
Director, Operational Test and Evaluation

AN/TPQ-53 (Q-53) Counterfire Radar

Initial Operational Test and Evaluation Report



October 2015

This report on the AN/TPQ-53 radar fulfills the provisions of Title 10, United States Code, Section 2399. It assesses the adequacy of testing and the operational effectiveness, operational suitability, and survivability of the Q-53 radar.

J. Michael Gilmore
Director

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Executive Summary

This document provides the Director, Operational Test and Evaluation's (DOT&E) assessment of the operational effectiveness, operational suitability, and survivability of the AN/TPQ-53 Counterfire Radar (Q-53). The evaluation is based on data from the Initial Operational Test and Evaluation (IOT&E 2) conducted by the Army Test and Evaluation Command in June 2015. This evaluation is supplemented with data from developmental testing that occurred between November 2012 and March 2015, and analysis from the first IOT&E that occurred between March and May 2014. The testing was adequate and conducted in accordance with the DOT&E-approved test plan.

The Q-53 is operationally effective for detecting single-fired rocket, artillery, and mortar munitions. However, the Q-53 is not operationally effective for detecting volley-fired mortar munitions. For single-fired munitions, the Q-53 provided accurate and consistent detection of counterfire acquisitions. The radar had problems characterizing artillery, rockets, and when operating in the 90-degree Short-Range Optimized Mode (SROM) mode. The Q53 radar will report false targets at a rate that exceeded Army threshold requirements. Q-53 met the point of impact requirement for most mortar and artillery missions; point of impact error for rockets is larger than that for mortars and artillery. The radar located the threat firing location point of origin within the required error for most conditions. Accuracy was degraded for volley fired artillery.

For volley-fired weapons, the Q-53 provided consistent counterfire acquisitions for artillery projectiles while operating in the 90-degree Normal and Short-Range Optimized Mode (SROM) modes. The radar had problems acquiring volley-fired mortars in 360-degree and 90-degree modes and volley-fired artillery in the 360-degree mode. During IOT&E 2, volley-fired rockets were not tested and the Army's current requirement document does not have a written requirement for volley-fired munitions. The Army recognizes this issue and has inserted a volley-fire requirement in the updated requirement document. Volley-fire is a standard technique used by a variety of threat nations, and was the technique used in both of the operational tests.

The radar will report false targets when no projectiles are in the search area. A false target occurs when the radar determines that a threat weapon is firing, when none is present. The radar may do this when there is nothing known in the air, or the radar may classify an aircraft as a ballistic trajectory. The false target rate improved from previous operational testing and met requirements for 90-degree Normal and 360-degree modes, but not for the 90-degree SROM. When the radar reports a false target as a normal target, the operator is not able to distinguish the false target from an actual target generated by threat fire missions. False targets can lead to units wasting time and resources by reacting to false warning and firing at non-enemy locations; be disruptive to units if they cause the Sense and Warn system to generate false alarms in defended areas; and can lead units to perceive the Q-53 radar as not reliable. The false targeting rate for aircraft remains a significant concern and warrants further investigation and corrective action.

The radar is required to characterize detected projectiles as mortar, artillery, or rocket. The radar correctly characterized every single-fired mortar shot as a mortar. By default, the radar will identify the detected projectile as a mortar unless it receives information suggesting

otherwise. As a result, the radar often mischaracterizes single-fired rockets and artillery as mortars, which could lead to errors in counterfire engagement solutions and intelligence preparation of the battlefield.

The Q-53 radar system demonstrated an operational availability of 0.99 during the IOT&E 2 (0.95 is required by the user), indicating that the radar is operationally suitable and available to support the commander's mission.

The Q-53 radar experienced several reliability failures during the IOT&E 2 causing the system to not meet reliability and maintainability requirements. Five of the eight failures were software-related failures that required crew action to troubleshoot and power cycle the system (similar to a complete re-boot of a personal computer). Failure to meet the reliability and maintainability requirements did not detract from overall system availability to support operational mission requirements.

The Q-53 system is survivable. The radar demonstrated improved cybersecurity from IOT&E. The classified annex details the cybersecurity analysis.

System Description and Mission

The Q-53 is the Army's next-generation counterfire radar intended to replace the fielded AN/TPQ-36 and AN/TPQ-37 Firefinder radar systems. The Q-53 locates the origins and expected impact locations of incoming threat mortar rounds, artillery rounds, and rockets. Unlike the current Firefinder radars, which detect rounds within a selected 90-degree sector, the Q-53 can operate in either a 90-degree static search mode (the Q-53 has three 90-degree modes: Normal, SROM, Long-Range Optimized (LROM)) or a continuous 360-degree rotating mode, which operates out to 20 kilometers. The 90-degree Normal mode is designed to locate targets over a large area (from 1.5 kilometers to 50 kilometers, depending on the munition type). The SROM is designed for shorter ranges (0.5 kilometers to 25 kilometers). SROM can detect targets at longer ranges, but its performance is degraded relative to the 90-degree Normal mode. SROM sacrifices the ability to detect long-range targets for an increased ability to detect short-range targets. The 90-degree LROM is designed to enhance target detections at the longer ranges (12 kilometers to 60 kilometers). As with SROM, the radar can detect shorter range targets while operating in LROM, but in non-LROM regions, the detections are expected to be below 90-degree Normal detections. There were limited LROM tests in the IOT&E; therefore, DOT&E will evaluate LROM in the Follow-on Operational Test and Evaluation (FOT&E) with the 240 mm rockets. The Q-53 radar offers the potential for lower life-cycle costs than the legacy Q-36 and Q-37 Firefinder radars, which are based on outdated technology that makes component replacement expensive and difficult.

The Q-53 can be operated by a crew of five Soldiers and is transportable by C-17 aircraft. The Army will operate Q-53 radar sections with a five-Soldier crew to ease the challenges of continuous 24-hour operations. During IOT&E 2, five-Soldier crews operated the radar from two Family of Medium Tactical Vehicles (FMTVs) equipped with armored cabs. The Mission Essential Group (MEG) consists of the radar antenna array mounted on a modified truck. A radar crew can perform all mission tasks operating from the MEG. The Sustained Operations

Group (SOG) provides a command and control shelter for more sustained operations that consists of an Environmental Control Unit (ECU), additional radios and workspace for planning and executing missions, and a separate vehicular-mounted commercial procured 10-kilowatt generator. The Army intends to replace the ECU and commercial generator with more robust military grade capabilities. The new systems will undergo testing during the planned FOT&E as described in the Test and Evaluation Master Plan. Each vehicle tows a 60-kilowatt generator.

Between 2010 and 2014, the Army fielded 38 Quick Reaction Capability (QRC) Q-53 radars to fulfill a combat theater Urgent Materiel Release request. The QRC radars have a similar design as the Program of Record (POR) radars, with some differences in hardware and software. The QRC radars will be retrofitted to the POR configuration after the Full-Rate Production decision, which is planned for November 2015. The Army plans to purchase 136 Q-53 POR radars. This report addresses the POR radars.

Test Adequacy

Operational testing of the Q-53 radar was adequate to support an evaluation of its operational effectiveness, operational suitability, and survivability. The Army's Test and Evaluation Command conducted IOT&E 2 at Yuma Proving Ground, Arizona, from June 3 – 27, 2015. Prior to the record test, the test unit received 80 hours of individual training and 80 hours of unit collective training, followed by a 48-hour pilot test. The record test period included four 72-hour scenarios. The record test portion amassed 500 operational test hours and 1,542 projectiles fired in artillery, rocket, or mortar fire missions. Either Soldier-maintainers or contracted Field Service Representatives (FSRs) performed all maintenance functions in accordance with Army doctrine.

The test did not include 240 mm rockets or 122 mm cannon artillery. These munitions will be addressed in testing after the Full-Rate Production decision.

Operational Effectiveness

The Q-53 radar is operationally effective for detecting single-fired weapons and volley-fired artillery projectiles. However, it is not effective for volley-fired mortars because it had difficulty detecting mortar projectiles fired in volleys. Due to test facility limitations, rockets were not volley-fired in the IOT&E 2, and the Q-53 does not have a written volley requirement. Volley-fire is a common artillery technique used by a variety of threat nations and was an important component of the Q-53's operational assessment. The Program Office plans on addressing volley-fire performance in future software upgrades.

The Q-53 radar will report false detections and has challenges correctly characterizing single-fired artillery and rockets munitions. The radar demonstrated a low false target rate in the 90-degree Normal and 360-degree modes, but had a high false target rate in the 90-degree SROM mode, exceeding the Army's threshold requirement. The radar met the point of impact requirement for most mortar and artillery missions. Point of impact error for rockets is larger than that for mortars and artillery. The radar located the threat firing location point of origin within the required error for most conditions. Accuracy was degraded for volley fired artillery.

The radar met the probability of detection requirements for single-fired munitions. In 90-degree modes, performance degraded when a Digital Terrain Elevation Data (DTED) extrapolation error was present. The Program Office has identified a fix and intends to test and implement the fix prior to fielding. The radar's probability of detection was well below requirements for volley-fired mortars. Once detected, the radar's prediction of the weapon's location was within Army requirements for most conditions to include single- and volley-fired munitions. Table 1 displays the Q-53 effectiveness performance during IOT&E 2. The green coloring signifies the radar meeting the requirement, the red signifies not meeting the requirement, and the yellow signifies both.

Table 1. Q-53 Effectiveness Performance Summary

Capability	Fire Type	Munition Type	Requirement ¹	360-degree	90-degree Normal	90-degree SROM
Probability of Detection (80% Confidence Interval)	Single	Artillery	0.85	0.87 (0.82 – 0.90)	0.87 (0.82 – 0.91)	0.60 (0.49 – 0.71)
		Mortar		0.74 (0.73 – 0.79)	0.87 (0.84 – 0.90)	0.96 (0.93 – 0.96)
		Rocket		0.86 (0.84 – 0.88)	0.998 (0.996 – 0.999)	0.997 (0.991 – 0.999)
	Volley	Artillery	None	0.66 (0.55 – 0.77)	0.97 (0.95 – 0.98)	0.87 (0.82 – 0.90)
		Mortar		0.15 (0.13 – 0.20)	0.39 (0.33 – 0.44)	0.63 (0.55 – 0.70)
		Rocket		Not Tested	Not Tested	Not Tested
Probability of Characterization (80% Confidence Interval)	Single	Artillery	0.85	0.78 (0.73 – 0.81)	0.67 (0.60 – 0.73)	0.90 (0.86 – 0.93)
		Mortar		1.0 (0.99 – 1.0)	1.0 (0.98 – 1.0)	1.0 (0.98 – 1.0)
		Rocket		0.73 (0.68 – 0.78)	0.69 (0.63 – 0.75)	0.74 (0.67 – 0.80)
	Volley	Artillery	None	1.0 (0.90 – 1.0)	0.99 (0.95 – 1.0)	0.98 (0.95 – 1.0)
		Mortar		1.0 (0.93 – 1.0)	1.0 (0.97 – 1.0)	1.0 (0.92 – 1.0)
		Rocket		Not Tested	Not Tested	Not Tested
Radar Accuracy	Single/ Volley	Artillery	Varies By Range	Met Req	Single: Met Vol: Not Met	Met Req
		Mortar		Met Req	Met Req	Met Req
		Rocket		Met Req	Met Req	Met Req
False Target Rate (per 12 Hours)	All	All	1.0	0.5 (0.2 – 0.8)	0.7 (0.4 – 1)	6.6 (5.4 – 7.9)
Availability	All	All	0.95	99% (98.7% - 99.9%)		
Reliability (Mean Time Between System Abort (MTBSA))	All	All	185 (80% Confident)	62.5 (38 - 107)		

¹ The Army is updating Q-53 requirements. The new requirements are expected to include a volley fire requirement and increase the allowed false target rate to one false target per 6 hours.

