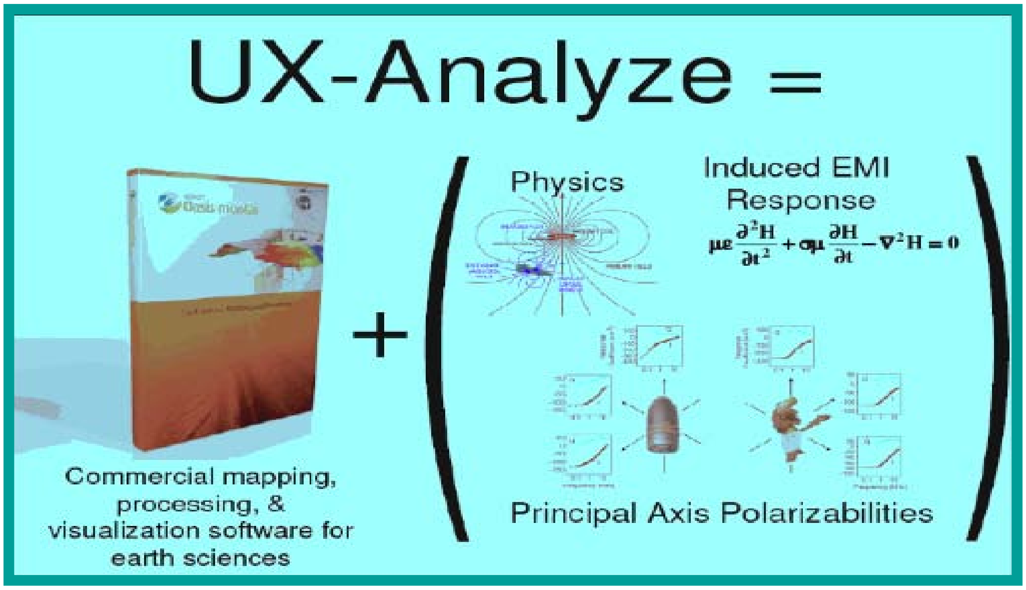
ESTCP
Cost and Performance Report

(MM-0210)



Feature-based UXO Detection and Discrimination

March 2008

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

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ACRONYMS AND ABBREVIATIONS

ASR	Archives Search Report
AUC	Area Under Curve
COV	coefficient of variation
DoD	Department of Defense
EMI	electromagnetic induction
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
FUDS	Formerly Used Defense Site
GPO	Geophysical Prove Out
HE	high explosive
IDA	Institute for Defense Analyses
IMU	Inertial measurement unit
mag	Magnetometer
ms	millisecond
MTADS	Multisensor Towed Array Detection System
NRL	Naval Research Laboratory
Pd	probability of detection
Pdisc	probability of correct discrimination
Pfa	probability of false alarm
QC	quality control
RMS	root mean square
ROC	receiver operating characteristic
RTK	real time kinematic
SAIC	Science Applications International Corporation
SNR	Signal to Noise Ratio
TOI	target of interest
UXO	Unexploded Ordnance

GLOSSARY

Characterization	Determination of parameters that are intrinsic to a target and can be used to make a discrimination decision
Classification	Formally, determination that an object belongs to a particular class of ordnance (i.e., is a 155 as opposed to an 81). Classification, by its formal definition, will not be explored in this study. Instead, in this document we will use the term classification as a synonym for discrimination.
Detection	Determination of the presence of a target, typically by observation of a signal level crossing a threshold set to limit the probability that a crossing would be caused by noise or interference.
Discrimination	Determination that a detected object is (1) high confidence clutter (and need not be dug) or (2) ordnance or unknown (and must be removed)
False Alarm (Detection)	Declaration of a target that is actually caused by noise, interference, geology
False Alarm (Discrimination)	Declaration of an item that could safely be left in the ground as ordnance or unknown
Target of Interest	For this study, defined to be intact munitions, both HE and practice; sizeable pieces of munitions (on the order of half a round); and items that look like munitions (e.g., pipes of similar size)

ACKNOWLEDGEMENTS

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We gratefully acknowledge Dr. Anne Andrews, Program Manager of ESTCP’s Munitions Management Thrust Area, and Dr. Jeff Marqusee, ESTCP Director, for their vision, support, and guidance throughout the life of this project.

The Principal Investigators for this project are Dr. Dean Keiswetter, SAIC, and Dr. Leslie Collins, Duke University. Key technical contributors include Mr. Tom Furuya, SAIC; Dr. Tom Bell, SAIC; Ms. Chunmei Yang, Duke University; and Ms. Lorraine Godwin, Geosoft Incorporated. The diverse, talented, and dedicated team merits heartfelt thanks for contributing in such an exemplary manner to the successful execution of the project.

1.0 EXECUTIVE SUMMARY

1.1 BACKGROUND

With current technology and survey practices, unexploded ordnance (UXO) site characterization is inefficient and incomplete. Not all buried UXO are routinely detected, and those that are cannot be routinely distinguished from other items in the ground that pose no risk. The impact on the Department of Defense (DoD) is clear—and expensive. A 2003 report by the Defense Science Board observed: “The … problem is that instruments that can detect the buried UXOs also detect numerous scrap metal objects and other artifacts, which leads to an enormous amount of expensive digging. Typically 100 holes may be dug before a real UXO is unearthed!”

Over the past decade, DoD has invested heavily in developing survey data analysis and processing techniques for use with commercial sensors that can improve UXO detection and discrimination between UXO and clutter. These techniques include characterization procedures for estimating target features from survey data (size, shape, depth of burial, orientation, etc.) and feature-based classification procedures to aid decision making.

Our technical approach promotes the selection of potential UXO targets using quantitative evaluation criteria and transparent decision-making processes. As such, we developed UX-Analyze, an analysis framework within Oasis montajTM that integrates quantitative analysis algorithms and custom-designed visualization schemes. UX-Analyze was conceived, coded, and validated under MM-0210. The analysis algorithms provide quantitative evaluation criteria. Specifically, they assume a dipolar source and derive the best set of induced dipole model parameters that account for the spatial variation of the signal as the sensor is moved over the object. The model parameters are target location and depth, three dipole response coefficients corresponding to the principal axes of the target (electromagnetic induction [EMI] only), and the three angles that describe the orientation of the target. The source’s size can be estimated using empirical relationships between either the dipole moment for magnetic data or the sum of the targets’ response coefficients.

1.2 OBJECTIVES OF THE DEMONSTRATION

The objective of this technology demonstration was to discriminate 4.2 inch mortars from native clutter at Camp Sibert, Alabama, by characterizing and classifying anomalies identified in EMI and magnetic survey data. Misclassifying a target of interest as an item that can be left in the ground (viz., a false negative) was defined to be the primary failure. The objectives were successfully achieved and documented.

