Hand Held Metallic Mine Detector Performance Baselining Collection Plan

Fort A.P. Hill, Virginia

May 1998
To
November 1998

Prepared
By
Joint Unexploded Ordnance Coordination Office (JUXOCO)
Fort Belvoir, Virginia

HAND-HELD METALLIC MINE DETECTOR EXPERIMENTS

Fort A.P Hill, May- Nov 1998

I. Introduction:

This paper outlines the experimental plan for the conduct of hand-held metallic mine detector experiments to be conducted at Fort A.P. Hill between May and November 1998. This plan includes the purpose of the data collection, a description of the target layout, the delineation of responsibilities, the data collection procedures, and the general concept for post processing the collected data.

II. Purpose of Experiment:

These experiments are designed to:

1) Baseline the performance of several hand-held metallic mine detectors by establishing receiver operator characteristic (ROC) curves for these detectors,
2) Evaluate several algorithm approaches to improve upon the "baseline" performance of these detectors, and
3) Obtain mine "signature" data .

III. Discussion:

Since most landmines have at least some metal content, metal detectors are the primary instrument used for detecting landmines. Metallic "clutter" causes numerous "false alarms" when using metal detectors. Metallic debris, such as barbed wire, spent cartridge cases, bullets, munitions fragments and other man-made objects constitute "clutter". When metallic mine detector operators find these clutter items instead of actual mines, it is termed a "false alarm". If searching for mines in a battlefield or former battlefield environment, "false alarms" compose the vast majority of the "finds" and significantly impact the efficiency of mine clearance operations. The obvious goal has long been to improve the capability of detecting mines while at the same time significantly reducing the number of false alarms.

Prior to any effort to improve the "detection vs false alarm" problem associated with hand held-metallic mine detectors, a baseline of their detection vs false alarm performance is necessary. Traditionally, establishment of baseline performance of a detection system involves creating a Receiver Operating Characteristic (ROC) curve. A ROC curve is simply a plot of the relationship between a system's detection performance and its false alarm performance. As would be expected, achieving higher detection performance (i.e. probability of detecting a target of interest) generally results in an increase in incidents of false alarms. While this tradeoff is inevitable, determining the extent of the tradeoff for a given system (i.e. via ROC curves) enables us to effectively explore ways to improve a system's performance.

Ideally, the generation of ROC curves for mine detection systems would be accomplished by making successive collection runs over a known target field, each at a different sensor (receiver) sensitivity or threshold settings. For each collection run, the target detection performance of the system as a probability value (i.e. # of correct detections divided by the number of opportunities for target detections) is plotted against the false alarm performance as a probability value (number of false alarms divided by the number of opportunities for false alarm). The resultant plotted points then form a ROC curve which can be used to predict the probability of false alarm (Pfa) for any probability of detection (Pd) for that system at that site.

Unfortunately, the very nature of the operation and employment of hand-held metallic mine detection systems makes the generation of traditional ROC curves difficult. The first problem is rooted in the equation for Probability of False Alarm (Pfa). Pfa is calculated by dividing the number of target declarations that are not truly targets (i.e. the number of false alarms) by the total number of opportunities for false alarms. Because the search often covers a relatively large area, it is difficult to determine the number of opportunities for false alarms. The false alarm opportunities are "synthesized" using different methods (see ref 1 for example). In addition, hand-held metallic detectors are employed by a human operator who is presumably making decisions on a continuous basis. Since determining the number of opportunities for false alarm is difficult, " ROC-like" curves are sometimes generated using a measurement of False Alarm Rate (FAR) in place of the probability of false alarm. FAR is simply the number of false alarms for a given collection run divided by the area covered by the sensor. While the use of a FAR provides some relative measurement of the false alarm performance for a hand-held system covering a specified area on a given collection run, it does not provide a very accurate measure of a hand-held systems true performance due to the inherent inability to rigidly control the actual area covered by the system. In other words, while an operator may physically walk over a specified area, it is unlikely that the sensor head is actually covering precisely that area—it could be less or perhaps even more if there is significant overlapping.

The second problem with developing a ROC curve for hand held mine detection systems is that since an operator is interpreting the results from the detector system, realistically, only a single point relating Pd and Pfa can be generated. This is because there is generally no way of precisely controlling and varying the operator's threshold for detection such that a reliable ROC curve can be established. Single performance points are not a very useful way of comparing the performance of sensor systems. For example, three sensor systems may generate very different Pd/Pfa performances (see Fig.1). However, with only single performance points, it is impossible to determine if these three points represent sensors operating on three different ROC curves (Fig 2) or whether the sensors are all really on the same ROC curve but were each run with different operator "thresholds" (Fig 3.)

The above problems make it extremely difficult to objectively compare the performance of current hand-held, metallic mine detection systems.

IV. Experimental Objectives:

The experiments outlined in this plan are intended to circumvent some of the problems associated with developing performance baselines for hand-held metallic mine detectors that are discussed above.

This experimental design endeavors to:

1. Establish "baseline" ROC performance curves for several hand-held, metallic mine detectors through:

    i. Digitization of the output and post-processing it at varying thresholds; and,
    ii. Directly calculating Probability (percent) of False Alarms (Pfa) rather than False Alarm Rates (FAR);

2. Evaluate new algorithms for improving upon the baseline performance of the hand held mine detectors, and

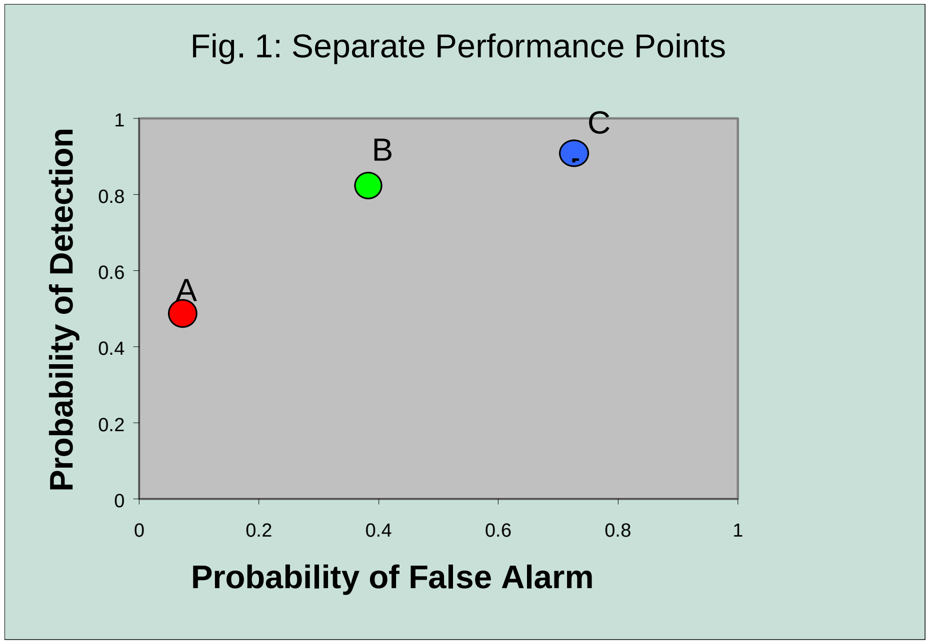
3. Obtain mine target "signatures".