Figure 1 provides a summary of DOT&E's regression analysis of the probability of detection using different operating modes to detect projectiles fired either single or in volley. In single-fire, projectiles are fired one at a time from a single weapon. In volley-fire missions,

multiple co-located weapons fire projectiles at the same time at a single target. In the IOT&E 2, three weapons fired the volley missions, and the distances between the weapons were operationally representative. Only artillery and mortar munitions were volley fired. For operational volleys, all three weapons fired the first volley at the same time. After the first volley, the weapons fired the remaining rounds as the unit loaded and launched the projectiles. Figure 1 shows the probability of detection for combinations of munition type, radar mode, and rate of fire, including 80 percent confidence bounds. The Army's current requirement document does not have a requirement for volley-fired munitions. Volley-fire is a standard technique used by a variety of threats, so it is important to assess the radar against this common field artillery technique. The 85 percent single-fire requirement is shown for the volley-fire as a reference point.

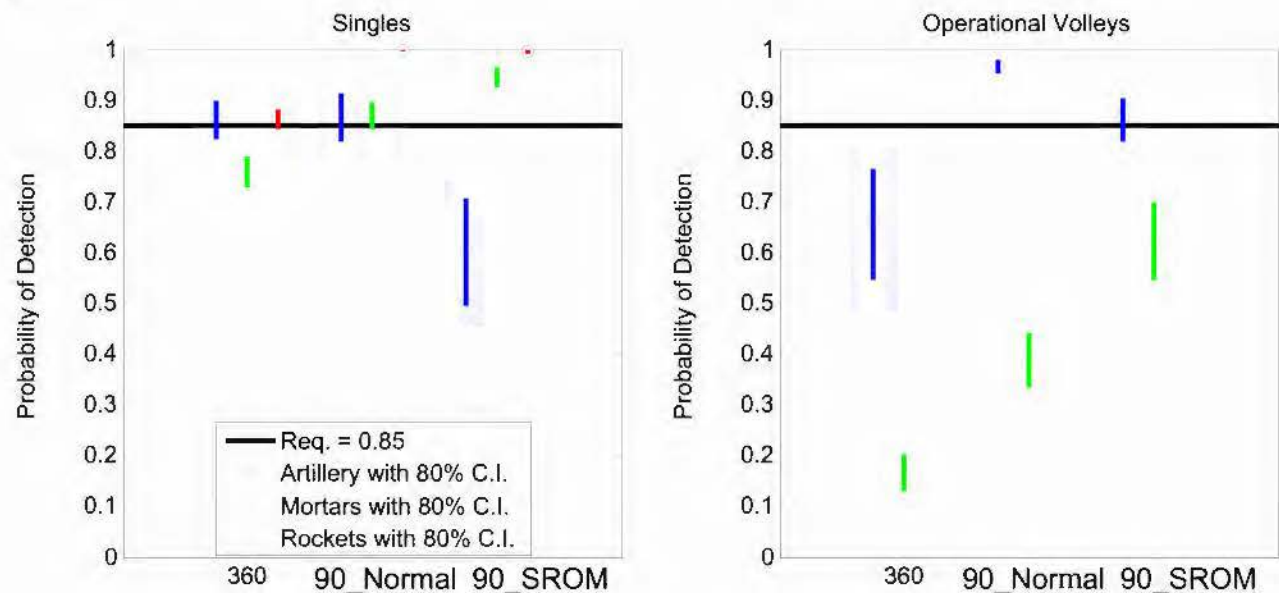


Figure 1. IOT&E 2 Probability of Detection

As seen in the left graph of Figure 1, the radar met or came close to meeting the requirement for single-fired munitions. In 90-degree modes (Normal, SROM), rocket detection was better than detection of mortar or artillery. In the 360-degree mode, the probability of detection for mortar single shots was lower than that for rocket and artillery.

The radar detected artillery fired in operational volleys in the 90-degree Normal with performance reduced while in the 360-degree mode. The radar had problems detecting mortars fired in volleys. One possible reason for the difference in performance between artillery and mortars is the time separation between each successive projectile fired. Shorter time separations impaired the radar's ability to detect the munition. In the IOT&E 2, mortars were volley-fired at a faster rate than artillery. This rapid firing of projectiles makes it difficult for the radar to distinguish individual projectiles because it may see multiple projectiles as a single object, leading it to categorize the projectiles as a larger object such as an aircraft. As a result, the radar would not declare the projectiles as a projectile threat and no target would be generated.

A more detailed analysis of the detection probability reveals that many factors influence the radar's performance. The radar's performance degrades for the following conditions:

- Volley-fired munitions – Volley-fired mortar munitions reduced radar performance in both probability of detection and the accuracy of determining the threat weapon's location.
- DTED issue – In the 90-degree modes, the radar incorrectly uses DTED to calculate the terrain mask, causing some projectile trajectories to travel below the radar beams when the conditions for the DTED errors were present. During IOT&E 2, the error was present in 18 of 188 threat missions. The conditions for this error are terrain dependent and may occur in mountainous terrain. The Program Office discovered this problem in developmental testing prior to IOT&E 2 and has developed and is testing a fix.
- 90-degree SROM artillery – The SROM is designed to maximize performance over the 90-degree Normal mode at short ranges versus artillery and it successfully did so for mortars. For artillery in IOT&E 2, probability of detection dropped below 90-degree Normal and the requirements when artillery was more than 15 kilometers from the radar. Q-53 tactics, techniques, and procedures (TTP) state that SROM artillery performance should be used out to 25 kilometers. The Army should investigate this performance and determine whether tactics changes are required.
- 360-degree mode mortars – The radar probability of detection was below requirements for mortars firing at the shortest IOT&E 2 ranges (less than 2.5 kilometers). From the radar's perspective, these are difficult trajectories because they spend a short time in the radar's search sector.

The radar met accuracy requirements for all conditions except for the 90-degree artillery volley-fired cases.

The Q-53 radar is required to characterize projectiles as mortar, artillery, or rocket. During IOTE 2, identifying artillery and rockets proved more challenging. By default, the radar will identify the detected projectile as a mortar. With the exception of the 90-degree SROM artillery, the radar did not meet the requirement for single-fired artillery and rocket shots. There is no volley-fired requirement, but the radar met the single-fired requirement for all volley-fired munitions. Commanders use information on munition types to plan counterfire and conduct intelligence preparation of the battlefield. The type of weapon and the volume of fire differ depending upon whether the intent is to attack mortar, artillery, or rocket weapons. Incorrect characterization of threat munitions can result in ineffective or wasteful counterfire missions. Knowing the type of weapon helps the commander determine the type of unit as well as the threat's strength. This can be critical in planning future attacks.

The radar reported false targets when no projectiles were in the search area. The 360-degree and 90-degree Normal radar modes kept false targets to a rate that met Army requirement thresholds. However, the 90-degree SROM false target rate did not meet the requirement threshold. While in the 360-degree, 90-degree Normal, and 90-degree SROM modes, the radar

averaged, 0.5, 0.7, and 6.6 false targets per 12 radiating hours, respectively; the Army limits the Q-53 radar to no more than one false target location per 12 radiating hours. During a 1.8-hour period, a radar in 90-degree SROM had 23 false targets. There were similar instances during developmental testing. When the radar reports a false target as a normal target, the operator is unable to distinguish the false target from an actual target generated by threat fire missions. False targets can lead to units wasting time and resources by reacting to false warning and firing at non-enemy locations; be disruptive to units if they cause the Sense and Warn system to generate false alarms in defended areas; and can lead units to view the Q-53 radar as not reliable. The Program Office plans on updating the radar software to reduce the false target rate.

The radar can generate false targets when aircraft are in the search area; this is important when the radar is operating near an airfield. The Q-53 radar operating in 360-degree, 90-degree Normal, and 90-degree SROM had 0, 6, and 5 false targets per 12 radiating hours, respectively. There were zero false targets in the 360-degree mode, but given the small number of radiating hours (11 hours), there is an 80 percent probability that the actual false target rate was less than 0.9 false targets per 12 radiating hours. The available data are not sufficient to correlate the false targets with aircraft activity. The false target rates for 90-degree Normal are significantly different from the false target rates seen in the other portions of the IOT&E 2, indicating the 90-degree Normal mode has a higher false target rate when deployed near an airfield. This warrants additional investigation. The Program Office plans on updating the software to reduce the false target rates due to aircraft.

In both IOT&Es, the counterfire cell managed the radars and conducted counterfire missions when the radar detected threat missions.

Operational Suitability

The Q-53 radar is operationally suitable. The Q-53 radar system demonstrated an operational availability of 0.99 during the IOT&E 2 (0.95 is required by the user), indicating that the radar is operationally suitable and available to support the commander's mission.

During the test, the radars were not available for 4 of 500 operating hours, making the radar available to a unit commander 99 percent of the time. The non-operational hours were the result of eight system aborts. The majority of the failures (five of eight) were software-related; five of the repairs required less than 30 minutes.

The radar did not meet its reliability requirement. The Army requires an 80 percent confidence that the average time between system aborts is greater than 185 hours. With eight failures in 500 hours, the achieved Mean Time Between System Abort (MTBSA) was 62.5 hours with an 80 percent confidence interval of 38 to 107 hours. The Army developed a new requirement of 91 hours MTBSA and the updated requirement is in joint staffing. If approved, the new requirement would be within the IOT&E 2 confidence interval. In addition, the radar did not meet the Army requirement of 0.3 hours Mean Time To Repair (MTTR). The IOT&E 2, MTTR was 0.5 hours with an 80 percent confidence interval of 0.30 to 0.85. The median repair time was 0.38 hours. Table 2 displays the Q-53 suitability performance during IOT&E 2.

Table 2. Q-53 Suitability Performance Summary

Capability	Requirement	Proposed Requirement ¹	Performance Point Estimate (80% Confidence Interval)
Operational Availability	0.95	0.90	99% (98.7% - 99.9%)
Reliability (MTBSA hours)	80% confident above 185 hours	91	62.5 (38 - 107)
Maintainability (MTTR hours)	≤ 0.3	≤ 0.3	0.5 (0.30 - 0.85)
Probability that 2 of 3 complete a 72-hour mission without a System Abort (Fires Brigade)	≥ 0.75 ²	NA	0.24 (0.06 – 0.52)
Probability that 1 of 2 complete a 72-hour mission without a System Abort (Brigade Combat Team)	NA	≥ 0.70	0.53 (0.28 – 0.76)
Mission Reliability Probability that a radar completes a 72-hour mission without a System Abort (Single Radar)	0.68 ³	0.45 ³	0.32 (0.15 – 0.51)

¹ The Army is updating Q-53 requirements. The requirements are currently being staffed with the Joint Requirements Oversight Council.