1.3 REGULATORY DRIVERS

A stated objective in the DoD’s Report to Congress in 2001 is to, among other things, develop standards and protocols for navigation, geolocation, data acquisition, data processing, and performance of UXO technologies, including software and visualization tools needed to provide regulatory and public visibility to and understanding of the analysis and decision process made in UXO response activities.

1.4 DEMONSTRATION RESULTS

We analyzed 870 EM61 MK2 array anomalies and 969 magnetic anomalies. We based the discrimination decision on the net polarizability (Sb) for EMI and on the inverted magnetic moment for magnetic anomalies (the two data sets were interpreted independently). Labeled data from a geophysical prove-out and from truthed anomalies within the survey area was used to establish decision boundaries.

At our chosen operating threshold for the EMI data, we correctly classified 100% of the 4.2 inch mortars (Pd of 1.0) and correctly classified 49% of the remaining non-targets of interest (TOI) as high confidence clutter that could safely remain buried.

At our chosen operating threshold for the magnetic data, we correctly classified 100% of the 4.2in mortars (probability of detection [Pd] of 1.0) and correctly classified 43% of the remaining non-TOI targets as high confidence clutter that could safely remain buried.

1.5 STAKEHOLDER/END-USER ISSUES

Discrimination decisions can, in general, be legitimately based on a variety factors, including estimates of size, burial depth, remnant magnetization, decay rate, and the relative magnitudes of the inverted magnetic polarizations. Of these factors, the estimated size is perhaps the most robust to minor data errors, such as positioning or orientation glitches, while the magnitudes of the recovered magnetic polarizations are the least. This demonstration showed that is possible to separate 4.2 inch mortars from native clutter found at Camp Sibert using size estimates derived from geophysical data that was acquired in survey mode.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY DEVELOPMENT AND APPLICATION

The anomaly characterization algorithms embedded in UX-Analyze assume a dipolar source and derive the best set of induced dipole model parameters that account for the spatial variation of the signal as the sensor is moved over the object. The model parameters are target X,Y,Z location, three dipole response coefficients corresponding to the principal axes of the target and the three angles that describe the orientation of the dipole. The size of the target can be estimated from the sum of the targets' response coefficients. The shape of the target can be estimated from the relative magnitudes of the three coefficients. For example, cylindrical objects, like most unexploded ordnance (UXO), have one large coefficient and two smaller, equal coefficients. Platelike objects nominally have two large and one small coefficient. Spherical objects have three roughly equal coefficients.

UX-Analyze was developed to allow users to systematically identify, extract, edit, and store data around individual anomalies. It provides efficient data structures and access for the analysis algorithms, stores the fitted parameters, and allows for multiple data types and surveys. This module is the interface between Oasis montaj and the demonstration analysis software (Figure 1).

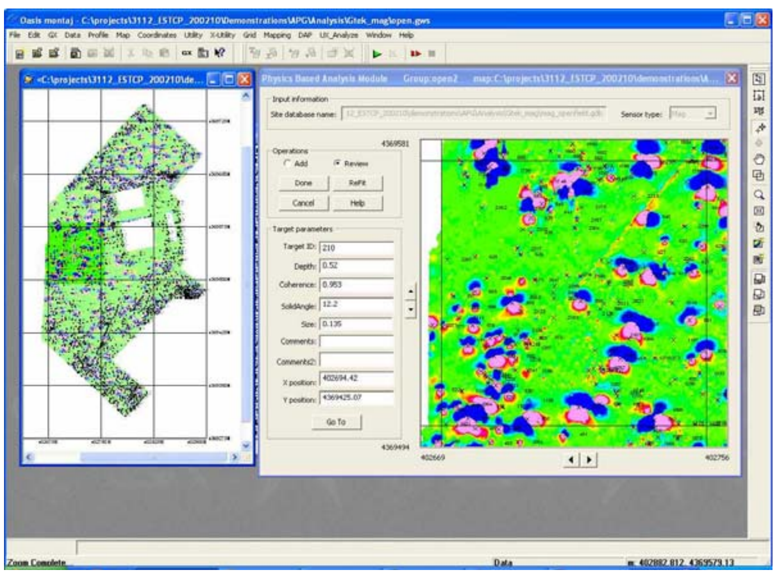


Figure 1. UX-Analyze Screen Snapshot During Data Analysis.

Characterization routines for magnetic and EMI data have been integrated with UX-Analyze framework. These 3-D routines include graphic displays and controls that allow the user to manually select and filter the input data for each anomaly (Figure 2).