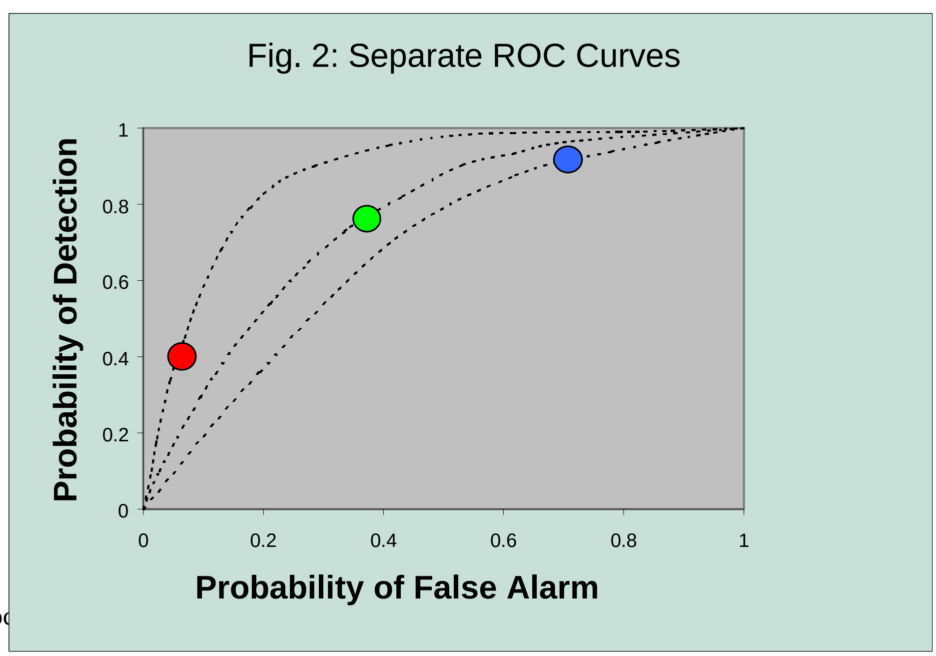
These objectives are discussed below:

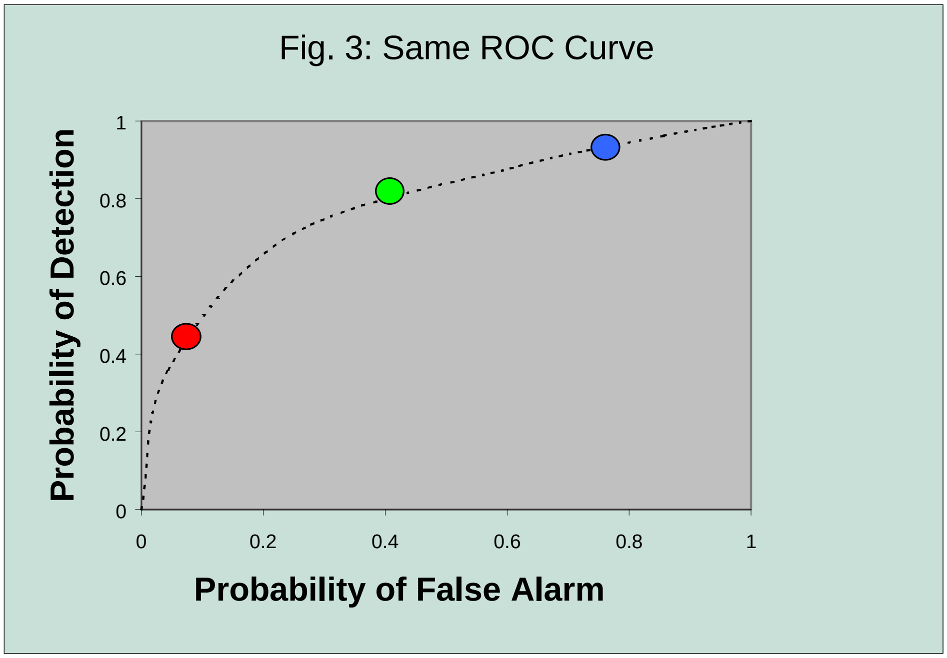
A. Establishment of ROC Curves

1. Digitization of Detector Output:

    a. AN/PSS-12. A key objective is to create a performance "baseline" for the US Army's standard hand-held metallic mine detector (AN/PSS-12). The variation in human operators complicates attempts to create a baseline in an operational "field-test" environment. On the other hand, "laboratory" tests suffer from the lack of "realism"offered in a field test. We plan to "instrument" a PSS-12 and operate it in a "field-like"environment. We plan to digitize, capture, and store the received signal at several points in the instrument as well as at the audio output to the operator. The stored data can be analyzed in several ways. At a minimum, we will generate a ROC curve by varying the “threshold” at the audio output which will, hopefully, yield the response presented to a “representative” operator using the standard PSS-12 instrument.