² The current requirement is based upon assigning three radars to a fires brigade. New configurations have two radars in each organization.

³ As derived from the reliability requirement (185 hours Mean Time Between System Abort (MTBSA) or 91 hours MTBSA).

Survivability

The Q-53 is survivable on the battlefield and showed significant improvement over cyber vulnerability from the IOT&E in May 2014. Details are in the classified appendix.

Recommendations

The Army should consider the following recommendations and verify the corrections of deficiencies during FOT&E.

Operational Effectiveness

- Carry out plans to improve and test the radar's performance against threat units firing mortar volleys
- Test the radar's performance against volley-fired rockets, after implementing a fix for volley-fire

- Test the planned fix for the DTED issue
- Investigate radar's 90-degree SROM probability of detection for short range artillery shots and update training manuals accordingly
- Improve the radar's probability of characterization
- Continue to investigate and solve the high false target rate in the 90-SROM configuration
- Continue plans to improve and further characterize and reduce false targets that are due to aircraft
- Address counter fire cell operations for frequency management, managing of blanking sectors and radar locations in their revised counterfire crew drill TTP for Q - 53.
- Address Q-53 load plans (Solider equipment, Q-53 subcomponent equipment) in order to utilize the SOG in an efficient manner. There is not enough on board carrying capability to accommodate the amount of equipment.

Operational Suitability

- Continue root cause analysis and resolution plans for software-related failures and verify fixes in FOT&E with Soldier crews
- Reduce software warnings and/or qualify the warnings (without requiring operators to consult the Interactive Electronic Technical Manual) to indicate when Soldiers must take immediate action
- Improve the grounding system to enhance emplacement/displacement responsiveness and decrease labor burden
- Prioritize the computer display windows so that fire missions are priority screens that override other graphical interface screens
- Increase vehicle on-board storage space/carrying capability to accommodate five-Soldier crews operating 72-hours
- Consider an additional vehicle (such as a cargo High Mobility Multipurpose Wheeled Vehicle (HMMWV)) that could serve as both an equipment vehicle and reconnaissance vehicle or provide security to assist with tactical repositioning and sustained operations

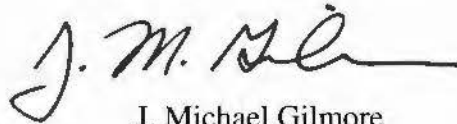
Survivability

Based on vulnerabilities identified in the classified annex, the Army should:

- Resolve identified cybersecurity vulnerabilities and validate with Soldiers in testing
- Conduct additional cyber testing on planned future software upgrades

The Army should conduct an FOT&E to include the following testing:

- Testing of the 240 mm rocket and 122 mm cannon munitions for both single- and volley- fire scenarios
- Tropics testing
- Operational testing when integrated with Indirect Fire Protection Capability Increments
- Planned volley-fire improvement testing
- An adversarial assessment for a planned wireless radio upgrade, planned wireless connection between radar and command and control vehicle, and new cybersecurity operating system upgrades
- Verification of potential fixes for SROM false targeting
- Additional testing of aircraft false targeting near airfields/high-clutter environments after improvements are made to software
- New systems testing of the 10-kilowatt generator for the Environmental Control Unit (ECU), which intends to provide robust, military-grade capabilities that can meet heating requirements in cold regions
- Testing of potential fixes for probability of characterization
- Testing of Q-53 radar reliability with Soldiers for future software upgrades

A handwritten signature in black ink, appearing to read "J. M. Gilmore", with a stylized flourish at the end.

J. Michael Gilmore
Director

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Section One System Overview

The Q-53 Counterfire radar is a mobile radar system designed to detect, characterize, and track projectiles fired from mortar, artillery, and rocket systems. The Army intends the radar to provide target location for threat indirect fire systems with sufficient timeliness and accuracy for effective counterfire. The Q-53 is designed to operate with the Counter – Rocket, Artillery, Mortar (C-RAM) system and the future Indirect Fire Protection Capability system. The Q-53 will replace the AN/TPQ-37 and AN/TPQ-36 radars.

Mission Description and Concept of Employment

The Army plans to use the Q-53 radar to execute counterfire acquisition responsibilities in both maneuver brigade and artillery organizations. Units will receive the Q-53 in multiples of two per formation so that each maneuver brigade, field artillery brigade, and division artillery will have two Q-53 radars as organic assets to acquire threat rocket, artillery, and mortar rounds and to transmit point of origin and expected impact location information. Point of origin and impact location information is sent through digital and voice command and control systems to initiate counterfire missions and/or provide intelligence information on threat artillery, rocket, and mortar positions.

The Army will also use the Q-53 to locate threat indirect-fire weapons for attack or as part C-RAM system. The Q-53 is one of many C-RAM sensors providing predicted threat indirect-fire impact locations. The C-RAM system warns Soldiers of the incoming threat indirect fire and uses trajectory data from the Q-53 radar. C-RAM was first deployed in July 2005.

System Description

The Q-53 is the Army's next-generation counterfire radar to replace the fielded AN/TPQ-36 and AN/TPQ-37 Firefinder radar systems. The Q-53 locates the point of origin and expected point of impact locations of incoming threat mortar rounds, artillery rounds, and rockets. Unlike the current Firefinder radars, which detect rounds within a selected 90-degree sector, the Q-53 can operate in either a 90-degree static search mode (Normal, Short-Range Optimized Mode (SROM), Long-Range Optimized (LROM)) or a continuous 360-degree mode. The Q-53 offers the potential for lower life-cycle cost than the legacy Q-36 and Q-37 Firefinder radars, which are based on outdated technology, making component replacement expensive and difficult to maintain.

The Army approved development of a Quick Reaction Capability (QRC) Q-53 radar in September 2006 and have fielded 38 QRC Q-53 radars. They are of a similar design and manufacture as the Q-53 Program of Record (POR) radar. The Army plans to retrofit all the QRC radars to the POR radars once a Full-Rate Production decision is made.

The Q-53 can be operated by a crew of five Soldiers and is transportable by C-17 aircraft. The Army is transitioning to a five-Soldier crew to increase unit survivability and ease the

challenges of continuous 24-hour operations. Five-Soldier crews were used during the Initial Operational Test and Evaluation (IOT&E 2). Soldiers operated the system from two Family of Medium Tactical Vehicles (FMTVs) equipped with armored cabs. The Mission Essential Group (MEG) (Figure 1-1, left side) consists of the antenna mounted on a modified truck. A radar crew can perform Q-53 functions operating from the MEG. The Sustained Operations Group (SOG) (Figure 1-1, right side) provides a command and control shelter for more sustained operations. The SOG consists of an Environmental Control Unit (ECU), additional radios, and workspace for planning and conducting missions, and a separate, vehicular-mounted, commercial procured 10-kilowatt generator. The Army intends to replace both the ECU and generator with more robust, military-grade capabilities that can meet heating requirements in cold regions. Those new systems will undergo testing during the Follow-on Operational Test and Evaluation (FOT&E) as described in the Test and Evaluation Master Plan. Each vehicle tows a 60-kilowatt generator.



Figure 1-1. Mission Essential Group (MEG) (left) and Sustained Operations Group (SOG) (right)

The Q-53 is deployable anywhere in the world and capable of operations in varying terrain and climatic conditions. The radar will use a two-level maintenance concept consisting of field-level and sustainment-level maintenance. All maintenance actions required to bring a non-operational Q-53 to a fully mission capable condition will be accomplished at the field level of maintenance by the Q-53's crew, contractor Field Service Representatives (FSRs) assigned under contractor logistics support, and/or maintenance personnel organic to military units assigned support responsibilities for the Q-53. The use of embedded maintenance technology helps field-level maintainers and technicians isolate malfunctions.

Field-level maintenance is on-system maintenance and consists of replacing modular designed line-replaceable units (LRU) and cables. The faulty LRUs and cables are either returned to the sustainment level of maintenance for repair or discarded. Resupply of failed LRUs is through the standard Army supply system. The Army intends operator efficiency to be enhanced by comprehensive embedded training, built-in test maintenance aids, and radar operations decision aids.

Sustainment-level maintenance consists of all maintenance tasks above field-level maintenance. Letterkenny Army Depot, Tobyhanna Army Depot, and Lockheed-Martin Corporation provide depot-level support.

Between 2010 and 2013, the Army fielded 38 QRC radars to fulfill a combat theater Urgent Materiel Release request. The QRC radars have a similar design as the POR radars, but there are some differences in hardware and software. The QRC systems will be retrofitted to the POR configuration after the Full-Rate Production decision, which is planned for November 2015. The Army plans to purchase 136 Q-53 POR radars. This report addresses the POR radars.

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Section Two

Test Adequacy

The Q-53 IOT&E 2 was adequate to support an assessment of the operational effectiveness, operational suitability, and survivability of the Q-53 radar. The test was conducted in accordance with the DOT&E-approved test plan and is intended to support a November 2015 Full-Rate Production decision.

The Army conducted the first IOT&E at Yuma Proving Ground, Arizona, in May 2014. Due to high false target, reliability, and cybersecurity issues, the Army decided to delay the Full-Rate Production decision, fix the issues, and conduct a second IOT&E (IOT&E 2). The Army Test and Evaluation Command conducted IOT&E 2 at Yuma Proving Ground, Arizona, from 3 June 3 – 27, 2015. Prior to the record test, the test unit received 80 hours of individual training and 80 hours of unit collective training, followed by a 48-hour pilot test. The record test period included four 72-hour scenarios followed by a fifth 72-hour vignette that focused on cyber and electronic warfare attacks. Crews operated the radar throughout the test periods. The IOT&E 2 employed two Q-53 radar systems configured into a division artillery command and control structure. All brigade combat teams, artillery fires brigades, and division artillery headquarters are equipped with two Q-53 radars.

The IOT&E 2 test unit consisted of two, five-Soldier crews, each led by a non-commissioned officer; two, six-Soldier counterfire cells to maintain 24-hour operations, each led by a counterfire officer (warrant officer); and one, three-Soldier maintenance team led by a non-commissioned officer. Contractor Field Service Representatives (FSRs) provided maintenance above field level.

The Army Test and Evaluation Command conducted the IOT&E 2 in a tactical field environment in accordance with the Q-53 Operational Mode Summary/Mission Profile (OMS/MP), which dictates the expected operational pace of movement and target acquisitions. The Soldier test unit operated the Q-53 radars in a realistic operational scenario emulating the system; observing live mortar, artillery, and rocket fire; and displacing to new locations. In accordance with the OMS/MP, movements were either survivability moves (averaging about 1 kilometer) or tactical moves (averaging about 22 kilometers). Soldier-crews conducted tactical operations in both daylight and darkness and conducted daily preventive maintenance checks and services and field-level maintenance on the Q-53 radars, vehicles, and generators.

The operational scenario required the radar crews to conduct counterfire operations in support of a notional maneuver force in both offensive and defensive operations. The radars operated either in 360-degree mode or 90-degree mode depending upon the counterfire cell's direction and planning. The 360-degree mode radars operated from the perspective of a forward operating base location and did not move during the 72-hour scenarios. The 90-degree mode radars supported offensive operations and moved at a pace dictated by the OMS/MP. The crews transmitted radar acquisitions to the counterfire operations cell using the Advanced Field Artillery Tactical Data System. The stationary Q-53 sent the acquisitions to the Forward Area Air Defense Command and Control (FAAD C2) workstation collocated with the counterfire cell.