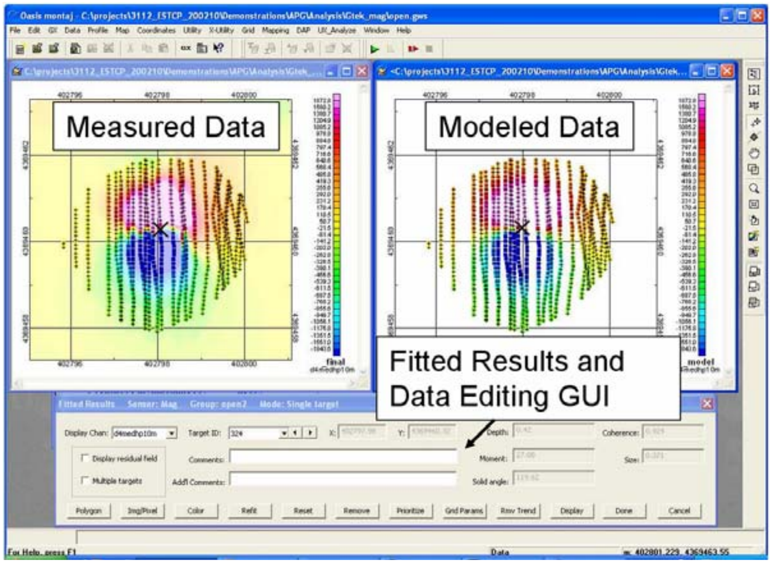
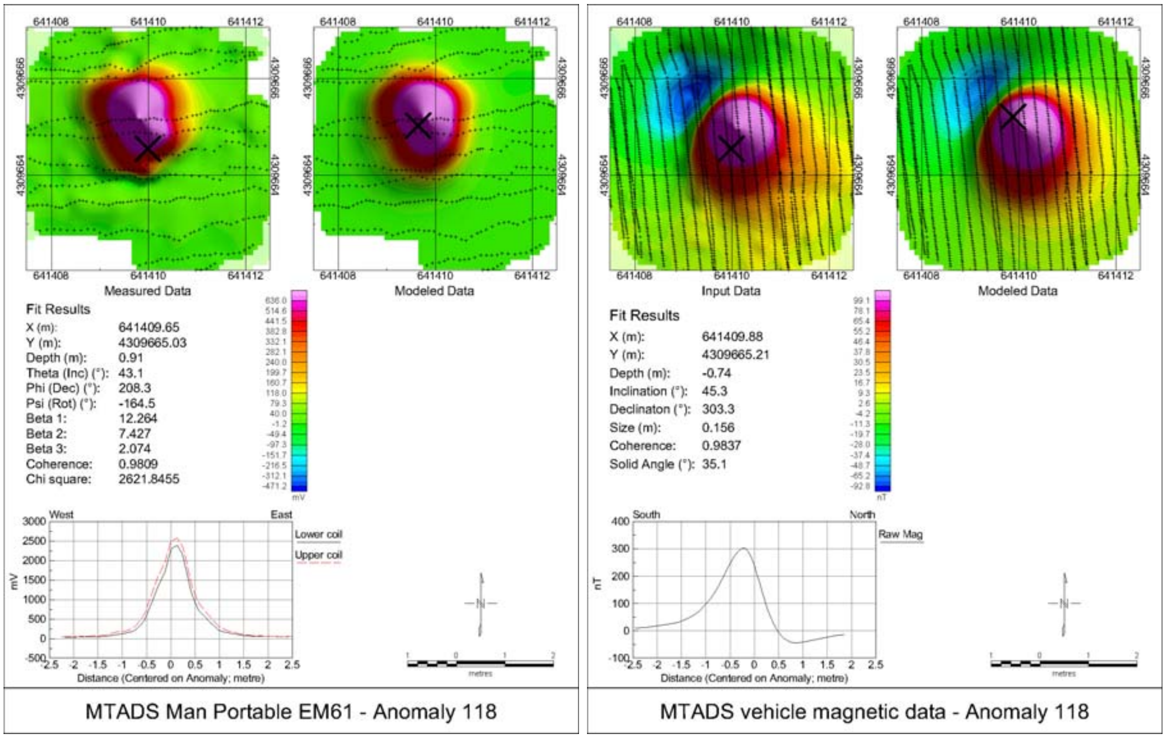


Figure 2. Screen Snapshots Showing the User Interface During Data Inversion.
The measured data is shown in the left map, the model parameters are displayed in the lower center window, and the forward model generated using the model parameters is shown in the right map.

UX-Analyze produces individualized anomaly reports, one for each anomaly, to document the decision process for each anomaly (Figure 3). In each plot, the measured data is graphically displayed next to the modeled data. The model parameters are listed in the middle of each page, and a profile extracted along the transect that is the closest to the inverted dipole location is located at the bottom.

Essentially, the anomaly plots graphically provide an intuitive confidence measure. If the measured and modeled data are indistinguishable, the reviewer can have confidence that the estimated source parameters are approximately correct. If the two maps are do not resemble each other, however, it tells us that the source in question (1) cannot be represented well using a point dipole source, (2) is not isolated, (3) does not have sufficient signal-to-noise ratio, or (4) was not properly sampled (spatially or temporally). In any case, if the two maps are dissimilar the inverted model parameters are most likely not correct.

This demonstration utilized magnetic and EMI array data acquired at Camp Sibert [12]. The data collection hardware consisted of a low-magnetic-signature vehicle that is used to tow magnetometer and EMI arrays over large areas (10-25 acres/day) to detect buried UXO (Figure 4). Spatial registration information is recorded using high performance real-time kinematic (RTK) Global Positioning System receivers with position accuracies of ~5 cm.



MTADS = Multisensor Towed Array Detection System

Figure 3. UX-Analyze Generates a One-Page Summary for Each Anomaly.
In the anomaly summaries shown above, the measured data is shown in the upper left hand corner, the inverted model parameters in the middle left, the forward model in the upper rights, and a profile in the lower left corner. This layout was selected to provide insight into the confidence of the analysis and conclusions. EMI data for the anomaly are shown in the left summary, and magnetic data on the right.

Figure 4. Naval Research Laboratories Multisensor Towed Array Detection System
(left: magnetomer array, right: EM61 MK2 array).

2.2 PROCESS DESCRIPTION

We received the final geopositioned, demedianed magnetometer and EM61 MK2data from the ESTCP Program Office. We inverted each anomaly, taking care to limit competing signatures and extraneous noise, using physics-based dipole models. Fitted model parameters include anomaly size (based on the moment for magnetic data and the trace of the polarizability tensor for EMI), shape (EMI only), XY position, depth, orientation, and fit error statistics. In addition to presenting the results of the inversion in spreadsheet form, UX-Analyze generated an anomaly summary sheet that shows the measured data, inversion results, and model data for quality control (QC) purposes.

TOIs were defined to include (1) intact munitions, both high explosive (HE) and practice, (2) sizeable pieces of the munitions of interest, on the order of half a round, and (3) items that look like munitions (i.e., pipes of similar size).

Items that may be safely left in the ground included HE fragments, single fins, cultural debris, geology, and small arms rounds (if present).

The demonstration focus was to identify items that may be safely left in the ground. *The main failure, therefore, was misclassifying a TOI as an item that can be left in the ground*. Individual targets were classified as indicated in Table 1. These discrimination labels were then used to calculate the rolled up performance measures presented in Section 4.

Table 1. Discrimination Labels (Categories).

Category	Comment	Recommended Action: (Dig or Leave in Place)
1	High confidence clutter	Leave in Place
2	Low confidence clutter	Dig
3	Can’t analyze	Dig
4	Low confidence TOI	Dig
5	High confidence TOI	Dig

The “Can’t Analyze” Category 3 label was used to identify targets that could not be inverted (i.e., the inversion did not converge) or could be inverted but the fit error statistics indicated that the results could not be trusted. We determined the threshold for the later case for each dataset individually using labeled data.

2.3 PREVIOUS TESTING OF THE ANALYSIS TECHNOLOGY

Our analysis framework and procedures, described in a number of publications [2-9], have been, or are being, successfully demonstrated in a variety of ESTCP Projects, including MM-9811, MM-9812, MM-199526, MM-9812, MM-9918, MM-0031, MM-0033, MM-0034, and MM-0108.

Previous testing of the analysis approach and software suite included a shakedown using a large volume dataset acquired at Standardized UXO Technology Demonstration Site, Aberdeen Proving Ground Maryland in 2006. During the shakedown test, we encountered programming bugs and logic problems that had not been exposed during development or tests with more modest data sets. We identified and resolved 71 bugs associated with data handling, 51 bugs associated with visualization, 15 bugs associated with the inversion routines, 22 bugs that were generated while adding new features and user interfaces, and 38 bugs associated with miscellaneous functionality. At the conclusion of the shakedown test, all identified problems had been fixed.

