in the command vehicle, an independent observer in another vehicle (i.e., chase vehicle) or by an observer in a location away from the command vehicle. In addition to the emergency stop, the platform brakes must be applied by a failsafe, mechanical device.

(9) Medium and large UGVs should be fitted with a strobe light, which indicates the test item is under remote control (at Aberdeen Test Center (ATC), a blue light will be used; at other test centers, a standout color that is not already allocated for another use will be chosen). This light will activate whenever an operator logs into the vehicle or whenever the vehicle is functioning robotically. The UGV should also be fitted with an audible alarm which activates whenever the UGV is beginning to move.

4. TEST PROCEDURES.

a. The following table provides a list of test procedures and data required that should be considered when designing a comprehensive UGV test.

Subtest	**Method**	**Description**
	Characteristics	
Preliminary Inspection	TOP 2-2-505[3]	Provides inspection and baseline operation prior to initiation of testing. Ensures test item is safe and ready to initiate testing.
Physical Characteristics	TOP 1-2-504[4]	Determines dimensions and other physical characteristics of the test. Physical characteristics data are critical data used in mobility analyses and transportability.
Weight Distribution and Ground Pressure	TOP 2-2-801[5] ITOP 2-2-801(1)[6]	Determines weight distribution and ground pressure measurements. Ground pressure measurements are critical data used in mobility analyses, tire performance, and transportability.

Subtest	Method	Description
Center of Gravity	TOP 2-2-800[7] ITOP 2-2-800(1)[8]	Provides information relative to roll stability, transportability, and input to mobility model programs.
Stowage	TOP 2-2-802[9]	Determines adequacy of on-board equipment stowage facilities in or on vehicles.
Transportability	ITOP 1-2-500(1)[10] TOP 1-2-500[11]	Determines transportability characteristics of military equipment. Includes highway, marine, air (rotary and fixed wing), and rail transport as well as lift and tie-down provisions.
Rail Impact	TOP 1-2-501[12]	Determines structural integrity of the test item as well as the adequacy of the tie-down system and tie-down procedures.
Final Inspection	TOP 2-2-505	Provides inspection and baseline operation following completion of testing
	Performance	
Acceleration/Max Speed	TOP 2-2-602[13] ITOP 2-2-602(1)[14]	Determines vehicle performance and safety characteristics while accelerating. Determines vehicle maximum safe speed capability.
Braking	TOP 2-2-608[15] ITOP 2-2-627(1)[16]	Determines vehicle performance and safety characteristics while braking.

Subtest	Method	Description
Grades and Slopes	TOP 2-2-610[17] ITOP 2-2-610(1)[18]	Determines vehicle performance and safety characteristics while operating on longitudinal and lateral slopes.
Steering and Handling	ITOP 2-2-609(1)[19] TOP 2-2-609[20]	Determines performance and safety characteristics of vehicle steering systems.
Standard Obstacles	TOP 2-2-611[21] ITOP 2-2-611(1)[22]	Determines vehicle performance and safety characteristics while operating on standard obstacles to include gaps, walls, v-ditch, aircraft loading ramps, and frame twisting.
Fording	TOP 2-2-612[23] ITOP 2-2-612(1)[24]	Determines vehicle performance and safety characteristics while fording. Includes shallow, deep, and submerged fording.
LOS/NLOS	TOP 2-2-543[25] (proposed)	Determines operating and safety characteristics of tele-operated and remotely operated unmanned ground systems while operating at their maximum telemetric ranges.
Soft Soil Mobility	TOP 2-2-619[26] ITOP 2-2-619(1)[27]	Determines vehicle performance and safety characteristics while operating in soft soils. Includes mud, sand, snow, swamps, wet clay, and rice paddies.
Winch and Tow Performance	TOP 2-2-712[28]	Determines performance and safety characteristics of automotive winches.