The FAAD C2 workstation is the interface between the Q-53 radar and the Counter, Rocket, Artillery, Mortar (C-RAM) system.

During the second record test vignette, a third radar section crew deployed to a location near the Yuma Marine Corps Air Station and conducted operations in the 360-degree, 90-degree Normal, and 90-degree SROM modes to test the ability of the radar to distinguish between aircraft and ballistic trajectories.

Gun crews representing threat fire support systems fired 1,542 artillery, rocket, and mortar projectiles of various calibers during the IOT&E 2. The 107 mm and 122 mm rockets were actual threat munitions. All other munitions fired in IOT&E 2 were U.S. munitions that were validated as being representative of a threat munition. The projectiles were grouped into missions, with most missions consisting of 10 projectiles. The numbers and types of projectiles and missions are shown in Figure 2-1.



Figure 2-1. Projectiles and Mission Types in IOT&E2

Threat missions were categorized by their firing rate. Standard missions were fired by a single weapon and fired one at a time as quickly as possible given safety considerations. Mortars were fired more quickly than other types of munitions. Operational volleys (O Volley) were fired by groups of three weapons, which were located in the same general location, separated by an operationally representative distance and fired at the same target. When given the fire command, the three weapons fired the first volley at the same time. Each of the subsequent nine projectiles was fired as quickly as possible. This is representative of a threat volley mission. For technical volleys (T Volley), 10 separate fire commands were given so that every volley was synchronized between all 3 weapons. For the simultaneous missions (Simo), weapons at six different locations fired their rounds simultaneously at six different targets. The Q-53 is required to detect and track up to six simultaneous rounds. DOT&E used data from the IOT&E 2 2 to determine the probability of detecting projectiles, the number of false detections, and the

accuracy of the estimated points of origin and points of impact. Other data collected included system reliability, availability, maintenance actions, and Soldiers' assessments by way of surveys.

A division artillery is supported by two Q-53 radars that can electronically interfere with each other if they are positioned too close together. Based upon the manufacturer's specifications, the training manual advises that Q-53 radar performance is best achieved when the radars are separated by more than 20 kilometers and when one of the radars is operating in the 360-degree mode. Units operating within a confined operational environment will find the 20-kilometer positioning recommendation restrictive and difficult to implement. During IOT&E 2, space limitations at Yuma Proving Ground, coupled with the requirement to maintain the OMS/MP movement rates, limited radar separation to between 6 and 24 kilometers. The radars were separated by less than 20 kilometers for 45 percent of the threat missions. The training manual states that radar interference can be reduced by using the sector blanking technique, in which the radar operating in the 360-degree mode is programmed to stop radiating as the search fan from the rotating antenna sweeps past the other radar. Sector blanking was used during IOT&E 2.

Threat crews fired missions into designated impact areas from predetermined firing positions. Eighteen percent of the data used in DOT&E's analysis had projectile trajectories partially outside the radar's search sector. These trajectories can be more difficult for the radar to track. They were included in the analysis because they are operationally realistic.

IOT&E 2 Test Limitations

Threat projectiles such as the 122 mm cannon and 240 mm rocket were not available for the IOT&E 2. Therefore, the Army will test those munitions FOT&E and DOT&E will report on the results. Tropical environment testing and changes to the military-grade generator and Environmental Control Unit (ECU) will also occur as part of the FOT&E as outlined in the Test and Evaluation Master Plan.

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Section Three

Operational Effectiveness

The Q-53 is operationally effective for detecting single-fired rocket, artillery, and mortar munitions. However, the Q-53 is not operationally effective for detecting volley-fired mortar munitions. The Q 53 Radar it is not effective for volley-fired mortars because it had difficulty detecting mortar projectiles fired in volleys. The radar had problems characterizing artillery and rockets and due to test range limitations, rockets were not volley-fired in the IOT&E 2. Q-53 does not have a written volley requirement at this time. Volley-fire is a common artillery technique used by a variety of threat nations. The Program Office plans to address volley-fire performance in future software upgrades.

DOT&E assessed the radar's ability to detect single- and volley-fired mortar, artillery, and rocket projectiles; locate the threat's position; characterize the munition type; and reduce false targets. As tested in the IOT&E 2, the radar has a high probability of detection for single-fired rockets. In general, the probability of detection for single-fired artillery and mortars either met or was close to the requirements. For volley-fired munitions, the radar met probability of detection requirements for volley-fired artillery in the 90-degree mode and was close to requirements in the 360-degree mode.

The radar had problems detecting projectiles in the 90-degree modes when the Digital Terrain Elevation Data (DTED) issue was present, in the 90-degree Short-Range Optimized Mode (SROM) when artillery was fired less than 15 kilometers away, and in the 360-degree mode when mortars were fired at short ranges. The radar was well below detection requirements for volley-fired mortars. For most conditions, the radar located threat positions within the accuracy requirements for single- and volley-fired mortar, artillery, and rockets.

The radar correctly characterized all mortar shots; however, the radar had problems characterizing artillery and rockets. The radar met false target requirements for the 360-degree and 90-degree Normal modes, but did not meet false target requirements for the 90-degree SROM. While operating near an airfield, the radar's false target rate was higher in the 90-degree Normal mode as compared to other portions of the IOT&E 2, when the radars were operated away from the airfield. The Program Office plans to improve the radar's volley-fire performance; the false detection rate in 90-degree SROM; and false detections in cluttered environments, such as near airfields. In both the first and second IOT&Es, the counterfire cell managed the radars and conducted timely counterfire missions when the radar detected threat missions. Table 3-1 displays the Q-53 effectiveness performance during IOT&E 2. The green coloring signifies the radar meeting the requirement, the red signifies not meeting the requirement, and the yellow signifies both.

Table 3-1. Q-53 Effectiveness Performance Summary

Capability	Fire Type	Munition Type	Requirement ¹	360-degree	90-degree Normal	90-degree SROM
Probability of Detection (80% Confidence Interval)	Single	Artillery	0.85	0.87 (0.82 – 0.90)	0.87 (0.82 – 0.91)	0.60 (0.49 – 0.71)
		Mortar		0.74 (0.73 – 0.79)	0.87 (0.84 – 0.90)	0.96 (0.93 – 0.96)
		Rocket		0.86 (0.84 – 0.88)	0.998 (0.996 – 0.999)	0.997 (0.991 – 0.999)
	Volley	Artillery	None	0.66 (0.55 – 0.77)	0.97 (0.95 – 0.98)	0.87 (0.82 – 0.90)
		Mortar		0.15 (0.13 – 0.20)	0.39 (0.33 – 0.44)	0.63 (0.55 – 0.70)
		Rocket		Not Tested	Not Tested	Not Tested
Probability of Characterization (80% Confidence Interval)	Single	Artillery	0.85	0.78 (0.73 – 0.81)	0.67 (0.60 – 0.73)	0.90 (0.86 – 0.93)
		Mortar		1.0 (0.99 – 1.0)	1.0 (0.98 – 1.0)	1.0 (0.98 – 1.0)
		Rocket		0.73 (0.68 – 0.78)	0.69 (0.63 – 0.75)	0.74 (0.67 – 0.80)
	Volley	Artillery	None	1.0 (0.90 – 1.0)	0.99 (0.95 – 1.0)	0.98 (0.95 – 1.0)
		Mortar		1.0 (0.93 – 1.0)	1.0 (0.97 – 1.0)	1.0 (0.92 – 1.0)
		Rocket		Not Tested	Not Tested	Not Tested
Radar Accuracy	Single/Volley	Artillery	Varies By Range	Met Req	Single: Met Vol: Not Met	Met Req
		Mortar		Met Req	Met Req	Met Req
		Rocket		Met Req	Met Req	Met Req
False Target Rate (per 12 Hours)	All	All	1.0	0.5 (0.2 – 0.8)	0.7 (0.4 – 1)	6.6 (5.4 – 7.9)

¹ The Army is updating Q-53 requirements. The new requirements are expected to include a volley fire requirement and increase the allowed false target rate to one false target per six hours.

Radar Performance Requirements

Table 3-2 shows the Q-53's current performance requirements. Accuracy and range requirements depend on the type of munition and the radar-weapon range. This report includes the analyses of missions with radar-weapon ranges consistent with the ranges in Table 3-2. The current requirements do not have a requirement for volley-fired projectiles; the Army is updating the requirements, but they have not yet been approved. The draft requirements state that the radar must meet the 85 percent probability of detection requirement in the 90-degree mode, when

projectiles are greater than 2 seconds apart. During IOT&E, 50 percent of the mortar volley fire was less than 2 seconds.

Table 3-2. Q-53 Performance Requirements

Capability	Q-53 Radar	
Sector Coverage	90 degrees	360 degrees
Mortar Range	0.5 – 20 km	3.0 – 15 km
Mortar Accuracy	30 meters or 0.3 % of range	50 meters or 0.5% of range
Artillery Range	3.0 – 34 km	5.0 – 20 km
Artillery Accuracy	30 meters or 0.3% of range	75 meters or 1.0% range
Rocket Range	8.0 – 60 km	8.0 – 20 km
Rocket Accuracy	30 meters or 0.3% of range	75 meters or 1.0% range
Probability of Detection	85% ¹	85% ¹
False Target Rate	1 per 12 hours	1 per 12 hours

¹ The Army requires the radar to detect 85 percent of single-fired projectiles. No requirement exists for volleys

Probability of Detection

Figure 3-1 provides a summary of the regression analysis using different operating modes to detect projectiles fired either single or in volley. In volley-fire missions, multiple co-located weapons fired projectiles at the same time at a single target. Three weapons fired the volley missions in the IOT&E 2. For operational volleys, all three weapons fired the first volley at the same time. After the first volley, the weapons fired the remaining nine rounds as fast as the unit could load and launch the projectile. The Q-53 is required to acquire six projectiles fired simultaneously. In simultaneous-fire missions, multiple geographically distributed weapons fired projectiles at the same time at different targets. The results for the four simultaneous missions were the same as single fired missions, so they were treated as single fired munitions in the regression analysis. Figure 3-1 shows the probability of detection for combinations of munition type, radar mode, and rate of fire, including 80 percent confidence bounds. The 85 percent single-volley requirement is shown for the volley-fire as a reference point.