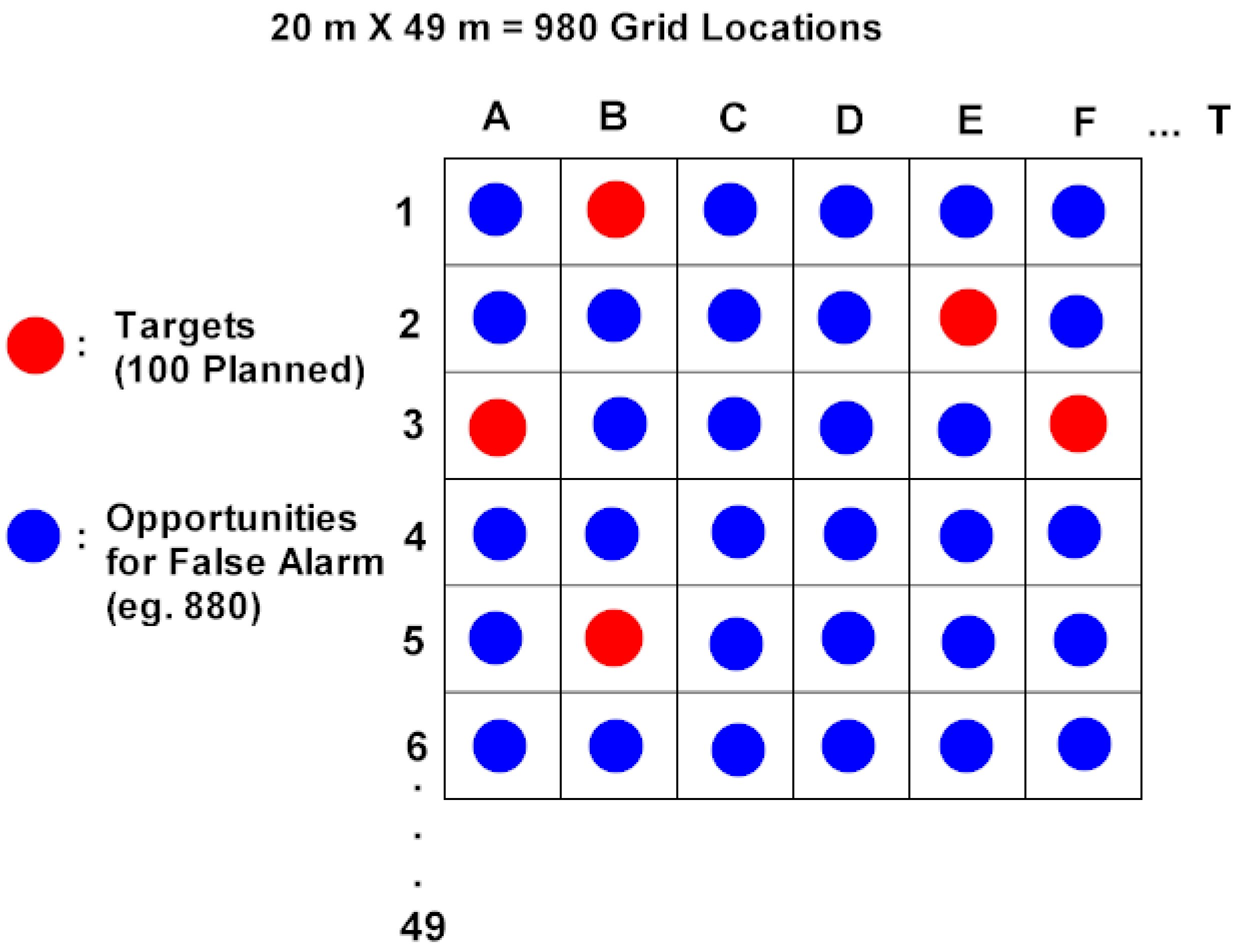


b. Other metal detectors. There are many high quality metal detecting instruments available in today's market. We plan to acquire 3 or 4 of these devices, instrument them, and compare their detection performance with the PSS-12 at the same site with the same targets. We are considering the following instruments: Minelab F1A-6, Vallon 1620C, Guartel MD 8, Foerster Minex (2FD 4.400.01). Some of these instruments are continuos wave (CW) systems while others are "pulse" systems like the PSS-12. The Foerster model instrument uses two frequencies. We will also use a multi-frequency prototype instrument (GEM 3) built by Geophex. The GEM 3 operates in the frequency domain while most of the other systems operate in the time domain.

2. Determination of Probability of False Alarm

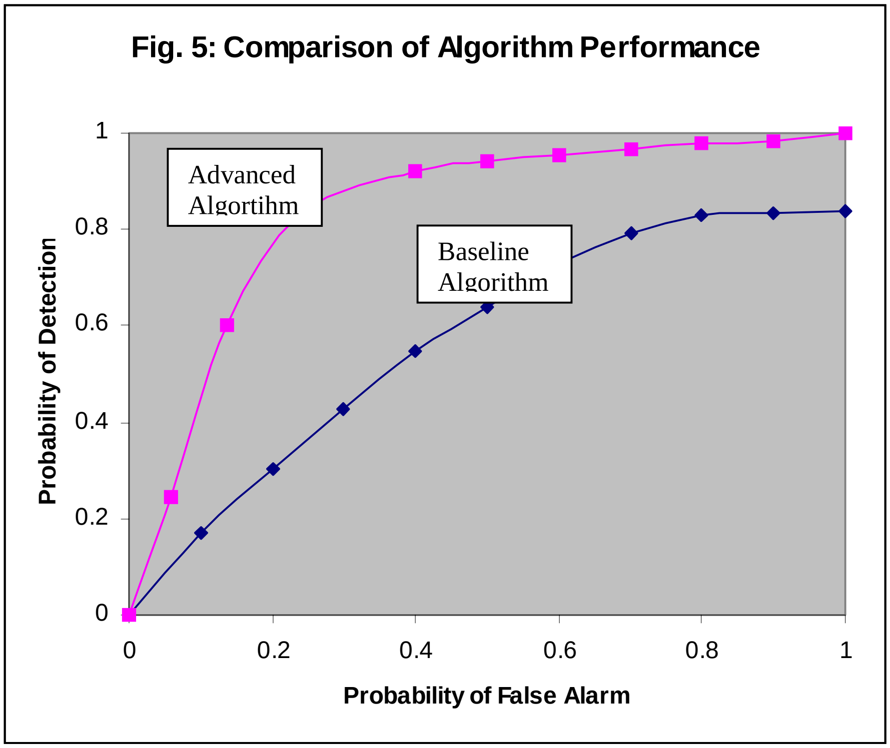
In support of ROC curve development for "baselining" the performance of hand-held metallic mine detectors, these experiments will try to determine an actual probability (percent) of false alarm (Pfa) instead of a false alarm rate (FAR). To accomplish this, the hand held-mine detectors will only collect data at specific "points" where either mine targets are buried or no mine targets exist. Each discrete area or node whereby sensor data is collected will be considered a "decision opportunity": Either the system declares a target or it does not. Since only the "no target" grid areas can be falsely identified as targets, the total opportunities for false alarms are determined by summing the number of discrete grid areas where no mine targets exist. The Pfa is then calculated by dividing the total number of false alarms which occurred during a run by the number of opportunities for false alarm for that run. The conceptual grid layout is shown in Fig 4.

Fig. 4: Hand Held Detection Test Grid



B. Algorithm Evaluation

Professor Leslie Collins and her colleagues from Duke University have developed new algorithms based on classical signal detection theory (Ref 2). Their method recognizes the statistical nature of the problem of detecting signals in noise and uses statistical techniques to deal with the decision uncertainties. They adopt a Bayesian approach to hypothesis testing based upon the maximum likelihood ratio statistic. When applied to “large” UXO metal targets, their work has shown significant reduction in the Pfa, while maintaining the same Pd.. Our intent is to try to extend these results into the area of “low metal” mines. Professor Lloyd Riggs and his coworkers at Auburn University have suggested a similar Bayesian approach (Ref 3). We plan to evaluate these advanced types of algorithms on the data collected with the instruments described above. Any gains offered by these algorithms will be shown by improved ROC curves over the “baseline” ROC curve using the presently employed algorithm. The ROC curves for the advanced algorithms will be generated based upon the same data set but processed using the new algorithm. These advanced algorithms will require post processing to implement. Figure 5 illustrates the concept of an improved ROC curve using advanced algorithm techniques.

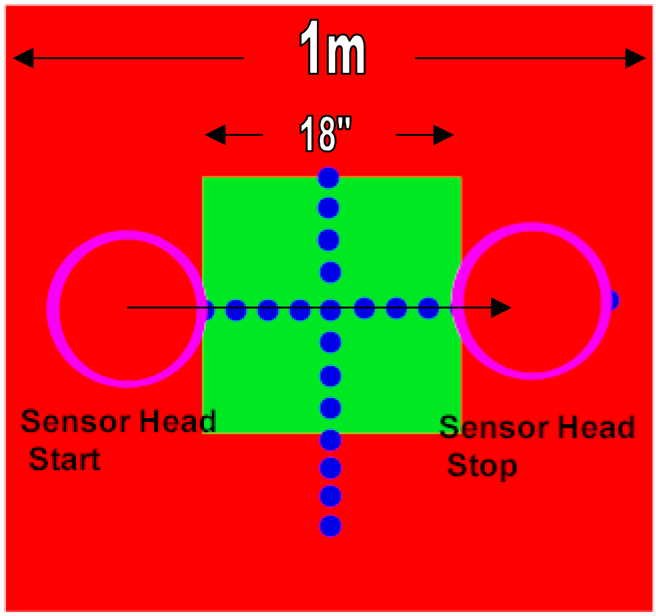


C. Signature and Data Collection

Since the hand held detectors will be instrumented for digital capture of the received signal data, this experiment serves as an excellent opportunity to collect and to archive mine target "signature" data. These signatures will be in the form of spatial sensor output profiles recorded from the hand-held instruments as they are moved across the targets. Known targets in the calibration plot will be searched by the hand-held detector in a well-defined manner. Searching in this manner allows a relatively precise, spatially correlated, sensor output to be obtained for each mine. The signature collection for each target in the calibration plot will consist of two passes over the target area: one from left to right, and the second from top to bottom. Each pass would consist of a number of stopping points (approximately 10 -20) where sensor data would be recorded. The number of stopping points will depend upon the instrument's "footprint" on the ground and will be determined by the experimenter. For example, the GEM 3 system has a 25-centimeter radius search head. This large search head coupled with the small size of some of the mines dictates a smaller spacing (~10cm) between measurements to provide better spatial sampling of target signatures. The collection in the calibration plot will be replicated once to measure each system's "noise". This same measurement procedure will be used for each system in the "blind" test grid.