Technology demonstrations were also carried out at live sites in Connecticut and Colorado. Demonstration plans and interim reports are on file with the ESTCP Program Office.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

This demonstration technology uses spatially referenced geophysical data to estimate target features using a dipole model. This has an inherent advantage over ancillary analysis, less robust methods commonly employed. Ancillary analysis methods sometimes include metrics such as the anomaly amplitude, half width, spatial footprint, or overall "look." These later metrics are, however, sensitive to the targets' orientation and depth of burial. The methodology demonstrated here separates the measured signatures into that which is inherent to the target, and that which is related to the geometry of the problem (such as distance to sensor and orientation).

The primary advantage, therefore, is the potential for discriminating between UXO and non-UXO-like objects based on quantified metrics calculated by inverting geophysical survey data. Results from past demonstration have, in fact, shown that that discrimination is possible using magnetic and electromagnetic data [10]. Magnetic discrimination is based primarily on the apparent fitted dipole size (or scaled dipole moment). Using EMI data, increased discrimination performance can sometimes be achieved by utilizing estimated shape information. If successful discrimination capabilities can be achieved, significant excavation savings can be realized by leaving the nonhazard clutter items unearthed or by altering the way in which they are recovered.

Known limitations to the data analysis approach adopted here result from non-unique inversion results, and overlapping, or non distinct, signatures in feature space. The former limitation, one in which multiple sets of model parameters explain the vast majority of the observed data, is well known. The second, while perhaps not as widely appreciated, is equally problematic. Inverting EMI data using dipole models results in three eigenvalues of the magnetic polarizability tensor, each corresponds to a principal axis of object. Discrimination is possible only to the degree that the derived eigenvalues are different for different objects and stable for similar classes of objects. In other words, even with ideal data, the estimated burial depth, apparent size, and shape features may not separate UXO and clutter signatures into distinct, non-overlapping classes. This is because the anomaly features derived from EMI and magnetic data are not unique to UXO. Clutter items that have similar shapes and burial attributes to ordnance can have geophysical signatures that are indistinguishable from UXO signatures and, as such, will have similar eigenvalues and therefore likely be classified as ordnance. Examples include items such as pipes, post sections, and axial symmetrical fragments.

3.0 DEMONSTRATION DESIGN

3.1 PERFORMANCE OBJECTIVES

Table 2. Performance Objectives for the Discrimination Study.

Type of Performance Objective	Primary Performance Criterion	Expected Performance (Metric)	Actual Performance Objective Met?
Quantitative	Correct characterization parameters	X,Y distance: <20 cm (1s) Z: <15 cm app size: (COV* <0.3)	Yes
	Maximize correct determinations of nonordnance	Discrimination eliminates >20% of the detections corresponding to items not of interest at the no-dig threshold	Yes
	Maximize correct determinations of ordnance	Discrimination retains all detected objects of interest above the no-dig threshold (may be multiple thresholds)	Yes
	Demonstrate effect of data quality (line spacing, location error, signal/noise levels, etc.) on the ability to correctly extract parameters and classify ordnance versus nonordnance	Data quality effects can be isolated and understood	Yes

*coefficient of variation (COV) – standard deviation/root mean square (RMS) error

3.2 SELECTING THE TEST SITE

Camp Sibert is located within the boundaries of Site 18 of the former Camp Sibert. The land is under private ownership and is used as a hunting camp. The criterion that drove the site selection process were (1) a single use artillery or mortar range, (2) simple clutter environment, (3) benign geology, (4) live ordnance used, and (5) benign topography and vegetation. Additional considerations were size (20-25 acres was desired), anomaly density (mostly isolated anomalies, 100-200 per acre), total anomaly count (2,500 to 5,000 anomalies were desired), and access/authorization to seed site with inerted targets.

3.3 TEST SITE HISTORY/CHARACTERISTICS

Information on the former Camp Sibert is available in the archival literature such as an Archives Search Report (ASR) developed in 1993. Camp Sibert is composed of mainly sparsely inhabited farmland and woodland and encompasses approximately 37,035 acres. The Gadsden Municipal Airport occupies the former Army airfield in the northern portion of the site. The site is located approximately 50 miles northwest of the Birmingham Regional Airport or 86 miles southeast of the Huntsville International Airport. The site is near exit 181 off Interstate 59 in Gadsden and located approximately 8 miles southwest of the City of Gadsden, near the Gadsden Municipal Airport.

3.4 PHYSICAL SETUP AND OPERATION

This data analysis demonstration utilized data acquired during the ESTCPs UXO Discrimination Pilot Program, which was conducted in 2007. As such, others were responsible for the significant tasks of establishing a geophysical prove out, seeding control targets, acquiring the geophysical data, overseeing recovery operations, and managing the information flow. These activities are being reported directly by the ESTCP Program Office. Key chronological dates with regard to the overall program are listed in Table 3.

Table 3. Timetable of Demonstration Events.

Event	Date
Data collection surveys	April/May 2007
Receipt of data from Program Office	June 18, 2007
Receive target lists of anomalies	June 29, 2007
Receive labeled data for training	August 6, 2007
Submit letter report regarding analysis approach and expected performance	August 22, 2007
Submit letter report regarding analysis approach and expected performance—revision	September 14, 2007
Submit analysis results (prioritized dig list)	September 25, 2007
Received performance results from IDA*	November 20, 2007
In-Progress Review	November 30, 2007
ESTCP/SERDP Symposium Brief	December 4, 2007

*Institute for Defense Analysis

4.0 PERFORMANCE ASSESSMENT

4.1 PERFORMANCE DATA

Scoring performances for our analysis of the EMI sensor data are reported in Table 4 and shown graphically in Figure 5. A receiver operating characteristic (ROC) chart is shown in Figure 6. From a declared category perspective, the Category 3 targets are plotted first, followed by Categories 5 (red), 4 (orange), 2 (yellow), and finally 1 (green).

Using the established thresholds, there were no classification failures. All UXO were categorized medium or high confidence UXO (Category 4 or Category 5), while correctly classifying 49% of the total digs as objects that could be safely left in the ground (Category 1).

Table 4. Performance Summary: EM61 MK2.