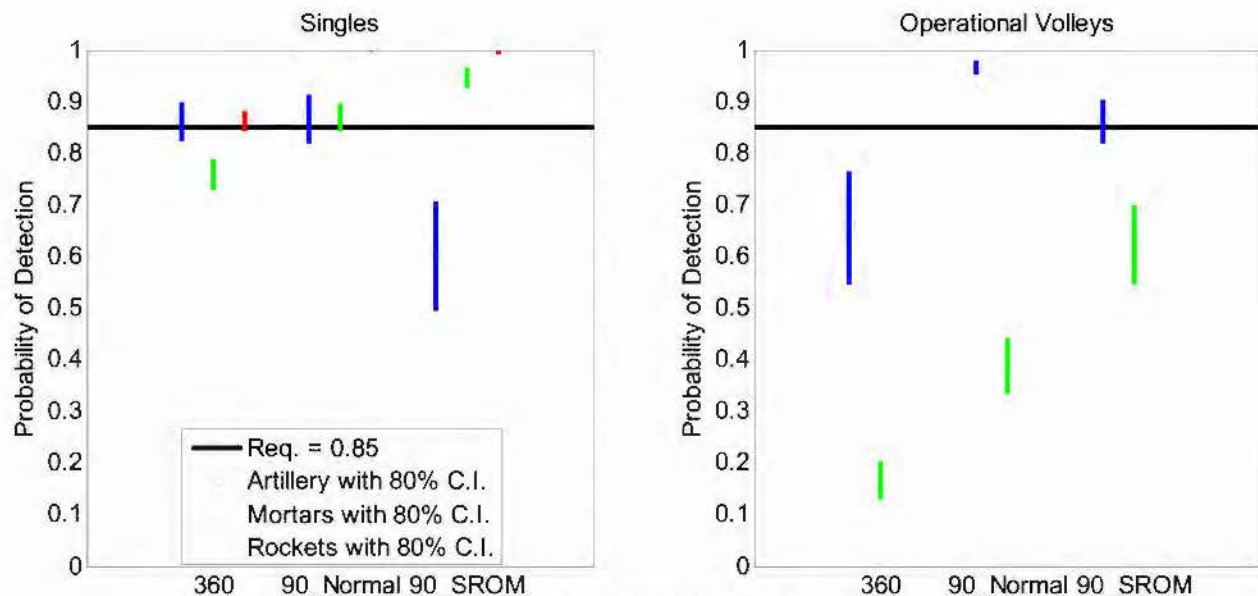


Figure 3-1. IOT&E 2 Probability of Detection

During IOT&E 2, artillery and mortar were volley-fired and the radar met or came close to meeting the requirement for single-fired and simultaneous shots. In 90-degree modes, rocket detection was better than detection of mortar or artillery. In the 360-degree mode, the probability of detection for mortar single shots was lower than that for rocket and artillery. This trend was not evident for simultaneous shots.

The radar detected artillery fired in operational volleys in the 90-degree modes, with performance reduced while in the 360-degree mode. However, the radar had problems detecting mortars fired in operational volleys. One possible reason for the difference in performance between artillery and mortar is the time separation between each successive projectile fired. Shorter time separations lead to greater difficulty in the radar's ability to detect the munition. Spaced projectiles that are fired rapidly make it difficult for the radar to distinguish each individual projectile, so the radar may see multiple projectiles as a single object. The radar then categorizes the objects as something other than projectiles, such as an aircraft. As a result, although the radar tracks the volley-fire, it does not declare it as a projectile and no target is generated. An attentive operator may notice the radar tracks, but the radar does not provide digital information on the weapon's location. Figure 3-2 shows the time separation for operational mortar and artillery volley shots. The mean time separation for artillery volley shots is almost twice that for mortar volley shots.

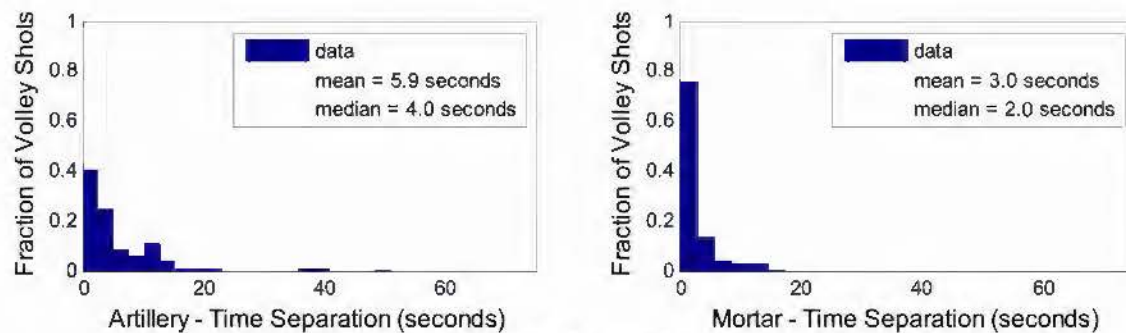


Figure 3-2. Time Separation of Shots

Figure 3-3 shows the comparison of IOT&E, IOT&E 2, and the Program Office's capstone event. The capstone event was a technical test using Soldiers, with scope similar to the IOT&E 2. With the exception of a few instances, the performance of the radar was consistent across all tests.

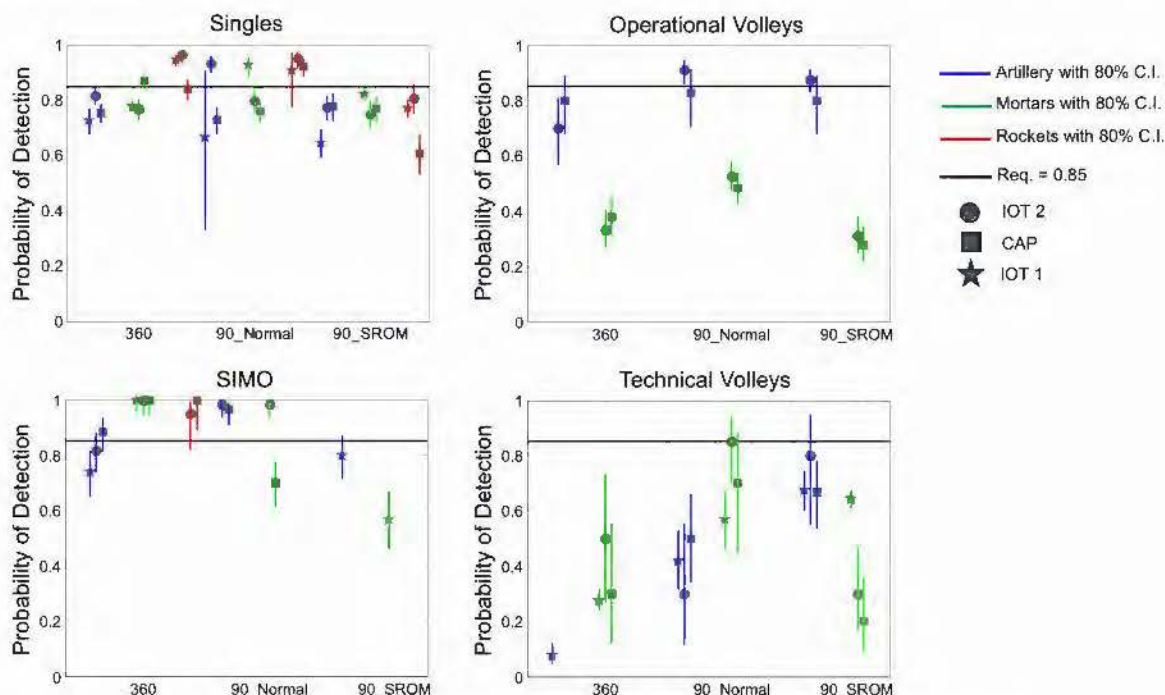


Figure 3-3. Radar Detection Comparison across Multiple Test Events

DOT&E's IOT&E 2 regression analysis found that multiple factors contribute to the Q-53's ability to detect projectiles. While many factors affect performance, a few key factors reduced the radar's ability to detect projectiles: volley-fire, the DTED issue, 90-degree SROM for artillery greater than 15 kilometers from the radar, and 360-degree for mortars at short shot ranges.

Volley Fire

Volley-fire reduces the radar's ability to detect mortar projectiles, as shown Figure 3-4. The Army recognizes this issue and has inserted a volley-fire requirement in the updated

requirement document. The proposed requirement states that the projectiles must have a time separation greater than 2 seconds. As shown in Figure 3-2, 50 percent of mortar projectiles fired in IOT&E 2 were less than 2 seconds. In response to the new requirement, the Program Office is updating the radar's software. The SROM mode is optimized for shorter ranges with radar performance deteriorating at longer radar-to-weapon ranges. The Normal mode is a general radar mode designed to cover wider radar to weapon range.

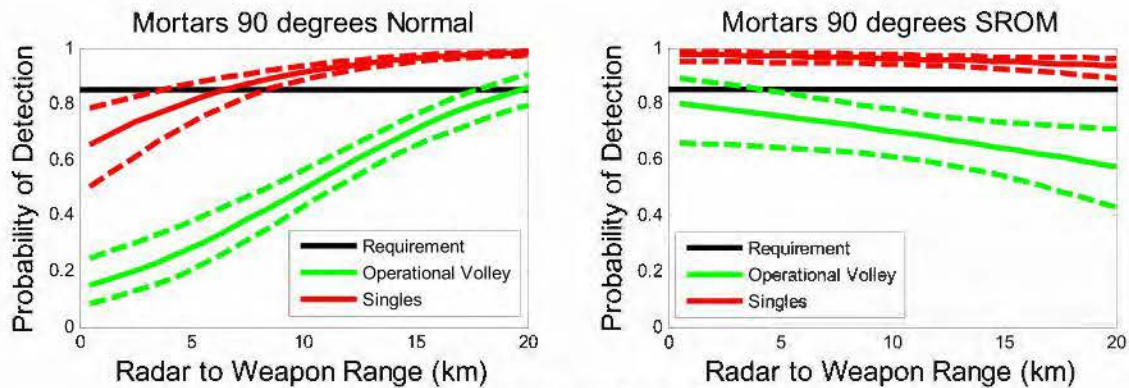


Figure 3-4. Effect of Fire Rate on Detection of Mortars

Digital Terrain Elevation Data (DTED) Issue

In the 90-degree modes, the radar adjusts the radar beams so they follow the terrain to detect projectiles rising above the terrain. This terrain mask can be determined in a number of ways, but the most common and convenient is to use DTED. The Program Office discovered a problem with how the radar uses DTED to determine the terrain mask in developmental tests prior to IOT&E 2. As the radar builds the terrain mask, it uses the previous extrapolated altitude as part of the extrapolation for the next altitude; because the radar is incorrectly calculating the results, the altitude errors build upon themselves. The error is not operationally significant if the terrain is flat, but if there is mountainous terrain in the terrain mask generation, the error can be large for portions of the search area, making the mask altitude so high that most projectiles travel below the radar beams and are not detected. This effect is shown in Figure 3-5. The DTED error thus affects performance in circumstances dependent on the surrounding terrain and the weapon's location in the search area. The Program Office has identified a potential fix and will test and implement the fix prior to fielding.

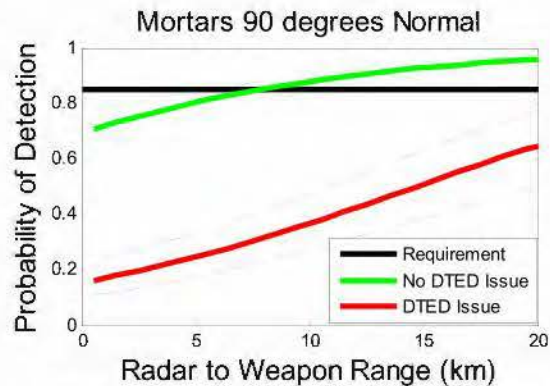


Figure 3-5. Example of Effect of DTED Issue on Radar Detection

90-degree SROM for Artillery

The 90-degree SROM mode is optimized to detect projectiles when fired at short ranges to the radar. DOT&E's IOT&E 2 regression analysis shows 90-degree SROM does improve performance for mortars at the closest radar-to-weapon ranges with little or no degradation at longer ranges (see Figure 3-4). For artillery at radar-to-weapon ranges greater than 15 kilometers, 90-degree SROM performance degrades as compared to 90-degree Normal. The training manual indicates that SROM will meet requirements for artillery at radar-to-weapon ranges less than 25 kilometers. The Program Office should investigate this issue and revise the training manual so commanders understand the consequences of using 90-degree SROM mode. If the trend is confirmed, the training manual should be revised so commanders understand the consequences of using 90-degree SROM mode.