A 1 meter square Data Collection Template will be constructed for placement over top of the 1 meter grids in both the calibration lane and the blind test grid to facilitate signature collection in the calibration lane and data collection in the blind test grid. The 1 meter template will be constructed of light weight plastic or wood and will have a series of marks denoting the sensor head stopping points from top to bottom and from left to right. The marks will be positioned such that the sensor head will incrementally cover an 18" square centered about the mine or opportunity point. Figure 6 illustrates the template and technique to be used for data collection at the 1 meter grid locations.

Fig. 6 Data Collection Template and Sensor Head Positioning Technique



V. Experimental Approach

1. General

a.Test Site and Preparation. We will conduct the experiments at Range 71A at Ft. A.P. Hill,VA. This range serves as a major countermine test area for CECOM, NVESD. The range has the necessary staff and facilities to support the experiments. Demolition and explosive testing and troop training have occurred on this range.

A 50 meter by 20 meter and relatively flat plot of ground at 71A was selected for construction of the hand held test grid. Prior to laying out the test grid lines, the VAMDs (Vehicular Array Metal Detector) was used to survey the area to determine the extent of metallic clutter in the test area. The survey revealed a very high density of metallic clutter in the chosen site (see figure 7 below). Since this hand held test proposes to baseline the performance of hand held metal detectors through the surveying of discrete and well characterized points in a test grid (containing known targets and known opportunities for false alarms), a heavily cluttered site presents significant problems. Therefore, it is essential that all the grid points of the test grid be cleared of metallic clutter. Any collected clutter will be characterized and then placed back into the test grid at survey points so as to provide representative clutter that can serve as discrete opportunities or false alarm.

Due to the extensive clutter revealed by the VAMDs survey, it was determined that the most efficient means for reducing the metallic clutter on the test site was to excavate the top 6 inches of soil. 71A personnel used a commercial grader and front end loader to perform the grading operation.

After grading the top layer of soil, the VAMDs was used to determine the amount of clutter reduction. The top soil was scraped one additional time and a final VAMDs survey was conducted. (See fig 8 and 9). The final survey revealed that the clutter content was now low enough that hand held metal detectors could be employed to hand clear the test site after marking the test grid. The test grid was then laid out into a 49m x 20 meter grid with 1 m by 1m grid squares. Golf tees and spray paint were used to mark the corners of the 1 m square grids.

After the test grid was marked, personnel used hand held metal detectors to hand clear the grid locations. The clutter was collected for examination and potential use as purposefully buried clutter. Figure 10 thru 12 show the site clearing activities to reduce and collect the metallic clutter and the setup of the test grid.

b. Clutter. Clutter represents one of the more difficult problems to deal with in mine detection testing. Present metal detectors have little or no ability to discriminate between the metal in mines and man-made, metallic clutter. To a metal detector, metal is the target, not mines. However, when looking for mines, metal clutter constitutes a "false alarm". Clutter is very site dependent and so false alarm rates vary dramatically when using the same instrument and targets at different sites.

Since the existing clutter had to be removed from our grid areas where we intend to bury mines, the clutter was dug up, identified and classified (weight, size, etc..). The clutter found included hundreds of pieces of metal including rusted shrapnel, exploded 50mm rounds, 20 mm rounds, rusted nails, small rusted metal fragments and bits, pieces of wire, small copper pieces and other unidentifiable metal. The clutter will be transplanted to some of our predefined "empty"grid areas to provide discrete opportunities for false alarm. The complete characterization of the clutter buried at each grid point will be documented.

It is our intent to bury known metallic clutter at a number of the 880 grid points that do not contain a mine target. Metallic clutter to be buried will be divided into four categories: Extremely Low Metal Content (less than 1 g), Low Metal Content (1 – 5g), Moderate Metal Content (5-40g) and Large Metal Content (greater than 40g).

c. Test Targets. "Low metal" mines present the greatest difficulty for metal detecting instruments. Consequently, the mine targets for these experiments will be predominately "low metal" mines. There is no precise definition of "low metal". At one end of the low metal extreme, we have mines containing less than 1 gram of metal, we have some in the range of 3 to 5 grams, and others as high as 18 grams. A few large, metal cased mines will be included for completeness. For the experiments we are conducting, the proposed target list is shown in **Table 1**. We currently plan to obtain a mix of the mines in Table 1. The mix will be determined by the availability of mine types. Each mine target will be assigned a number. A target folder will be created for each mine. This folder will contain pictures of the mine and a complete description of its configuration, metal composition, etc.). The mines will be randomly assigned to a numbered grid area.

d. Target Burial Depths. "Tactical" burial depths are planned. Tactical depths vary and are somewhat different for AT and AP mines. We take our definition of tactical depths from FM 20-32 (ref 5). As indicated in reference 4, some countries use mechanical mine planting machines. These machines tend to yield a slightly deeper and more uniform burial depth than hand emplacement. Reference 4 cites a burial range for AT mines of 120 mm to 250 mm using mechanical planters. We recognize that in reality mines can "end up" considerably shallower or deeper both intentionally and unintentionally. However, in these experiments, our intent is not to explore the extremes of sensitivity to burial depth but to establish baseline performance at the most common depths. The burial depth will be carefully measured to the top of the mine and recorded for each location. The proposed ranges of depths of the targets for this experiment are delineated in Table 1. Emplacement will be in accordance with ref 4 and 5 (See App. A and B for appropriate excerpts) .

Table 1: Mines To Be Used in AP Hill Hand Held Test

Mine Name	Type	Diam (cm)	Description & Composition	Modification for AP Hill Test	QTY	Burial Depths
TM46	AT M	30	Soviet metal case AT mine.	Empty metal case. Total metal content: 2406 g.	3	1-5 inches
VAL-69	AP M	10	Italian plastic case bounding fragmentation mine.	Boosters and dets removed. Total metal: 2800g	5	Surface –2 inches
M19	AT LM	33	American rectangular plastic blast mine containing ~ 1 g metal. Metal components include Copper detonator tube and stainless steel firing pin.	Actual metal components present except dets have been cleaned out and primary explosive removed. Total metal: .94g Firing pin:.19g; det tube:.75g	5	1- 5 inches
TMA4	AT LM	28	Former Yugoslavian plastic cased blast mine with low metal content. Metal components include Alum. detonator tubes.	Actual metal components present except fuses have been cleaned out. Total metal: .75g	4	1 –5 inches
VS 2.2	AT LM	23	Italian plastic blast mine with low metal content. Metal components include firing pin (non-ferrous), aluminum detonator tube, stainless steel ball bearing, and a steel spring.	Primary explosive charge removed except detonator tube cleaned out. Total metal: 3.29g. Firing pin:.09g; Det. tube: 1.18g; Ball: .43g; Spring: 1.59g	7	1- 5 inches
TS50	AP LM	9	Italian plastic-cased cylindrical blast mine with low metal content. Metal includes Copper det tube, stainless steel spring, steel spring, 2 stainless steel ball bearings, firing pin (non-ferrous) and a pressure plate (non-ferrous).	Primary explosive charge removed except detonator tube cleaned out. Total metal: 4.408g Det tube: .38g; Stainless spring: .06g; steel spring: .44g; 2 ball bearings: .1g; pin: .16g; plate: 3.26g.	35	Surface – 2 inches
VS50	AP LM	9	Italian round plastic-cased blast mine. Metal includes copper det tube, steel pressure plate, steel spring, and firing pin (non-ferrous).	Primary explosive charge removed except detonator tube cleaned out. Total metal: 18.21g Plate: 17.39g; spring: .43g; firing pin: .07g; det tube .40g.	10	Surface – 2 inches
PMA3	AP LM	10	Former Yugoslavian plastic/rubber cased blast mine with Chemical fuze. Metal includes aluminum det tube and stainless steel striker pin.	Demilled boosters and detonators. Total metal: .35g Tube: .27g; pin: .08g	7	Surface – 2 inches
T 72 (AP)	AP LM	7.9	Chinese plastic cased AP mine.	Demilled boosters and detonators.Total metal:	6	Surface – 2 inches
TM62P3	AT LM	32	Former Soviet Union blast mine with Plastic case; only metal is in fuze.	Complete with cleaned out dets or equivalent metal parts.	5	1- 5 inches
M14	AP LM	5.6	US and Indian manufactured plastic bodied blast mine with low metal content Metal includes copper det tube and steel firing pin.	Demilled detonators or equivalent. Total metal: .60g Tube: .41g; pin: .19g.	20	Surface – 2 inches