EM61 Array UXA

	Cultural	Munition Debris	No Contact	Rock	Soil	UXO
1	75	155	2	22	101	0
2	8	59	1	3	11	0
3	17	16	0	18	44	0
4	4	28	1	1	7	6
5	2	34	1	1	4	113
TOTAL	106	292	5	45	167	119

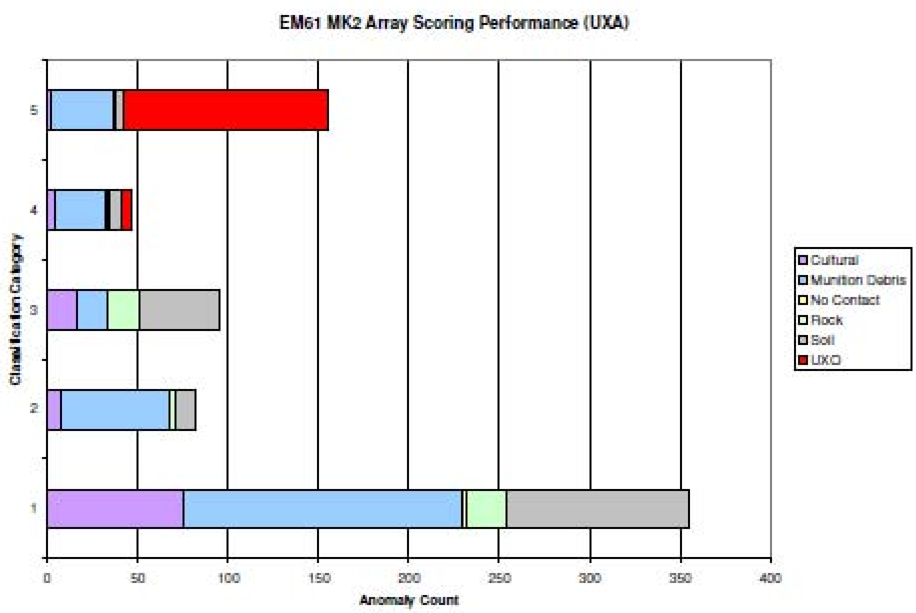


Figure 5. EM61 MK2 Array Performance as a Function of Classification Category.

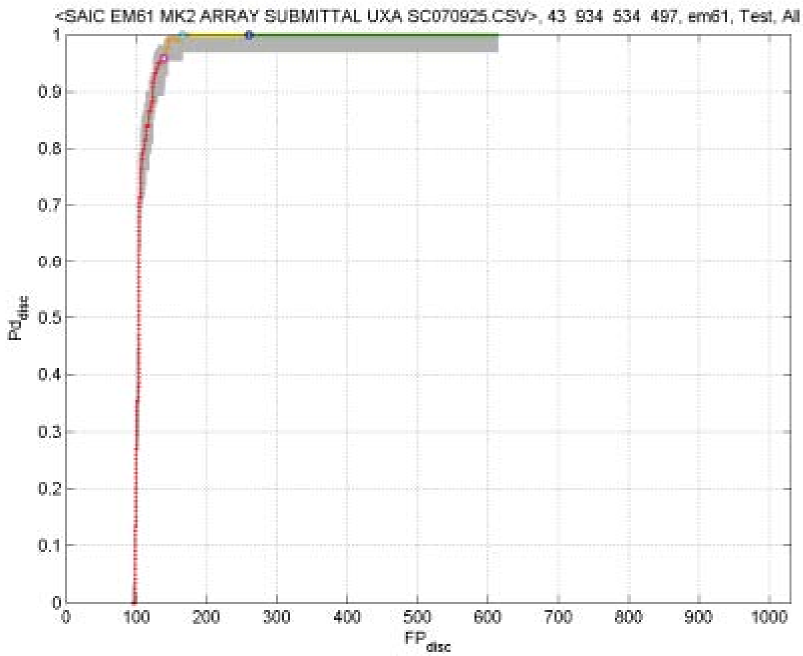


Figure 6. EM61 MK2 Array ROC Chart
(Analysis based on size metric).

Scoring performances for the magnetometer (mag) analysis are reported in Table 5 and shown graphically in Figure 7. A ROC chart is shown in Figure 8. Using the thresholds adopted for this analysis, there were no false positives, while eliminating 43% of the total digs.

Table 5. Performance Summary Mag Array

Mag Array

	Cultural	Munition Debris	No Contact	Rock	Soil	UXO
1	60	258	2	18	22	0
2	4	41	1	3	12	3
3	35	63	2	42	56	0
4	1	33	0	3	15	45
5	1	23	1	2	8	70
TOTAL	101	418	6	68	113	118

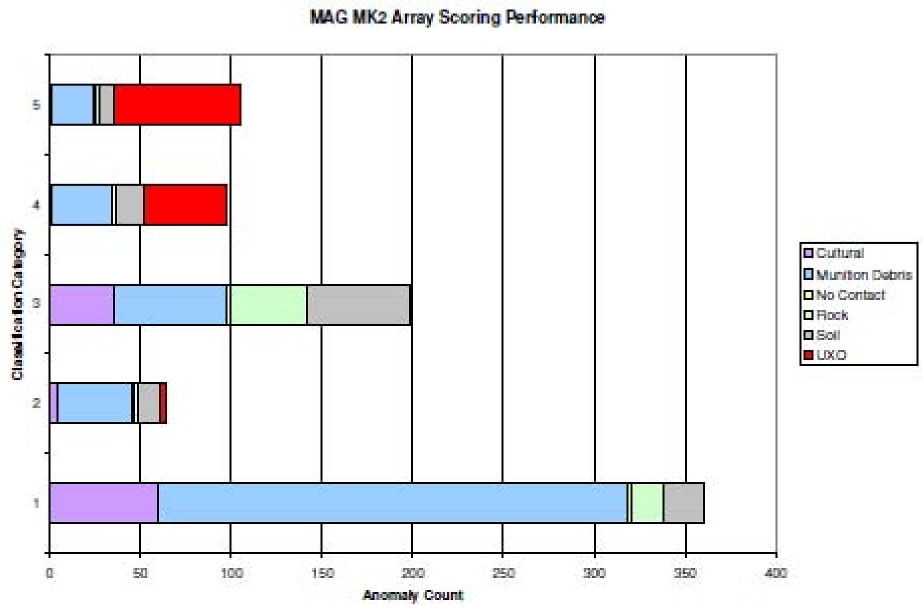


Figure 7. Mag Array Performance as a Function of Classification Category.