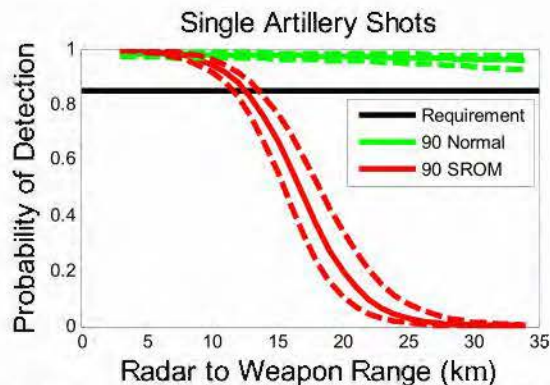


Figure 3-6. Effect of DTED Issue on Radar Detection

360-degree for Short Shot Range Mortars

The radar probability of detection was below requirements for mortars firing at the shortest IOT&E 2 ranges (less than 2.5 kilometers). Figure 3-7 shows the effect of shot range on the probability of mortar detection for single shots. From the radar's perspective, these are difficult trajectories because they spend a short time in the radar's search sector.

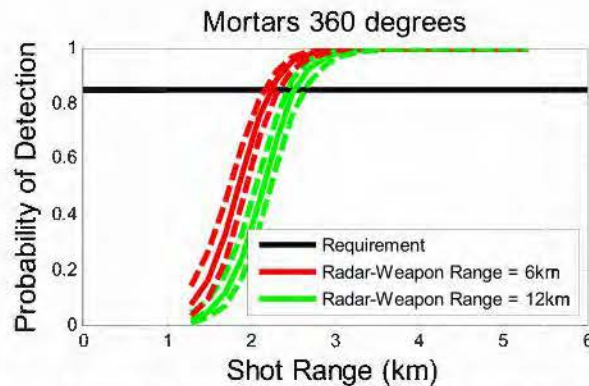


Figure 3-7. Effect of Short Range on Radar Mortar Detection

Probability of Characterization

The probability of characterization is the probability that the radar correctly identifies the munition as artillery, mortar, or rocket. It measures the fraction of projectiles identified given the number of projectiles fired. The probability of characterization is shown in Figure 3-8.

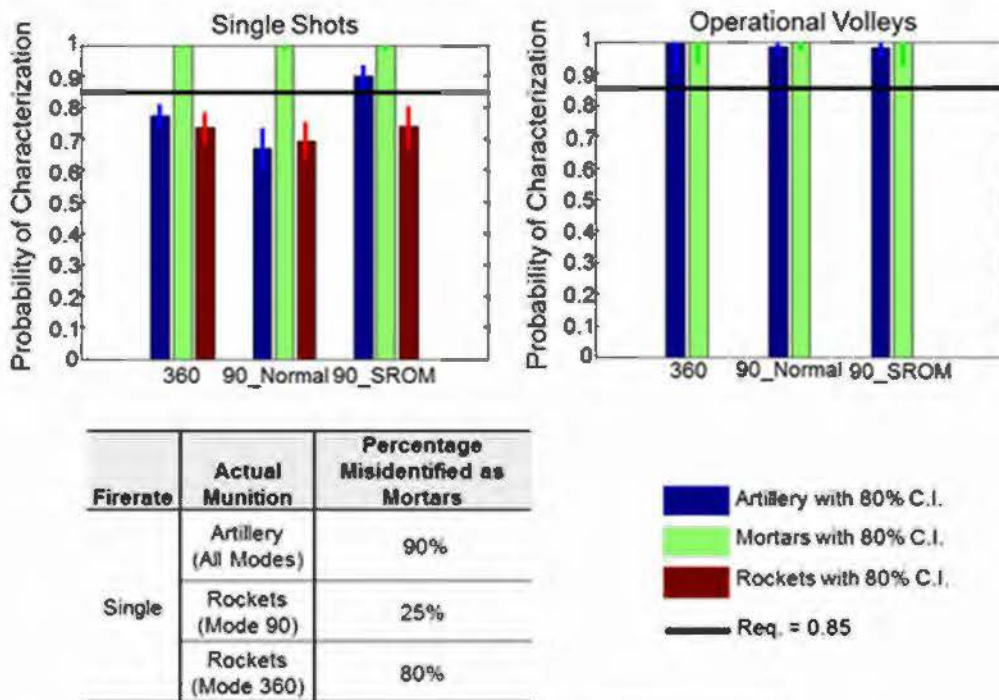


Figure 3-8. Probability of Characterization

As tested, the radar met the requirement for characterizing single-fired and simultaneous mortars with confidence. The radar characterized the detected projectile as a mortar unless it received information suggesting otherwise. However, characterizing artillery and rockets proved more challenging. The radar did not meet the 85 percent requirement for artillery and rockets, except for artillery using 90-degree SROM. The radar met the requirement for simultaneous shots in the 360-degree mode with confidence, but did not do so for artillery in 90-degree Normal. The radar met the single-fired requirement for volley-fired munitions.

Commanders use information on munition types to plan counterfire and conduct intelligence preparation of the battlefield. The type of weapon and the volume of fire are different for mortar, artillery, or rocket threats. Therefore, incorrect characterization of threat munitions can result in ineffective or wasteful counterfire missions. Knowing the type of weapon helps the commander determine the type of threat unit as well as its strength. This can be critical in planning future attacks.

Point of Origin Error

The point of origin error is the median error of the radar's prediction of the threat weapon's location. The effectiveness of counterfire attacks depends upon the accuracy of the radar's estimate of the threat weapon's location. The radar located the threat firing location point of origin within the required error for most conditions as shown in Figure 3-9. Accuracy was degraded for volley-fired artillery.

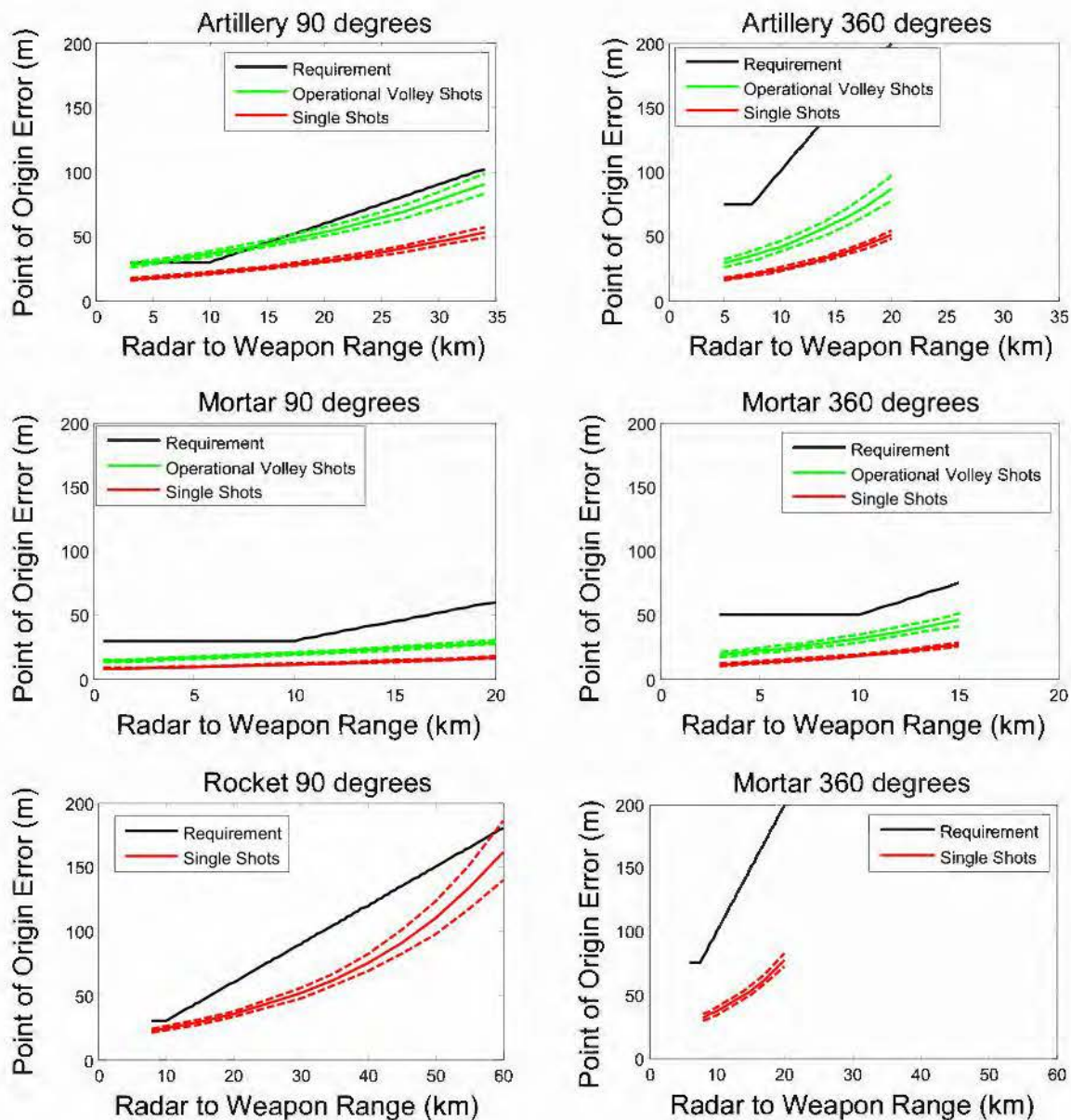


Figure 3-9. Point of Origin Error

Point of Impact Error

The point of impact error assesses the radar's ability to identify the point of impact of the detected projectile, and is used to warn troops of incoming projectiles and prioritize counterfire missions. Threat missions affecting near-friendly units are given a higher counterfire priority. The accuracy of the point of impact estimate is not as critical, since knowing a general location of the impact suffices for both warnings and prioritizing counterfire missions. Figure 3-10 shows the IOT&E 2 data for point of impact error for each mission conducted by munition type, radar mode, and rate of fire.