e. Test Layout. As mentioned, Figure 4 illustrates the proposed layout for the experiment. The grid arrangement is beneficial for several reasons. Firstly, it allows for a simple, direct calculation of the Pd and Pfa estimates. Secondly, the grid obviates the need to determine when and where the sensor head "encounters" the target. This makes "scoring" easier as well as determining when the sensor is over the target to capture the sensor "raw data". The proposed grid size is 20 x 49 meters which yields 980 grid areas. The approach is to bury mines at approximately 100 of these grid areas. The Pd calculation is simply N/100. The remaining 880 intersections would be opportunities for "false alarms". Therefore, the Pfa estimate is N/880. We recognize that this grid arrangement is artificial and that it does not represent how an actual area mine search would be conducted. We also realize that the sample size for calculating a Pd estimate for an individual type of mine (e.g. M-14) will be small. However, when we consider the class of mines (i.e. low metal), the sample size will be large.

f. Algorithm Training. The advanced algorithms require some estimates of the probability density function (pdf) for both the targets and the background clutter. To facilitate developing these statistics, the calibration area will contain whatever clutter happens to be present plus a **representative** sample of clutter removed from the "blind" grid site. If "new" clutter is introduced to the "blind"grid areas, samples of the same "new" clutter will also be placed in the calibration area. We feel it is unrealistic to duplicate the **exact** clutter **(size, mass, composition, orientation, etc.)** in the calibration lanes that is present in the "blind" grid areas. The purpose here is to measure how well the new algorithms can separate mines from the representative clutter one finds in an area.

g. Instrumentation of Detectors.

AN/PSS-12

The AN/PSS-12 consists of a transmit and receive coil. A linearly increasing current is driven into the transmit coil and after a few tens of microseconds this current is rapidly extinguished (turned off). The magnetic field radiated by this linearly increasing current induces a voltage directly into the receive coil of AN/PSS-12 and also causes eddy currents to flow in any nearby metallic object. These induced eddy currents in turn radiate a scattered magnetic field which also induces a voltage into the receive coil of the AN/PSS-12. The signal (voltage as a function of time) at the output of the receive coil therefore is composed of the sum of two parts -- the direct coupled voltage from the transmit coil pulse and the voltage induced by eddy currents which flow in a nearby metallic object. This combined voltage will decay exponentially; with the direct coupled voltage generally decaying at a different rate than the object coupled voltage. As is often the case, especially for low-metal mines, the direct coupled voltage is large whereas the object coupled voltage is small. For detection (not identification) purposes all one need be concerned with is determining any change in the decay rate of the received voltage due to the presence of an object.

Processing carried out in the AN/PSS-12 generates an audio tone whose frequency is roughly proportional to the amount of change in the received waveform caused by the metallic object. For identification (not detection) purposes, and for reasons beyond the scope of this brief discussion, it is important to capture as much of the decaying exponential associated with the object as possible. Capturing a high fidelity representation of the object's response presents instrumentation challenges. The voltage at the output of the receive coil can approach 100 volts in early time. Without the proper protection a voltage of this amplitude can destroy sensitive data acquisition circuitry. Later in time, when the object response may dominate, voltage levels can be very low - on the order of microvolts, requiring large amplification, especially when digital-to-analogue converters (DAC) with limited resolution are employed.

With the above discussion as background, we intend to use a National Instruments DAQCard-5102 (PCMCIA) plugged into a laptop computer as our data collection device. The 5102 provides two channels of analogue input, a trigger input, and two digital trigger input/outputs. We envision using channel one of the 5102, with the proper attenuation, to capture the early part of the response directly at the output of the receive coil. As this voltage decays, we intend to switch to channel two of the 5102 and apply amplification, dynamically as needed, to obtain a high fidelity of the late time response of the receive voltage. Data collected will be stored in the lap top's memory for subsequent analysis. We are using the software program LabVIEW (a defacto industry standard) to control the 5102.

GEM-3

Unlike the PSS-12, the GEM-3 already has digital signal output capability. As such, the GEM-3 will be hooked to a laptop for digital storage. The GEM-3 can be programmed to measure responses at different discrete frequencies. Every time a response is measured by the GEM-3, the in-phase and quadrature responses are stored in an ASCI file on the hard disk of the laptop with a measurement number. A separate log file will be maintained to tie the measurement number to a specific site location. For example, 1=A1#1, would mean grid location A1 first of n measurements. A consistent method of taking the individual measurements over the grid areas will be followed to ensure compatible data collection. All data will periodically be backed up to a floppy disk.

h. Meteorological/Atmospheric/Geologic Monitoring:

Standard Meteorological Data (MET) will be collected during all phases of the experiment when sensor data is actually being collected. The following MET parameters will be collected at 15 minute intervals during collections:

Air temperature
Humidity
Barometric pressure
Rain rate

Additionally, the following continuos soil measurements will be taken:

Soil Temperature at 1, 2 and 4 inches
Soil Moisture/conductivity at 2 inches

Additionally, we are considering procuring a device to measure magnetic permeability of the soil.

A comprehensive soil analysis will also be performed on several soil samples across the test grid and calibration lanes. The soil analysis will be performed by the Waterways Experiment Station (WES). WES previously characterized two sites at Fort A.P. Hill for the DARPA clutter experiments. This characterization involved extensive measurements of the soil parameters. These measurements were made at a site a mile or so from our proposed site.

i. Calibration Plot. A calibration area will be established with known targets and known clutter, at known locations to assist in developing mine and clutter signatures and checking out sensors and instrumentation. This area will be adjacent or near the “blind” grid site. The calibration area will be consist of 5 lanes, each 25 meters long and 1 meter wide.   The calibration area will contain at least one of each mine contained in the “blind” grid. The exact locations of the mines will be marked and the mine particulars indicated. We will take “signature data” on these mines as discussed previously. The metal detecting instruments will be able to use this calibration area to “measure” target signatures and to otherwise calibrate the instruments.

The calibration plot will also include known pieces of clutter obtained from the hand clearing of the blind test grid and calibration plot. Clutter pieces that have been characterized will be placed in the calibration plot at documented locations and depths and will be available for sensor/algorithm calibration.

In addition to the calibration plot, an additional larger area, near the test grid will be marked to allow collection of additional background clutter statistics to be used for development of the improve discrimination algorithms to be employed in this experiment.