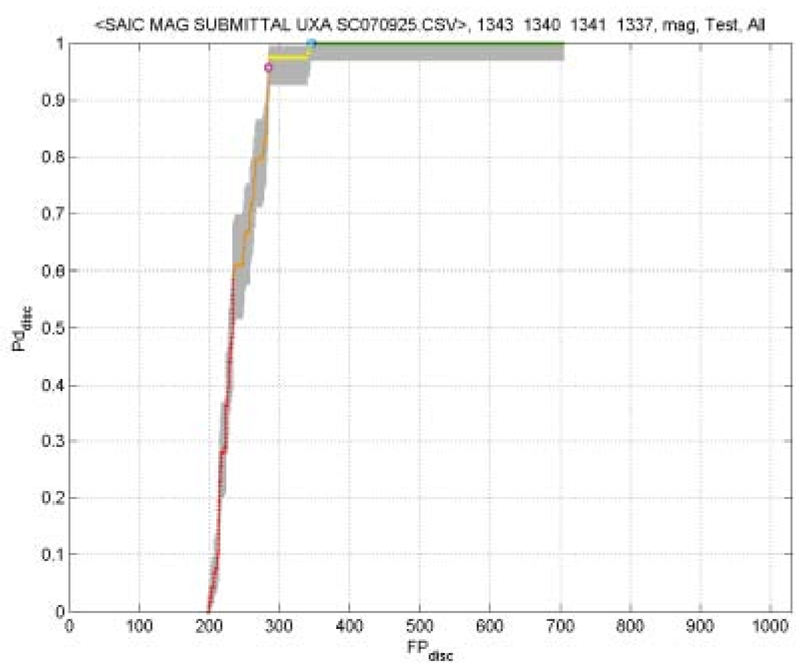


Figure 8. Mag Array ROC Chart.

4.2 PERFORMANCE CRITERIA

Our prioritized dig lists were scored against the emplaced targets by analysts from the Institute for Defense Analyses. Performance results for each of our six prioritized dig lists are shown in Tables 6 and 7.

In Tables 6 and 7, the ROC calculation excludes Category 3 items because they were, by default, recommended to be removed and therefore do not contribute any gains due to the discrimination process. Also, the metric used for the estimation of size is the coefficient of variation (COV), which is simply the standard deviation divided by the root mean square (RMS) value of the size parameter. It essentially reports variability in the estimated size parameter.

Table 6. Performance and the Confirmation Methods: EM61 MK2 Array

Performance Metric	Expected Performance (pre demo)	Performance Confirmation Method	Actual Performance (post demo)
Pdisc (emplaced) at Pthreshold	>95%	Comparison to seeded items	1.0
Pfa at 100% Pdisc	<80% of FA remain	Validation digging	0.270
ROC	0.4	Gains over chance diagonal Validation digging	0.470
Accuracy of parameter estimation	X,Y Distance: <20 cm Z: <15 cm size (UXO only): COV<0.3	Comparison to truth data Comparison to truth data Comparison to truth data	18cm (12cm/s) 20cm (17cm/s) 0.28

Pdisc = probability of correct discrimination
Pfa = probability of false alarm

Table 7. Performance and the Confirmation Methods: Magnetic Array

Performance Metric	Expected Performance (pre demo)	Performance Confirmation Method	Actual Performance (post demo)
Pdisc (emplaced) at Pthreshold	>95%	Comparison to seeded items	1.0
Pfa at 100% Pdisc	<80% of FA remain	Validation digging	0.486
ROC	0.4	Gains over chance diagonal Validation digging	0.416
Accuracy of parameter estimation	X,Y Distance: <20 cm Z: <15 cm size (UXO only): COV<0.3	Comparison to truth data Comparison to truth data Comparison to truth data	14cm (10cm/s) 10cm (12cm/s) 0.24

4.3 DATA ASSESSMENT

A performance comparison of results for magnetic and EMI data are shown in Figure 9. Although both approaches performed well (Table 6 and Table 7), the EMI-based results had fewer Can't Analyze declarations (Category 3) and better separation between classes than the magnetic (as visually observed by the slope of the curve as well as Area Under Curve (AUC) of 0.97 for EMI versus 0.91 for mag).

The sources of the "Can't Analyze" Category 3 declarations turned out to be small fragments, scrap metal, no contact, or soil (see Figure 10 for photographs of the recovered targets). These anomalies were characterized by low amplitude responses and small spatial footprints and were not, therefore, well characterized by our models (Figures 11 and 12). The largest clutter items were the half shells, which were presumably created when the 4.2 inch shell casings split open at impact.

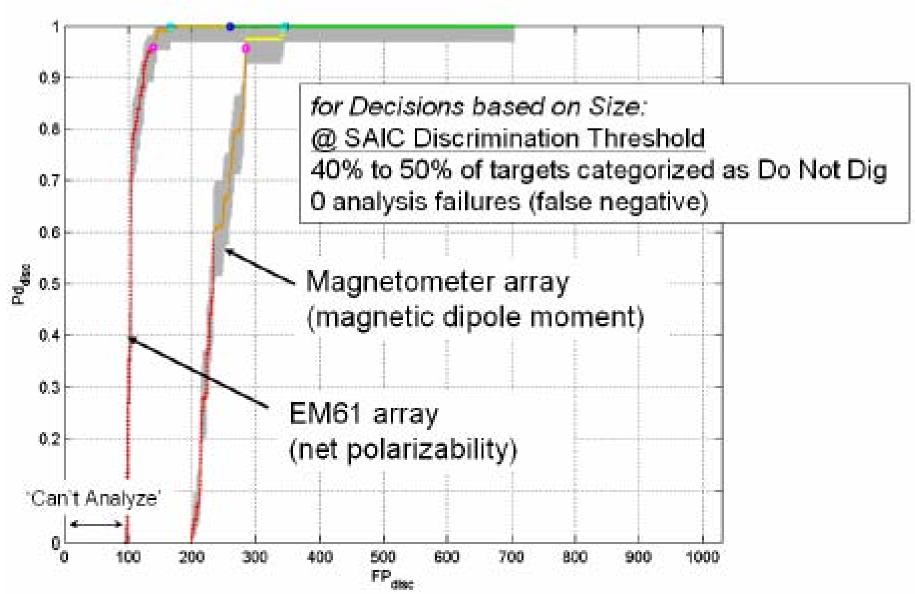


Figure 9. Performance Comparison of Size-Based Classification for Magnetic and EMI Array Data.

Figure 10. Photographs of Objects Recovered from the Sibert Demonstration Area.