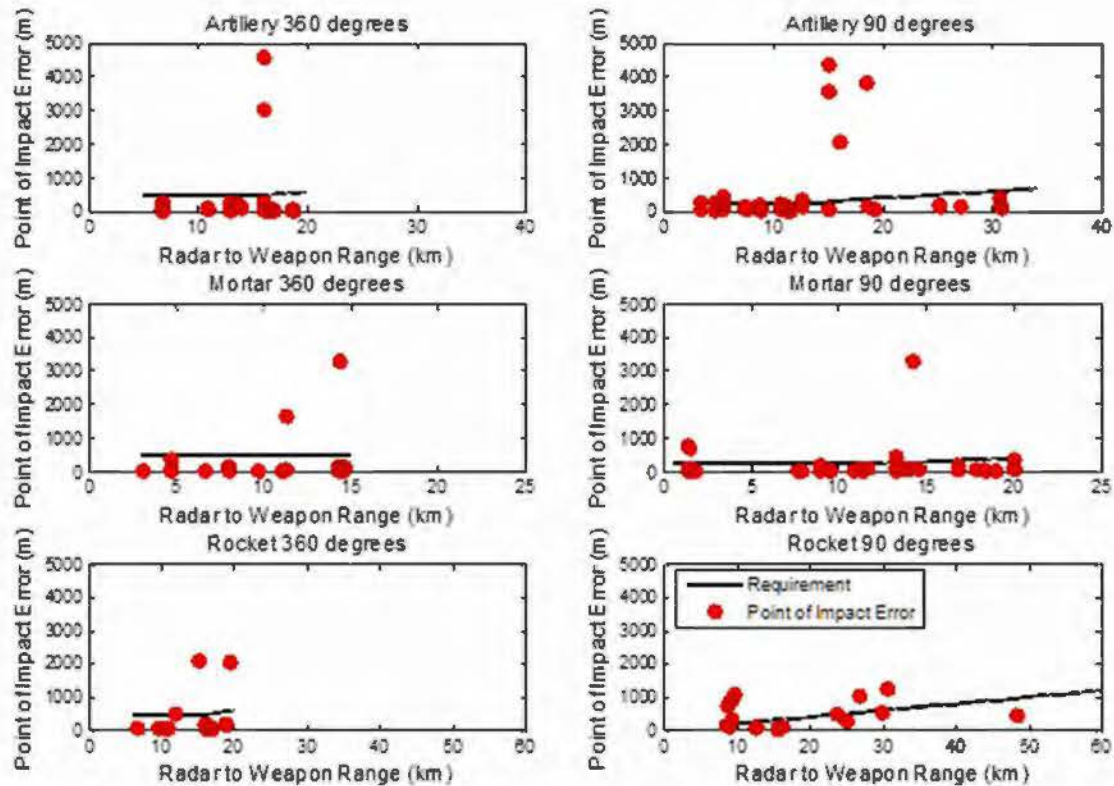


Figure 3-10. IOT&E 2 Point of Impact Error

The radar met the point of impact requirement for most mortar and artillery missions as shown in Figure 3-10. Point of impact error for rockets is larger than that for mortars and artillery. The point of impact errors are tied to the Q 53 software.

False Target

A false target occurs when the radar determines that a threat weapon is firing, when none is present. The radar may do this when there is nothing known in the air, or the radar may classify an aircraft as a ballistic trajectory. The majority of the IOT&E 2 false targets were generated when there were no known projectiles or aircraft in the vicinity. During the second 72-hour record vignette, a radar crew operated close to the Yuma Arizona Marine Air Station to examine the radar's ability to distinguish between ballistic trajectories and aircraft.

Table 3-3 shows the false target rates when there were no known projectiles or aircraft in the vicinity of the false target. The Army requires the radar to have no more than one false target in 12 radiating hours. The Q-53 radar met requirements during the IOT&E 2, while in the 360-degree and 90-degree SROM modes. However, it did not meet the requirement for the 90-degree SROM mode. The Army is updating its false target requirement, but the 90-degree SROM results would still not meet the new requirement (less than 1 false target per 6 hours). During a 1.8-hour period, one radar provided 23 false locations. The cause for this surge is not known, but it indicates that the 90-degree SROM rate can vary due to unknown conditions.

Removing this surge from the 90-degree SROM total still gives a false location rate (3.6 per 12 radiating hours) above the requirement.

Table 3-3. False Target Rate per 12 Radiating Hours

Radar Mode	Requirement	IOT&E 2 False Target Rate/ 12 hours (80% CI)	First IOT&E False Target Rate/ 12 hours (80% CI)
360-degree	1 per 12 hours	0.5 (0.2 – 0.8)	7.4 (6.8 – 7.9)
90 Normal	1 per 12 hours	0.7 (0.4 – 1)	20.6 (17.8 – 23.4)
90 SROM	1 per 12 hours	6.6 (5.4 – 7.9)	32.3 (30.7 – 33.9)
Total	1 per 12 hours	2.1 (1.8 – 2.5)	16.6 (16.0 – 17.3)

CI – Confidence Interval; SROM – Short-Range Optimized Mode

As shown in Table 3-3, the IOT&E 2 false location rates are a significant improvement over the results seen in the first IOT&E. However, although the SROM false location rate has improved, the Program Office recognizes the false location rate as a deficiency that must be improved. The Army plans to improve radar software to lower the SROM false target rates.

Table 3-4 shows the IOT&E 2 results when a Q-53 operated near the Yuma Marine Air Station. There is no specific Army requirement for classifying aircraft as projectiles. The rates seen while operating near the air station are greater than the false target requirement. The data available for this event do not allow correlating false targets with aircraft activity at the airfield. There is a significant difference between 90-degree Normal when operated near the airfield and in the other portions of the IOT&E 2 away from the airfield, which indicates a potential false target issue when operating near an airfield. The Program Office recognizes this as a potential issue and plans software upgrades to lower the radar's false location rate due to aircraft and other environmental clutter.

Table 3-4. False Target Rate per 12 Radiating Hours during Airfield Operations

Radar Mode	Number False	Number Radiate Hours	False Target Rate/ 12 hours (80% CI)
360-degree	0	11.0	80% Confident < 1.8
90 Normal	9	17.4	6 (4 - 9)
90 SROM	13	29	5.4 (3.5 .5 8 1)

CI – Confidence Interval; SROM – Short-Range Optimized Mode

False target rates can cause significant operational disruption. High false target rates will lead to wasted missions on non-targets and result in commanders not trusting the Q-53 radar. False warning of incoming indirect fire can cause significant disruptions at forward operating bases, as each warning requires Soldiers to take protective cover. By requiring detections of at least two sensors, the Counter Rocket, Artillery, and Mortar (C-RAM) system can reduce false warnings, but rates as high as 32 per 12 hours would tax the system and lead to distrust of the Q-53 radar's force protection capability. This could result in a counter fire mission being developed in the counter fire cell and sending a fire mission to a firing unit.

Counterfire Cell Operations

Soldiers in the counterfire cell are responsible for managing the radars under its control. The counter fire cell manages the radars' locations, search sectors, and frequencies, and will make recommendations for the placement of the radars, search sectors, and radar mode. These factors are important because they ensure that the radars cover the required area of operations while minimizing interference between radars. The radar search sectors and the location of nearby radars should not overlap because this can cause radar interference. For the 360-degree radar, the radar can blank angular sections of the search area. While rotating, the radar will stop radiating while pointed at the blanked sector. Army tactics, techniques, and procedures (TTP) recommend centering the blanked sector on the nearby radar with a 10-degree angular width around the radar and suggests that the Q-53 radars be placed more than 20 kilometers from other Q-53 radars operating in the 360-degree mode.

During IOT&E and IOT&E 2, the counterfire cell managed the radars throughout the pilot and record test and made recommendations for the placement, orientation, and operating mode of the Q-53 radars. During IOT&E 2, testers, acting as unit commanders, reviewed the counterfire cell's recommendations for radar locations, search sectors, and frequencies. The testers did not deny any of the counterfire cell recommendations, as the counterfire cell understood how to manage the radars in an operational environment. During test execution, the test officer did make adjustments to the radar deployment order as necessary to ensure consistency with the design of experiments and test plan construct. The counterfire cell managed

the blanking sectors and radar locations. In one specific instance, the counterfire cell failed to assign sector blanking. In other cases, the blanking separation was less than 10 degrees, because the counterfire cell used the radar's planned position rather than the radar's known position after completing position emplacement. The Army should address these errors in their revised counterfire crew drill and TTPs for the Q-53.

The counterfire cell did have a few problems managing the frequencies of the radars under their control. The Q-53 radar uses three radar frequencies between the ranges of 3,110 to 3,490 megahertz (MHz). To avoid radar interference, it is important that nearby radars operate on frequencies at least 25 MHz less than or greater than the frequencies of the other radars. The counterfire cell is responsible for ensuring that the radars maintain the frequency they were given at the beginning of operations. During one time period, the radars operated on similar frequencies. The data for these cases were not used for the radar performance analysis. Frequency management is difficult because there is no digital method for monitoring the radar's frequency. The counterfire cell had to contact the radar operators and ask them to report their frequency. The Army should address frequency management in their revised counterfire crew drill and TTPs for the Q-53.

Section Four Operational Suitability

The Q-53 radar system demonstrated an operational availability of 0.99 during the IOT&E, indicating that the radar is operationally suitable and available to support the commander's mission.

The demonstrated performance of the Q-53 radar during the IOT&E 2 indicates that the program is not meeting reliability and maintainability requirements. During IOT&E 2, Soldiers and/or Soldier maintainers were able to fix all system aborts with simple procedures and available spare parts. The frequent system aborts did not affect mission accomplishment.

The quantitative suitability measures consider reliability, availability, and maintainability measures for the overall radar system, including the antenna array, the transport vehicle, the support vehicle, and the associated generators. Qualitative suitability characteristics include performance of emplacement and displacement operations, tactical movement, survivability movement, and Soldier feedback from after-action reviews and survey questionnaires. Table 4-1 shows the quantitative suitability calculations.

Table 4-1. Suitability Parameters

Parameter	Requirement	Performance Point Estimate (80% Confidence Interval)
MTBSA (hours)	80% confident above 185 hours MTBSA	62.5 (38 - 107)
MTTR (hours)	≤ 0.3	0.5 (0.30 - 0.85)
Operational Availability	$\geq 95\%$	99% (98.7% - 99.9%)
Probability that 2 of 3 complete a 72-hour mission without a System Abort (Fires Brigade)	$\geq 0.75^1$	0.24 (0.06 - 0.52)
Probability that 1 of 2 complete a 72-hour mission without a System Abort (Brigade Combat Team)	$\geq 0.70^2$	0.53 (0.28 - 0.76)

MTBSA – Mean Time Between System Abort; MTTR – Mean Time To Repair

¹ The current requirement is based upon assigning three radars to fires brigades. Emerging configurations have two radars in each maneuver brigade, fires brigade, and division artillery.

² The new draft requirement is a probability of 0.70 that one of two radars complete a 72-hour mission without a failure.

During 500 record test hours, the system experienced eight system aborts, leading to a loss of 3.98 operational hours for troubleshooting and/or maintenance activities. During the IOT&E 2, the radar was available for combat operations 99 percent of the time.