2.   SCHEDULE AND EXPERIMENT FLOW:

Site Preparation:

The first task is site preparation. The site will "surveyed" to obtain a **qualitative** indication of the clutter levels using the Schiebel Vehicle-Mounted Metallic Mine Detection (VAMIDS) system. The site will then be evaluated using a PSS-12 detector to establish the grid areas or nodes. Nodes selected for burying mine targets will be "cleaned" of metallic clutter. Removed clutter will be collected and identified as far as possible. The clutter will be separated into three categories (Large, medium, and small metal) to roughly correspond to the metal content of the mine targets to buried in the test grid. Selected clutter will then be buried at all of the "non-mine" nodes. The clutter will be photographed weighed and its location identified. Soil samples will be collected and provided to WES for comparison with their earlier data taken at A.P. Hill.

Schedule:

a. Calibration Area Set Up. First priority will be given to completing the calibration area. This is because the test instruments will first use the calibration area to take target "signatures", gather clutter statistics, and checkout instrumentation and data collection procedures. The calibration area will be adjacent to or at least very near the experiment grid. The calibration area will contain at least one of each mine target that will be used in the "blind" experiment grid. The mines will be buried at several burial depths. A representative sample of clutter from the "blind" grid will be added to the "existing" clutter in the calibration area. The calibration area will be completed by 14 May 1998. The calibration area will be a lane, 1 meter wide by 50 meters long. It is envisioned that the instruments will run in the calibration area for 3-4 days gathering data. Several visits to the calibration area separated by several week intervals are planned. These intervals will allow for data analysis and adjusting of the advanced algorithms prior to running in the "blind" experiment grid area.

b. Calibration Lane Data Collection and Signature Collection. After the calibration area has been established, the instrumented hand held detectors will be run over the calibration lane to collection data for adjusting the detectors and for confirming that the burial depths for the mine targets in the test grid are reasonable. Additionally, signatures of the mines buried in the calibration lane will be collected in accordance with the signature collection technique described earlier. The calibration data and signature collection is expected to last approximately one week.

c. Calibration Data Analysis. After the calibration data is collected, it is expected that analysis of the data will take approximately three weeks. During this period, Duke and Auburn participants will be optimizing their systems and preparing for signature collection and blind test runs.

d. Additional Calibration Data. Analysis of the calibration data may reveal a need to perform additional calibration collections. Two weeks are anticipated for additional collection of data on the calibration lane.

e. Test Grid Setup. While the calibration data is being processed, the test grid containing the buried mine targets and clutter will be completed. The test grid is expected to be completely laid out and ready for testing by June 30, 1998.

f. Test Grid Runs. Upon completion of signature data collection, each instrumented sensor will collect data over the 980 grid locations of the blind test grid. A total of five runs will be performed for each sensor. Data will be collected in accordance with the signature collection protocol using the 1 meter template as described earlier. Each run is expected to take 1 to 2 days per sensor. Approximately 8 weeks is allotted for completion of all 5 runs for each sensor.

g. Data Processing and Analysis. After completion of all the data runs, the data will be post processed by Professor Riggs and Collins. The post processing will include:

   1. Compiling the Target Signature Data collected from the calibration plot into spatially correlated target signature profiles.

2. Providing “target/no target” declarations over a range of “threshold” settings for each of the 980 grid points surveyed, for each sensor, and for all runs. There should be at least 10 threshold settings used to ensure a reasonable number of points to establish a ROC curve. This data will serve as the data for constructing the baseline ROC curves for each sensor.

3. Providing the same declarations for each sensor and for all runs, but after employment of new algorithms as discussed earlier.

h. ROC Curve Development. During this period, the government will develop ROC Curves for:

1. Each sensor in an as built/as operated condition (i.e. baseline ROC Curve).
2. Each sensor after improved algorithm techniques have been employed.

i. Review of Results. After completion of all ROC Curves and receipt of all target signature data, all participants will meet to review the results from the collection experiment.

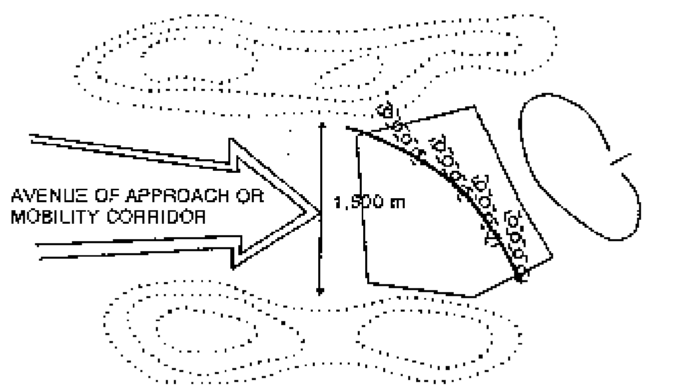
j. Written Report. A written reports will be provided which contain the ROC curves for all sensors and the results of any algorithm improvements to the baseline ROC curves obtained.

k. Data Dissemination. Upon completion of the written report, all target signatures will be made available to the UXO community via the UXOCOE ATR Database website.

RESPONSIBILITIES:

Target Inventory/Modifications: Countermine –71A
Site Construction and Target Emplacement: E-OIR Measurements/Countermine – 71A
Site Surveys (as necessary): TBD
Meteorological Monitoring (as necessary): TBD
Site Logistics/Operation During Testing: E-OIR Measurements
Power to Site: 71A
Sensor Modifications/Digital Interface Setup: Duke & Auburn
Raw Data Collection/Storage: Duke & Auburn
Data Post Processing/Analysis: Duke & Auburn/E-OIR Measurements
Post Experiment Report/Documentation: E-OIR Measurements, Duke, & Auburn
Data Dissemination and Formatting for ATR Database Web Site: E-OIR Measurements

Appendix A: Excerpt from FM 20-32



WIDTH OF AA/MC = 1,500 m
OBSTACLE EFFECT: TURN
LINEAR EFFORT RESOURCE FACTOR: 1.2
TURN MINEFIELD FRONTAGE NORM: 500 m

DETERMINE NUMBER MINEFIELDS IN GROUP:
1,500 x 1.2 = 1,800 m LINEAR EFFORT
1,800/500 = 4 TURN MINEFIELDS (ROUND UP)

Figure 2-19. Example of minefield resourcing

Emplacing Mines

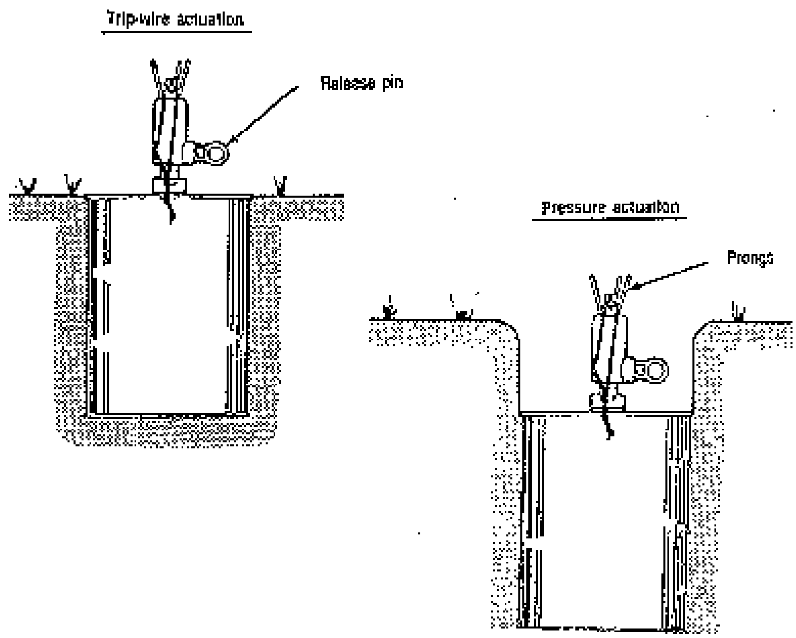
The method used to lay and conceal each type of mine depends on the method of mine operation, the type of ground in which the mine is to be laid, and the type of ground cover available for camouflage.