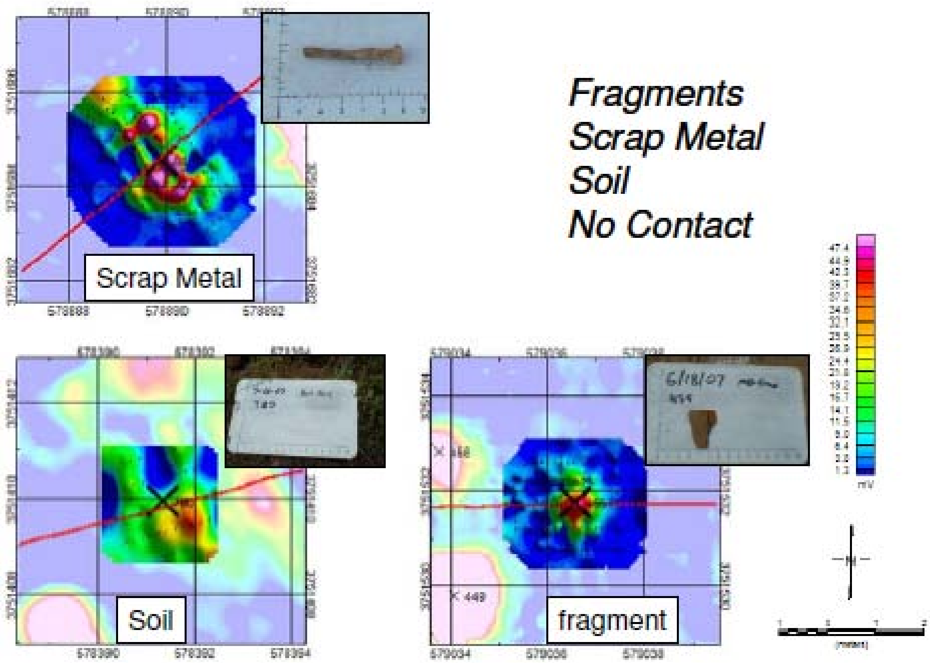


Figure 11. Example EMI Anomalies Classified "Can't Analyze" (Category 3).

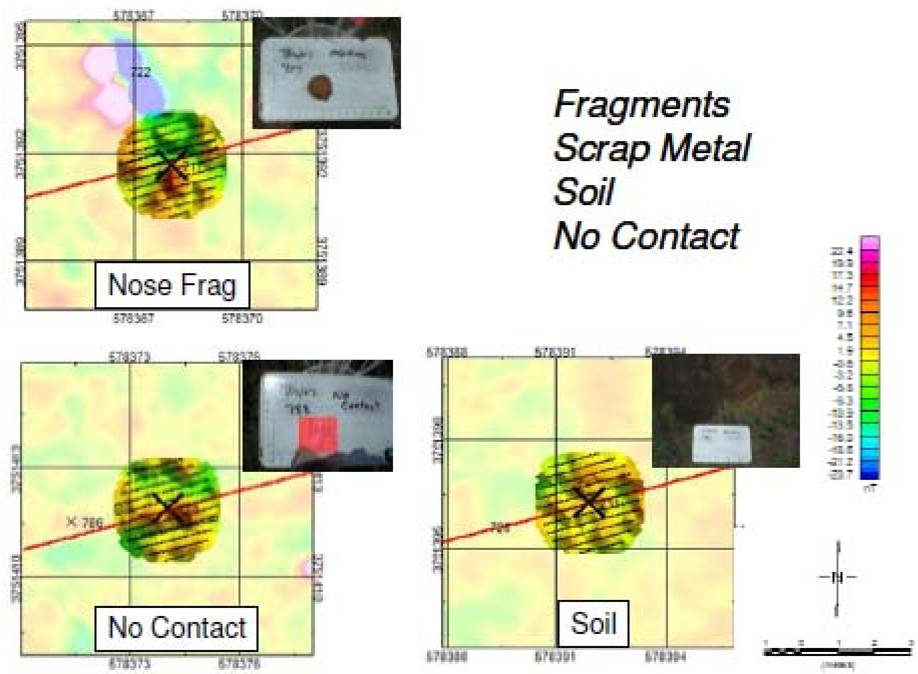


Figure 12. Example Magnetic Anomalies Classified "Can't Analyze" (Category 3).

4.4 TECHNOLOGY COMPARISON

After the excavations were complete, 803 clutter items were collected from Camp Sibert, renumbered (to protect their identity), and shipped to test facilities in Blossom Point, Massachusetts. The idea was to collect data in a controlled setting in order to collect extremely high-quality data that could be used to establish discrimination bounds for this collection of UXO and clutter. By recording signatures for each object individually at optimal coil-target separations, the in-air controlled tests inherently removed all positioning errors, eliminated any possible overlapping signatures, eradicated motion noise, and did away with unwanted soil response.

Time-domain EMI data were collected using a new fixed-geometry array developed under funding from MM-0601. The sensor consists of 25 transmit (Tx)/receive (Rx) pairs arranged in a 5x5 fixed-separation grid. The net polarizability, defined here as Sbi for t = 0.04-0.06 ms shows that the 4.2 inch mortar target strength is clearly larger than any clutter item (Figure 13). This suggests that perfect discrimination is possible for this distribution of UXO and clutter if the deleterious effects of poor positioning, survey noise, and competing geological sources are eliminated.

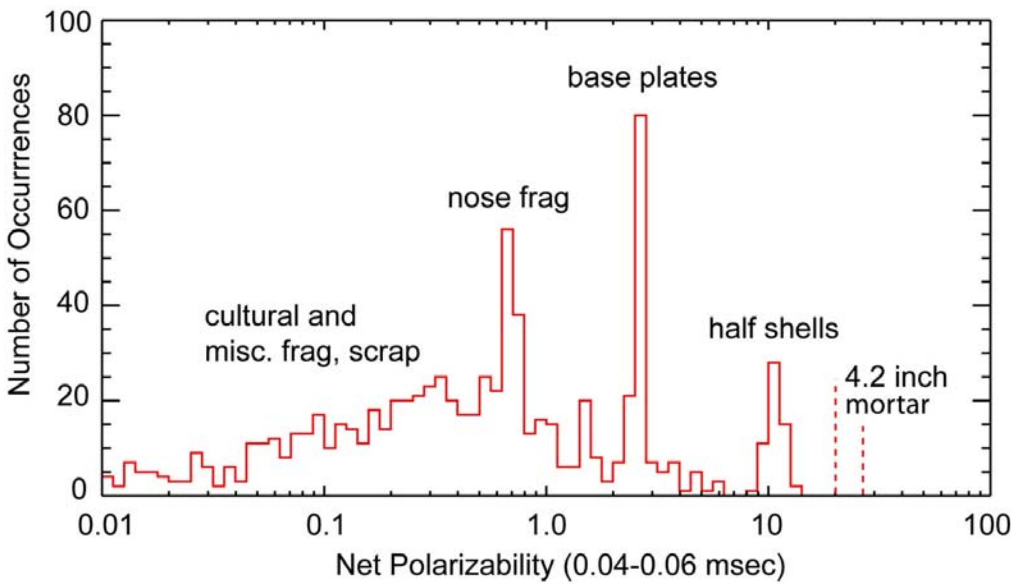


Figure 13. In-Air Target Strength (net polarizability, Σβi for t = 0.04-0.06 ms) Suggests Perfect Discrimination is Possible for this Collection of TOIs and Clutter.
(The 4.2 inch mortar target strength is clearly larger than any clutter item.)