Subtest	Method	Description
Drawbar Pull	TOP 2-2-604[29] ITOP 2-2-604(1)[30]	Determines vehicle power available for acceleration, towing, or hill climbing.
Full-Load Cooling	TOP 2-2-607[31] ITOP 2-2-607[32]	Determines cooling characteristics of engine, power train, and auxiliary components of vehicles when subjected to full- and part-throttle operations, repeated steering maneuvers, and exposure to extreme environments.
Software Performance	ITOP 1-1-056[33]	Used to evaluate a system's software functional capabilities. It does not specifically address other software-related issues, such as safety or security. The method for undertaking the software performance assessment discussed in this document addresses software T&E as an integral element of system T&E and is targeted at the system performance level. Key elements of this approach include the allocation of system requirements to software, assessment of software performance, and assessment of the impact of software on overall system performance.

Subtest	Method	Description
Autonomous Navigation	TBD	Used to evaluate the safety and performance of UGVs equipped with Autonomous Navigation and Obstacle Avoidance subsystems. This procedure includes methods to evaluate way-point navigation, obstacle detection and avoidance, and human detection and avoidance. This TOP is not yet developed.
Electric System Performance	TOP 2-2-601[34]	Provides procedures for evaluation vehicle electrical system performance including power supply for weapons and other subsystems.
Position Locations and Navigation System	TOP 6-2-598[35]	Used to determine the performance and accuracy of integrated position location and navigation systems.
C4ISR	TBD	Determines the performance and safety characteristics of embedded C4ISR subsystems.
Intelligent Controllers	TBD	Verifies safety and performance of UGV control units. This TOP is not yet developed.
Autonomous Obstacle Detection and Avoidance	TBD	Determines safety and performance characteristics of a UGV's obstacle detection and avoidance system. This TOP is not yet developed.

Subtest	Method	Description
UGV Sensors	TBD	Validates the adequacy and accuracy of UGV sensors as part of the UGV system. This TOP is not yet developed.
CTIS Performance	TBD	
	Logistics	
Maintainability	TOP 2-2-503[36] TOP 6-2-504[37] ITOP 2-2-509(1)[38]	Determines the maintainability characteristics of vehicles.
Logistics Supportability	TOP 2-2-004[39]	Determines the logistic supportability of the test item through quantitative and qualitative analysis of the test item.
Reliability, Availability, Maintainability	ITOP 2-2-506[40] ITOP 2-2-509 TOP 2-2-506[41]	Quantitative analysis of data collected during endurance testing in order to determine the overall ability of the system to complete tasks.
Technical Manuals	TBD	Determines adequacy and accuracy of provided system technical manuals.
Fuel Consumption	TOP 2-2-603[42] ITOP 2-2-603[43]	Determines vehicle fuel consumption during both controlled and typical service operating environments
New Equipment Training	TOP 10-2-501[44]	Determines adequacy and accuracy of provided system training.

Subtest	Method	Description
BIT/BITE Embedded Diagnostics	TOP 6-2-335[45]	Used to evaluate system particular test, measurement, and diagnostic equipment. This test also takes into consideration not only the interface between the test equipment and the system, but also the interface between the test equipment and other elements of the planned maintenance support such as manuals, repair parts, common test equipment and tools, and calibration facilities, etc.
Training Devices	TBD	Verifies the safe integration of training devices to UGV's.
	Safety/Software	
System Safety	TOP 1-1-060[46] TOP 2-2-508[47]	Used to identify and evaluate hazards associated with test items. Testing will provide determination or assessment of personnel and equipment hazards in the system and associated operation and maintenance hazards.

Subtest	Method	Description
Critical Software Analysis and Testing	ITOP 1-1-057[48]	Describes the activities necessary to ensure that safety is designed into software that is acquired or developed and that safety is maintained throughout the software life cycle. It provides uniform procedures for developing and implementing a safety-critical software test methodology of sufficient comprehensiveness to identify the software caused hazards of a system and to impose design requirements and management controls to prevent mishaps. The objective is to ensure that the software design takes positive measures to enhance system safety, and that software errors which could reduce system safety have been eliminated or controlled to an acceptable level of risk.
Tele-operation	TBD	
Anti-Tamper Performance	TBD	Used to verify security and information assurance characteristics of UGV's. This TOP is not yet developed.