Hand laying is laborious and time-consuming (standard pattern), but it is more flexible than row mine laying and allows better mine concealment. Hand laying is well-suited for protective and nonstandard point minefields. It can be used in terrain where the nature of the ground makes row mine laying methods impractical.

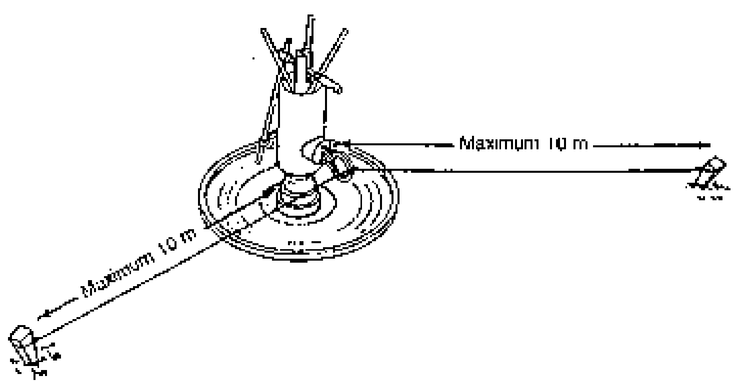
Whatever the mine emplacement technique, there are certain general rules that should be followed. To achieve their maximum effect, mines must be laid so they cannot be seen and so a vehicle's wheel or track or a person's foot exerts enough pressure to detonate them.

The following rules should be applied to achieve maximum effects of mines:

★ **Mines with prongs or studs.** Mines with prongs or studs should be buried flush with the ground so that only the tips of the mechanism are exposed (Figure 2-19, page 2-30). Mines buried in this manner are held firmly upright. The target exerts a direct downward pressure rather than a sideways thrust. These mines are protected from damage and are difficult to see. If buried more deeply, they become unreliable because the layer of spoil may prevent the mine mechanism from operating. If mines are activated by a trip wire, they should be buried so the trip wire is at least 2 to 3 centimeters above the ground (Figure 2-20, page 2-30).



★ *Figure 2-19. Prong or stud-operated igniter*



★ *Figure 2-20. Trip-wire operated igniter*

Bearing boards. Due to the high pressure required to activate AT mines, it may be necessary to place a board or other bearing plate under mines buried in soil with a low bearing pressure. Otherwise, mines may be forced down without detonating.

Concealment. When a hole is dug for a mine, the spoil should be placed in a sandbag to reduce evidence of laying. If a sandbag is not available, spoil should be heaped. After the mine is laid, camouflage all traces of digging. Where the ground cover is turf or other matted, root material, spoil that cannot be hidden should be removed. In the area where the mines are placed, sod should be cut out by using an X-, I-, or U-shape. The sod is then rolled back in place to camouflage the mine. Loose earth over mines will eventually consolidate, so immediately after laying, the mine location should look like a small mound (Figure 2-2 1). Care must be taken to ensure the mound is incon -

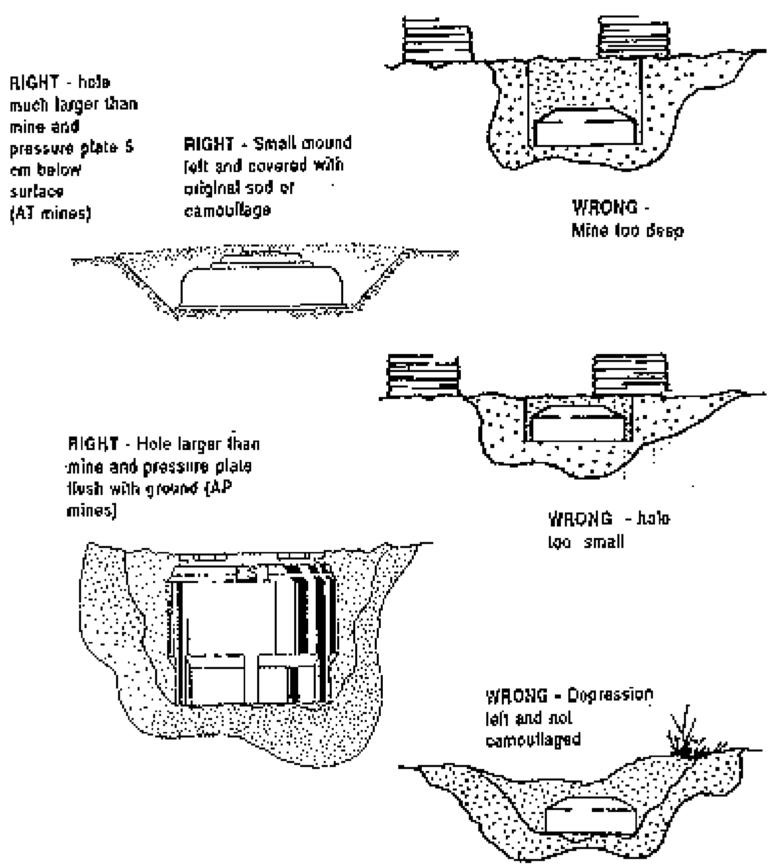


Figure 2-21. Burying and concealing mines

spicuous and blends with the surrounding area. A final check is made after concealing each mine so that faults can be corrected progressively. This is very important, because faults cannot be corrected later.

Mines with pressure plates. Mines with pressure plates will function when completely buried as long as the cushion of earth above them is not too thick. AT mines are normally buried with the top of the mine approximately 5 centimeters below ground level. AP mines are usually placed in a hole and only covered with camouflage material. If the hole is only slightly larger than the mine, the weight of the target may be supported by the shoulder of the hole, and the mine will fail to activate. Such bridging action can be avoided if the hole is dug much wider than the mine (Figure 2-22).

Mines with tilt rods. Tilt-rod fuzes normally require the body of the mine to be buried and the tilt-rod assembly to be clear of the ground (Figure 2-23). A tilt-rod fuze is preferred in areas where vegetation is sufficient to conceal the extension rod. Camouflage materials are carefully used to prevent premature detonation or interference with the normal functioning of the fuze. Extension rods are camouflaged before the mine is armed.

AT mines in standard pattern minefields should be buried. However, if conditions dictate, mines with a single-impulse fuze may be laid on the surface. Mines with double-impulse fuzes should always be buried because if they are laid on the surface, they are likely to be physically damaged when the first pressure is being exerted by a tracked vehicle. Also, buried mines have some resistance to countermeasures while surface-laid mines have none. Consideration must also be given to sympathetic detonation of AT mines, whether buried or surface-laid (Table 2-1).