The radar did not meet its reliability requirement because of the number of failures. The Army requires an 80 percent confidence of meeting a Mean Time Between System Abort (MTBSA) of 185 hours. The Q-53 achieved 62.5 hours MTBSA with an 80 percent confidence interval of 38 to 107 hours during IOT&E 2. The 185-hour requirement is derived from the requirement for the radar to have a 75 percent probability that two of three radars operate failure-free for 72 hours. The new artillery doctrine prescribes two radars for each brigade and/or division artillery headquarters, whereas fires brigades under the previous construct have three radars. The Army is staffing updated requirements to address these changes and adjust the overall reliability requirement. Table 4-1 also shows the probability of operating failure-free for fires brigades (two of three) as 0.24 against the current requirement for 0.75 and brigade combat teams/division artillery (one of two) as 0.53 against the proposed requirement of 0.70. The proposed requirement equates to 91 hours MTBSA and is within the IOT&E 2 MTBSA confidence interval (38 to 107 hours). The total repair and troubleshooting time of 3.98 hours led to an achieved Mean Time to Repair (MTTR) of 0.5 hours with an 80 percent confidence interval of 0.30 to 0.85 hours, which places the MTTR at the extreme edge of the threshold of 0.3 hours with 80 percent confidence.

The achieved operational availability indicates that the failure frequency and the repair times had minor impact on overall mission availability with respect to the radars being available to the commander. The potential mismatch between requirements values may highlight the need to better operationalize the requirements in terms of mission availability.

Mission reliability is a parameter that bridges the failure-focused nature of MTBSA and MTTR with the operational context of mission accomplishment. During IOT&E 2, the Q-53 achieved mission reliability for a single radar of 0.32 with an 80 percent confidence interval of 0.15 to 0.51. The current mission reliability requirement as derived from the MTBSA value of 185 hours is 0.68. The new draft requirement, with a revised 91 MTBSA hours requirement, yields a mission reliability requirement of 0.45.

The operational availability is based on the results of the IOT&E 2 and is similar to operational readiness associated with a mission. Soldier crews conducted 57 tactical and 23 survivability moves during the IOT&E 2, accumulating 875 kilometers of cross-country and unimproved road travel – a distance consistent with the Operational Mode Summary/Mission Profile (OMS/MP). The operating hours include travel time. The repair-time information focuses on the eight system abort failures and includes troubleshooting, parts requisition, and physical maintenance actions, ranging from simple tasks such as computer reset to more complex part replacement using line replaceable units (LRUs). Repair actions for all failures during the IOT&E 2 used organizational stocks either carried with the crew equipment or available with the unit maintenance team. The duration of the failures ranged from 12 minutes to 1.1 hours. Five of the eight failures were software-related failures that required crew action to troubleshoot and then power cycle the system (similar to a complete re-boot of a personal computer). While the

achieved reliability and maintainability scores from the IOT&E 2 are not consistent with system requirements, the failure to meet the reliability and maintainability requirements did not detract from overall system availability to support operational mission requirements.

The requirement for a 0.75 probability that two of three radars operate failure-free reflects the importance of no more than one radar being non-operational at a time. From an operational perspective, when one radar is non-operational, a commander can compensate by moving or adjusting the search sectors of the remaining operational radar.

Hardware failures are consistent with direct resource implications such as cost and time. In IOT&E 2, three of the eight failures were hardware related. The hardware MTBSA is 167 hours with an 80 percent confidence interval of 75 to 454 hours. The hardware MTTR value is 0.35 hours with an 80 percent confidence interval of 0.15 to 0.91 hours, yielding an operational availability point estimate of 99.8 percent. From a hardware-specific perspective, the system met all quantitative requirements thresholds. The current Q-53 Capability Production Document sets parameters for reliability, availability, and maintainability that are not mathematically compatible. The MTBSA and MTTR requirements values yield an operational availability value of 99.8 percent, indicating that the failure rate and repair requirements thresholds are more stringent than necessary to achieve the required operational availability of 95 percent. Based upon the Capability Production Document requirement for MTBSA (185 hours with 80 percent confidence), the MTTR value can be as high as 9.7 hours and still meet the availability requirement of 95 percent. Table 4-2 displays the Q-53 suitability performance during IOT&E 2.

Table 4-2. Q-53 Suitability Performance Summary

Capability	Requirement	Proposed Requirement ¹	Performance Point Estimate (80% Confidence Interval)
Operational Availability	0.95	0.90	99% (98.7% - 99.9%)
Reliability (MTBSA hours)	80% confident above 185 hours	91	62.5 (38 - 107)
Maintainability (MTTR hours)	≤ 0.3	≤ 0.3	0.5 (0.30 - 0.85)
Probability that 2 of 3 complete a 72-hour mission without a System Abort (Fires Brigade)	$\geq 0.75^2$	NA	0.24 (0.06 - 0.52)
Probability that 1 of 2 complete a 72-hour mission without a System Abort (Brigade Combat Team)	NA	≥ 0.70	0.53 (0.28 - 0.76)
Mission Reliability Probability that a radar completes a 72-hour mission without a System Abort (Single Radar)	0.68 ³	0.45 ³	0.32 (0.15 - 0.51)

MTBSA – Mean Time Between System Abort; MTTR – Mean Time To Repair

¹ The Army is updating Q-53 requirements. The requirements are currently being staffed with the Joint Requirements Oversight Council.

² The current requirement is based upon assigning three radars to fires brigades. New configurations have two radars in each organization.

³ As derived from the reliability requirement (185 hours MTBSA or 91 hours MTBSA).

Additional Suitability Considerations and Soldier Observations

Soldiers consider the Q-53 an improvement over current radar systems and highlight automatic platform leveling and Global Positioning System navigation capabilities as major strengths. The grounding kit and limited storage provisions for crew and individual equipment are detractors during operational employment. During tactical field operations, radar crews must conduct displacement and emplacement actions to address repositioning requirements to support counterfire missions and enhance survivability by avoiding enemy detection and subsequent enemy artillery fire.

The Q-53 has a requirement for emplacement not to exceed 5 minutes and for displacement not to exceed 2 minutes. The Army's proposed requirement is 10 minutes for emplacement and 5 minutes for displacement. The requirement applies to daylight. During the IOT&E 2, radar crew median emplacement and displacement times were 7.6 and 9.0 minutes during daylight. At night, however, the emplacement and displacement times were 9.0 and 12.4

minutes. The current system design requires electrical grounding kit (see Figure 4-1 below) installation and removal during emplacement and displacement operations. The grounding kit installation and removal tasks were the dominant reason for test crews not meeting Q-53 displacement and emplacement time requirements. During the IOT&E 2, the emplacement and displacement times had no adverse effect on mission accomplishment and the operational rationale for emplacement and displacement time requirements is not clear. The fielded Q-36 and Q-37 counterfire radars have emplacement and displacement training standards of 10 minutes/5 minutes and 30 minutes/15 minutes. The Q-53 radar crews met the time standards for the Q-37 legacy system.



Figure 4-1. Soldiers Installing the Electrical Grounding Kit

Soldier and leader surveys administered after the initial training and IOT& 2 indicate additional considerations regarding tactical and sustained operations. During tactical operations, the crews experienced numerous software warnings/fault messages that required operator decisions to either acknowledge the fault or conduct troubleshooting steps in the technical manual. Responding to the faults and warnings can detract from mission accomplishment and in some cases, lead to a system abort if operators choose to resolve the fault by power cycling during a mission. An additional banner or phrase to indicate severity or need for immediate action would mitigate misinterpretation and adverse mission impact. The computer screen does not prioritize the target acquisition display to override other displays when conducting operations other than responding to a radar acquisition. For sustained operations in a combat environment, the crews expressed concern regarding their ability to accommodate section equipment and personal gear in the limited carrying capacity of the section vehicles.

The Q-53 has two Family of Medium Tactical Vehicles (FMTVs) to carry the five-Soldier crew. The primary mission vehicle carries the antenna array and has no additional cargo-carrying capacity beyond small cargo holds inside the cab and limited external mounting positions for crew equipment and logistics items, such as pioneer tools, netting/tents, and fuel/water cans. The support FMTV has a shelter that is designed to house computer command and control devices, radios, and additional individual equipment. Soldiers need to be meticulous when loading plans to accommodate the equipment necessary to sustain a five-Soldier crew for 72 hours of operations or longer. There is not enough storage space to accommodate the amount

of equipment. During IOT&E and to a lesser degree in IOT&E 2, Soldiers commented that the importance of adhering to the load plans often encumbered their ability to conduct displacement operations. Soldiers and leaders in both tests were consistent in their recommendations for an additional vehicle (such as a cargo High Mobility Multipurpose Wheeled Vehicle (HMMWV)) that could serve as both an equipment vehicle and reconnaissance vehicle to assist with tactical repositioning and sustained operations. The additional vehicle may require an additional crew member without leveraging another Soldier from the parent unit.

Section Five Recommendations

The Army should consider the following recommendations and verify the correction of noted deficiencies during Follow-On Operational Test and Evaluation (FOT&E).

Operational Effectiveness

- Carry out plans to improve and test the radar's performance against threat units firing volleys
- Test the radar's performance against volley-fired rockets, after implementing a fix for volley-fire
- Test the planned fix for the Digital Terrain Elevation Data (DTED) issue
- Investigate radar's 90-degree Short Range Optimized Mode (SROM) probability of detection for short range artillery shots and update training manuals
- Improve the radar's probability of characterization
- Continue to investigate and solve the high false target rate in the 90-degree SROM configuration
- Continue plans to improve and further characterize and reduce false targets that are due to aircraft
- Address counter fire cell operations for frequency management, managing of blanking sectors and radar locations in their revised counterfire crew drill TTP for Q - 53.
- Address Q-53 load plans (Solider equipment, Q-53 subcomponent equipment) in order to utilize the SOG in an efficient manner. There is not enough on board carrying capability to accommodate the amount of equipment.

Operational Suitability

- Continue root cause analysis and resolution plans for software-related failures and verify fixes in FOT&E using Soldier crews
- Reduce software warnings and/or qualify the warnings (without requiring operators to consult the Interactive Electronic Technical Manual) to indicate when Soldiers must take immediate action
- Improve the grounding system to enhance emplacement/displacement responsiveness and decrease labor burden
- Prioritize the computer display windows so that fire missions are priority screens that override other graphical interface screens
- Increase vehicle onboard storage space/carrying capability to accommodate five-Soldier crews operating 72-hour.

- Consider an additional vehicle (such as a cargo High Mobility Multipurpose Wheeled Vehicle (HMMWV)) that could serve as both an equipment vehicle and recon vehicle or provide security to assist with tactical repositioning and sustained operations

Survivability

Based on vulnerabilities identified in the classified annex, the Army should:

- Resolve identified cybersecurity vulnerabilities and validate with Soldiers in testing
- Conduct additional cyber testing on future software upgrades.

The Army should conduct an FOT&E to include the following testing:

- Testing of the 240 mm rocket and 122 mm cannon munitions for both single- and volley-fire scenarios
- Tropics testing
- Operational testing when the radar is integrated with Indirect Fire Protection Capability Increments
- Planned volley-fire improvement testing
- An adversarial assessment for a planned wireless radio upgrade, planned wireless connection between radar and command and control vehicle, and new cybersecurity operating system upgrades
- Verification of potential fixes for Short SROM false targeting
- Additional testing of aircraft false targeting near airfields/high-clutter environments after improvements are made to software
- Testing of potential fixes for probability of characterization
- New systems testing of the 10-kilowatt generator and Environmental Control Unit (ECU), which are intended to provide robust, military-grade capabilities that can meet heating requirements in cold regions
- Testing of Q-53 radar reliability with Soldiers for future software upgrades