Subtest	Method	Description
Modeling and Simulation	ITOP 1-1-001[49] ITOP 1-1-002[50]	Used to verify accuracy and adequacy of system models and provides guidelines to ensure consistent documentation of the use of modeling and simulation technology in support of test and evaluation.
Fire Extinguisher System	TBD	Determines performance characteristics of vehicle on-board fire extinguisher system.
	Human Machine Interface	
Human Factors	TOP 1-2-610[51]	Used to provide human factors engineering assessment of equipment.
Noise Levels	TBD	Used to determine operating noise levels.
NBC Performance	TBD	
Toxic Fumes	TOP 2-2-614[52]	
Displays and Controls	TBD	Used to evaluate human machine interface between the operator and the UGV control unit.
	Environmental	
Environmental Performance - High Temperature - Low Temperature - Temperature Shock - Solar Radiation - Rain - Humidity - Fungus - Salt Fog - Sand and Dust - Icing/Freezing Rain - Shock - Vibration	TOP 2-4-001[53] TOP 2-4-002[54] MIL-STD-810[55]	Determines the operating, maintenance, and durability characteristics of unmanned ground vehicles when operating in extreme environments.

Subtest	Method	Description
EMI/EMC - Radiated Emissions - Radiated Susceptibility - HERO - HERF - HERP - HESD - PESD - HEMP - Near Strike Lightning - Bonds and Grounds - Conducted Susceptibility - Conducted Emissions - Intra-system EMC	TOP 1-2-512[56] TOP 1-2-511[57] TOP 2-2-613[58]	Determines whether the item tested meets the electromagnetic radiation effects, static electricity, and lightning criteria and the maximum electromagnetic radiation environment to which the test item may be exposed without adverse effects. Ensures that the equipment under test is able to operate in its intended electromagnetic environment without its performance being degraded and without degrading the performance of other system(s) in close proximity
	Survivability	
Nuclear Survivability	TOP 1-2-612[59]	Determines the effects of a specified nuclear environment on an unmanned ground vehicle.
Armor/Survivability	ITOP 2-2-617[60] ITOP 4-2-508[61]	Determines the vulnerability of unmanned ground vehicles and their components and subsystems to various levels of threats including, but not limited to IEDs, mines, etc.
Signature Measurements	TBD	
Chemical Survivability	TBD	
	Weapons	
Autoloader Ammunition Compatibility	TBD	
Azimuth and Elevation Control Systems	TBD	
Autoloader Performance	TBD	

Subtest	Method	Description
Boresighting	ITOP 3-2-836(2.1.1)[62]	Detects angular changes between gun and sighting systems, with or without the aid of an MRS, after vehicle operations over cross-country courses and primary and secondary roads, after firing, and after a period of temperature changes.
Computer Solutions	ITOP 3-2-836(2.4.1)[63]	Non-firing tests that determine the differential angle between the main weapon and sight line (ballistic solution) generated by a computerized fire control system in response to given inputs.
Fields of Fire	TOP 3-2-813[64]	Determining the given area which a weapon or group of weapons can cover effectively with fire from a given position for vehicle-mounted primary and secondary armament. This includes maximum elevation and depression angles at all traverse positions; maximum traverse angles or provisions for continuous traverse; and minimum range of anti-personnel fire at all positions of traverse.
Frequency Response	ITOP 3-2-836(1.3.2.3)[65]	Determines the frequency response characteristics of UGV gun/turret drive systems in the turret whether they are installed on UGVs or on test stands.

Subtest	Method	Description
Rangefinder	TOP 6-2-166[66]	Evaluates the performance and safety characteristics of laser rangefinders under a variety of expected operating conditions.
Weapon Firing/Accuracy	ITOP 3-2-836(2.2.1)[67]	Determines the unintended deviation of the LOS of a stabilized gun/turret and a stabilized sighting system.
Target Acquisition and Tracking	ITOP 3-2-836(2.3.5)[68]	Used to measure the target tracking capability of a UGV mounted optical or electro-optical sighting system operated by an automatic system, under specified conditions in the laboratory and in the field.
Sight Plumb & Synch	ITOP 3-2-836(2.1.2)[69]	Evaluates the capability of vehicle-mounted main-gun sighting systems.
Stabilization	ITOP 3-2-836(1.3.2.2)[70]	Determines the stabilization performance of the UGV gun/turret drive systems in the turret whether they are installed on the UGVs or on the test simulators.
Time-of-fire, Rate-of-fire	ITOP 3-2-836(2.3.4)[71]	Used to determine times necessary to complete various aspects of the target engagement sequence.
Autonomous Target Acquisition	TBD	Used to evaluate the safety and performance of automatic and un-commanded target acquisition systems. Includes procedures to evaluate a system's ability to acquire, classify, identify and track various targets. This TOP is not yet developed.