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5.0 COST ASSESSMENT

5.1 COST REPORTING

Cost categories for the overall ESTCP Discrimination Pilot Program include mobilization, field survey, data analysis, demobilization, and reporting.

Cost categories for the analysis reported herein are shown in Table 8.

Table 8. Demonstration Costs.

Cost Category	Details	Sub Category	Unit Cost ($)
Preprocessing	Loading, re-leveling, filtering, and data handling prior to inversion	Mag Array	3,000
		EM61 Array	4,000
Anomaly extraction	Extracting anomaly signatures from site database	Mag Array	4,000
		EM61 Array	6,000
Data characterization	Inverting anomaly data for model parameters	Mag Array	10,000
		EM61 Array	15,000
Data classification	Performing feature-based classification	Mag Array	2,000
		EM61 Array	3,000
Documentation	Preparing dig sheet	Mag Array	2,000
		EM61 Array	2,000
Reporting	Preparing and revising technical documents	Demonstration Plan	7,500
		Demonstration Report	15,000
		TOTAL	**73,500**

Roughly 900 anomalies were identified in the magnetic and EMI data. The estimated costs required to process and analyze comparable data (viz., a data set that is leveled with isolated anomalies), excluding one-time, demonstration-related costs such as experimentation, optimization, non-routine analysis and testing, and reporting are presented in Table 9.

Table 9. Cost Tracking Categories for SAIC Data Analysis.

Cost Category	Details	Sub Category	Hours	Cost* ($)
Preprocessing	Loading, re-leveling, filtering, and data handling prior to inversion	Mag Array	60	7,200
		EM61 Array	60	7,200
Anomaly extraction	Extracting anomaly signatures from site database	Mag Array	40	4,800
		EM61 Array	40	4,800
Data characterization	Inverting anomaly data for model parameters	Mag Array	20	2,400
		EM61 Array	20	2,400
Data classification	Performing feature-based classification	Mag Array	16	1,920
		EM61 Array	16	1,920
Documentation	Preparing dig sheet	Mag Array	8	960
		EM61 Array	8	960
			TOTAL	**34,560**

*@ $120 per hour

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6.0 IMPLEMENTATION ISSUES

6.1 COST OBSERVATIONS

The analysis approach demonstrated here utilizes the spatial distribution of the measured magnetic or EMI signatures. As such, it requires high signal-to-noise data with a high degree of spatial precision across the footprint of the anomaly.

The costs to acquire data that will support discrimination decisions are higher than that required if the goal is only to detect the presence of an object. The factors affecting acquisition costs relate to particulars of the sensing system, spatial registration system, the target objectives, and the site environment. Although these costs are not the focus of this demonstration, they are very important to the ultimate transferability of this approach.

The analysis costs are also higher if attempts are made to quantitatively discriminate rather than only to detect. The factors affecting analysis time are significantly affected by (1) the degree to which the anomalies are spatially separated, (2) the number of anomalies, and (3) the amount of geologic-related signatures that have wavelengths similar to the targeted signatures. The data density is also a factor, but only marginally so compared to the factors listed above because it affects computer run time and not analysts' labor.

6.2 PERFORMANCE OBSERVATIONS

Discrimination performance is measured by our ability to characterize and classify one object from another. The factors that affect performance, therefore, relate to (1) the similarity (in feature space) between the TOI and non-TOI, (2) our ability to accurately measure the responses, the presence of signatures that spatially interfere or otherwise compete with the UXOs response, as well as (3) our ability to quantitatively characterize and classify the source objects. Many of these factors are not under our direct control.

6.3 SCALE-UP

There are no critical issues with regard to scaling up the demonstration costs reported here to larger, full-scale implementations. The cost categories may not, however, scale linearly. The factors listed in Section 6.1 will determine which, if any, cost categories dominate future technology deployments.

6.4 OTHER SIGNIFICANT OBSERVATIONS

There are many technical factors that can affect implementation of the analysis technology discussed in this report. As mentioned earlier, the analysis approach demonstrated here utilizes the spatial distribution of the measured magnetic or EMI signatures. As such, it relies on accurate 3-D spatial measurements as well as on stable geophysical measurements. The attitude of the geophysical sensor is also critically important to inverting for meaningful model parameters. If the data going into the inversion routines are noisy or contain systemic problems, the final discrimination decisions will not be acceptable.

6.5 LESSONS LEARNED

Discrimination decision between TOI and targets that are not of interest can be based on a variety of metrics. Some of these metrics include estimates of shape, size, remnant magnetization, decay rate, magnetic crossover, or even depth of burial. One of the most robust features is the estimated size, which, at this site, was used to correctly eliminate 49% of the selected EMI targets without incurring a single false negative.

6.6 END-USER ISSUES

Encouraging explicit discrimination decisions requires a recognition that implicit discrimination always occurs, an appreciation for and acceptance of risk-based decisions, capable contractors, validated technologies, and knowledgeable buyers. Because there are many players, opinions, situations, and objectives within the UXO cleanup space, multiple demonstrations and continued process and technology advancements are needed.

The ESTCP Program Office established an Advisory Group to facilitate interactions with the regulatory community and potential end users of UXO discrimination technology as part of the UXO Discrimination Pilot Program. Members of the Advisory Group included representatives of the U.S. Environmental Protection Agency (EPA), State regulators, Corps of Engineers officials, and representatives from the services. Together, they defined goals for the UXO Discrimination Pilot Program and developed Project Quality Objectives used in this report.

The discrimination mindset that should be promoted is one that encourages geophysical service providers to deliver a dig list that is prioritized according to objectives defined by the site's stakeholders. The decision metrics and thresholds should be quantitative, transparent, and documented. Stakeholder priorities could reasonably relate to size, depth of burial, shape, material type, or munitions type(s). Once the prioritized dig list is delivered, the stakeholders decide the ensuing actions. Stakeholders and/or site managers can realize financial savings by either modifying excavation procedures based on the probability of being a TOI or by declaring that no further action is required for specific anomalies. The point is that the decision to take action always remains with the stakeholders—as it must, if the discrimination mindset is to be accepted.

6.7 APPROACH TO REGULATORY COMPLIANCE AND ACCEPTANCE

The UXO industry is a regulatory driven industry. At this time, we do not know of any policies that require the use of discrimination technologies at live sites. Recent reports by the Defense Science Board, however, clearly recognize the potential for cost savings if reliable and defensible discrimination decisions can be realized. Additionally, the Corps of Engineers, Huntsville, have modified data item description MR-005-05A to include fields, albeit optional, that can be used to document anomaly specified estimates, such as those generated by an inverse modeling approach as reported here.

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APPENDIX A

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