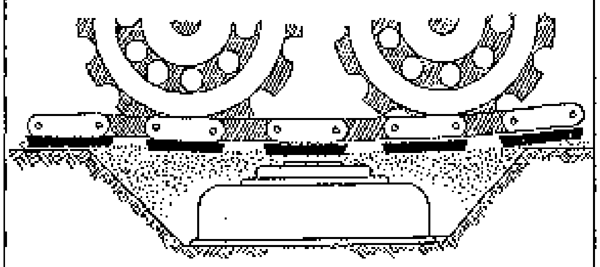


Figure 2-22. Buried mines

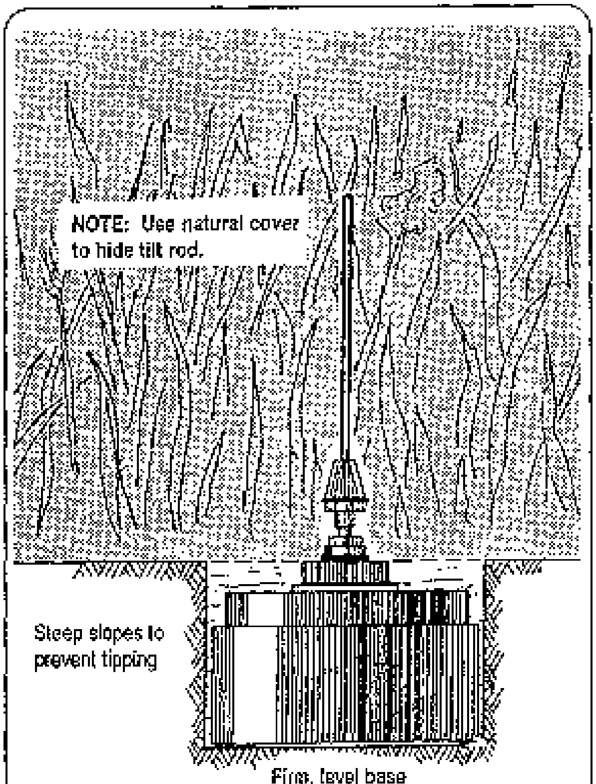


Figure 2-23. Buried mine with tilt-rod fuze

Table 2-1. Sympathetic detonation chart

	M16	M15	M19
Surface-laid	--	14 ft/4.2 m	25 ft/7.6 m
Buried flush	5 ft/1.5 m	8 ft/2.4 m	18 ft/5.5 m
Buried 2 in	--	5 ft/1.5 m	15 ft/4.8 m

Unless mines contain integral AHDs, the extra time to lay mines with AHDs may be unacceptable. If the enemy is known to have a limited breaching capability, time may be wasted on laying mines with AHDs.

In very rocky ground, the difficulty of burying mines and the necessity for surface laying will have a bearing on suitable mines. For example, small, blast-type AP mines are hard to detect and easy to camouflage. They are much easier to camouflage than larger, fragmentation mines. The AT mine used will make little difference because the mine size will always make camouflage very difficult.

Using maneuver assistance to emplace minefields. During large mine-laying operations, engineers seldom have sufficient man - power to carry out all minefield tasks. Other combat arms units must often provide work parties. Engineers must be capable of organizing, controlling, and supervising combined arms work parties. They must also instruct them in new equipment and techniques. Working parties may be integrated with engineers or given certain tasks which are within their capabilities.

When laying a standard pattern minefield, consider supplementing work parties with other combat arms soldiers to comprise the following:

- Class IV/V (mines) supply point or mine dump party. Used to uncrate, prepare, and remove empty boxes and residue.
- Laying party. Used to position mines within strips and dig holes.
- Marking party. Used to construct the perimeter fence and emplace mine signs.

The most time-consuming tasks when laying a row minefield are unpacking, preparing, fuzing, and loading mines. This is an ideal task for other combat arms soldiers and using them allows for more efficient mine-laying operations.

MINEFIELD SUPPLY OPERATIONS

At the maneuver-battalion level, sustaining mining operations is an extremely difficult task. Centralized throughput operations by corps or division stop at the battalion level. Mass quantities of mines are centrally received, broken down into useable packages, and then distributed throughout the sector based on the obstacle plan. At some point in the distribution plan, the maneuver battalion turns over control of the mines to engineers who then emplace them in tactical minefields. Mine warfare logistics at the battalion level can be complex, require prudent use of scarce haul and material handling equipment, and demand positive command and control.

This section describes some of the underlying principles in mine supply operations. It concentrates on the flow of Class IV/V (mines) through the battalion sector. The flow of obstacle materials within the maneuver battalion sector is a maneuver unit responsibility. However, it is effectively a shared responsibility between the engineer and the maneuver unit.

Appendix B: Excerpt From

The Vehicular Mine Threat”, Hambric, Harry N, & Schneck, William C., Proceedings of the Sixth Annual TARDEC Combat Vehicle Survivability Symposium, Mar 28, 1995.

In low intensity conflicts, large anti-hull IEDs (Improvised Explosive Devices) are often fabricated from dud artillery/mortar rounds or bulk explosive and set either for command detonation or fitted with a variety of fuzing arrangements (see Appendix A). In Somalia, the typical improvised mine had an estimated 30 pounds of explosive with the largest having about 60 pounds. In addition to blast effects, these mines may also provide a primary fragmentation hazard, with the 155mm howitzer shell being the most dangerous munition likely to be found in this role.[63]

The penetration of the shaped charge/EFP equipped mines varies from 20mm to 250mm.[64] The manufacturers' data would seem to indicate that depth of penetration is not necessarily a function of charge size. For this reason, whether a mine is scatterable or not does not provide useful survivability information. In addition, the behind armor damage is not quantified.[65]

The blast mines fitted with full width attack fuzes have from 14.3 to 22.8 pounds of explosive fill.[66] The damage they cause is dependent on vehicle design. The lack of perforation of the armor or permanent bowing of less than a certain amount is an inadequate measure of performance. Mobility kills and crew casualties often occur because of transient deformation and violent translation.[67]

An important consideration in determining the threat posed by anti-hull blast mines is the amount of overburden above the mine. In conventional operations, manually emplaced mines are typically covered with no more than about two inches of soil due to the effort required to dig deeper, the limited amount of time typically available to emplace a large number of mines, and the decreased fuze sensitivity and blast effectiveness of the more deeply buried mine. Mechanically buried mines may be found with 5 to 6 inches of overburden (see Table 7) in soft soils and significantly less in hard/rocky soils or when time is short.[68] In OOTW, larger improvised manually emplaced IEDs are used to interdict routes and may be found as deep as 2 to 3 feet.[69]

Table 7. Mine Burial Depth *(To the bottom of the mine)*

Origin	System	Depth[70]	Remarks
Russia	GMZ	250mm	
	PMR-3 & PMZ-4	120mm	Yugoslavia & East Germany (MLG-60) produced copies
Italy	ST-AT/V	200mm	
Sweden	FFV 582	200mm	
France	MATENIN		
UK	BARMINE Layer	130mm	
US	M-57	152mm	

In low intensity conflict, most mines are laid in a fashion similar to that described above. However, due to the limited number of mines normally emplaced, some large, command detonated mines are laid at greater depth to frustrate detection. The effect of the resulting ejecta on the vehicle must be considered during vehicle design.[71]

Survivability design options include the use of spall liners, dragmats[72] and electronic countermine devices[73] to defeat/minimize the effect of EFPs and shaped charges, armor of sufficient thickness to stop the ejecta and fragments from deep buried mines and IEDs (using artillery shells), and V-shaped blast deflectors along the centerline of the vehicle to defeat blast mines.[74]

REFERENCES

1. “Performance in December 1996 Hand-Held Landmine Detection Tests at APG”, Andrews, Altshuler, Rosen, Porter; IDA Report March 1998.

2. “Wideband Electromagnetic Induction for Metal-Target Identification: Theory Measurement and Signal Processing”; Geng, Garber, Collins and Carin; Duke University; IEEE Trans. and Geoscience and Remote Sensing, September 1997.

3. “Use of Quasi-Magnetostatic Responses for Metallic Object Discrimination”, Riggs, Mooney, Lawrence, February 17, 1998.

4. “The Vehicular Mine Threat”, Hambric, Harry N, & Schneck, William C., Proceedings of the Sixth Annual TARDEC Combat Vehicle Survivability Symposium, Mar 28, 1995.

5. “Mine Countermine Operations”, Army FM 20-32, 19__.