Subtest	Method	Description
	Electromagnetic Interference	
Interference	MIL-STD-461E[72]	Provides verification requirements for the control of the electromagnetic interference (emission and susceptibility) characteristics of electronic, electrical, and electromechanical equipment and subsystems.
Interface requirements	MIL-STD-464A[73]	Establishes electromagnetic environment effects interface requirements and verification criteria for UGVs.
E3 Control	MARINE CORPS ORDER 2410.2B, E3 CONTROL[74]	

5. DATA REQUIRED.

The content explaining the data to be acquired for the testing of UGVs is outlined in Section 5 of TOP 2-2-541[75] and TOP 2-2-542[76]. Section 5 of TOP 2-2-541 addresses the data required for safe mobility testing of UGVs, while Section 5 of TOP 2-2-542 addresses the data required for the testing of Weaponized UGVs.

6. PRESENTATION OF DATA

a. Describe the inspection, specific test procedures, and results for each item using narration, tables, photographs, x-rays, charts, and graphs as appropriate or as outlined in the procedures specific methodology.

b. Reduce, summarize, and analyze data from each subtest appropriate to the subtest data topic and failure definitions derived specifically for the item and the subtest category. When unique analytical tools (i.e., models, simulations, statistical techniques) are used, these should be described in sufficient detail to enable the reader to understand the basis for the analysis.

APPENDIX A. FREQUENCY ALLOCATION FORM

(1)	Name of Program
(2)	Purpose of Program
(3)	Security Classification
(4)	Frequency
(5)	Transmitter Power (Watts)
(6)	Time of Usage
(7)	Required Start and End Dates
(8)	Transmitter Nomenclature
(9)	Transmitter Location
(10) (a) (b) (c) (d) (e) (f)	Transmitter Antenna Data Type/Name Gain Site Elevation Antenna Feedpoint Height Orientation Polarization
(11)	Receiver Nomenclature
(12)	Receiver Location
(13) (a) (b) (c) (d) (e) (f)	Receiver Antenna Data Type/Name Gain Site Elevation Antenna Feedpoint Height Orientation Polarization
(14)	J/F-12 Number (if assigned)

APPENDIX B. DOCUMENT REVIEW CHECKLIST

DTC Test Checklist (Reference DA PAM 73-1)

In order to properly assess the safety, performance, and reliability of a UGV, a detailed documentation review must be conducted. This documentation review provides a more thorough understanding of UGV characteristics and in some instances can reduce the amount of physical testing required and can assist in reducing the assigned risk assessment code reported in safety releases. The documentation review is required in order to ensure that proper safety protocols are emplaced prior to initiation of testing. The following documents should be included in the test item data package; it is preferable that these documents be provided as early as possible prior to the start of testing.

1. Safety Assessment Report.

2. Health Hazard Assessment Report.

3. All test data available regarding the item requiring the Safety Release. If no current test data are available, any other information that can be used (for example, prior Government test data, contractor test data), with the emphasis on safety data.

4. Environmental documentation.

5. Training plans.

6. Equipment publications.

7. Mission scenario/mission profile.

8. Test Plan.

9. Test and Evaluation Master Plan.

10. Frequency Allocation Documentation.

11. Software Requirements Specification.

12. CHPPM Certifications (Laser and High Power RF).

13. System Requirements Document.

14. Security Classification Guide.

15. Source of troops involved in operational testing.

16. Test Readiness Review

When sufficient data are not available on which to base a Safety Release, additional testing may be necessary. In such cases, required testing will be performed by DTC, and test costs will be paid by the materiel developer; the time required for issuing a Safety Release would increase accordingly. DTC will issue the Safety Release to the operational test activity with a copy furnished to the U.S. Army Training and Doctrine Command (TRADOC).

APPENDIX C. REFERENCES

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Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (TEDT-TMB), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: TEDT-AT-AD-F, U.S. Army Aberdeen Test Center, 400 Colleran Rd., APG, MD 21005-5055. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.