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Optimization of Army-Navy/Portable Special Search (AN/PSS)-14 Operator Training

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Robert D. Clark, Alan D. Davison, and James J. Staszewski

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14. ABSTRACT

The research goal was to optimize Army-Navy/Portable Special Search (AN/PSS)-14 mine detector operator training duration and content. Results from training observations and analysis of Soldiers' learning progression curves indicated that AN/PSS-14 operators who certified through the course were not adequately skilled. Results also showed that the operators learned little with regard to ground-penetrating radar (GPR) use and consequently were not confident in discriminating mines and clutter. The authors recommended a better understanding of GPR functionality and the teaching of target discrimination. Additional time needs to be spent on learning how to develop the spatial patterns (footprints) that different objects produce through metal detection and GPR signals. Training sessions need to be standardized and structured into the crawl-walk-run format with more "hands-on" experience. The Sweep Monitoring System needs to be used more fully. Instructors need to better provide prompt, consistent, and frequent performance feedback. We recommend more stringent quality control of mine simulants, controlled clutter in the mine lanes, burying of the test piece, and multiple grading standards (probability of detection, target discrimination, time standard) that are consistent and more accurate. Recommendations were integrated into a new program of instruction.

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AN/PSS-14, mine, training, optimization, probability of detection

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1. Introduction

1.1 Background

1.1.1 The Land Mine Threat

Since World War II, land mines have posed a major threat to U.S. ground forces. An effective force multiplier, land mines play an especially important role in the asymmetric warfare in which the U.S. has engaged in conflicts of the past 15 years. Hambric and Schneck (1996) provided an assessment of the land mine threat stating, “Mines are a major threat in all types of combat and will be the major threat in operations other than war…which are expected to be the most likely missions for U.S. forces in the future…The widespread employment of land mines threatens to neutralize U.S. advantages in firepower and mobility by severely limiting our ability to maneuver and by disrupting our tactical synchronization.” Subsequent assessments from Operations Joint Endeavor (U.S. GAO, 2001; Schneck & Green, 1997) and Enduring Freedom (LaMoe & Read, 2002) have validated this appraisal and suggest that its severity may have been underestimated. Moreover, the counter-mine problem seen in the contemporary operational environment was predicted to worsen (LaMoe & Read, 2002). Kern’s (2005) recent assessment of the threat echoes that of LaMoe and Read (2002):

> We must take this challenge [to defeat mine threats] seriously and field the best solutions quickly to protect our forces. We must learn how to detect at distance and speed to ensure our future operational concepts are not derailed by the old simple devices…this problem demands our best work now…asymmetric warfare using mines of multiple varieties.

1.1.2 Progress in Land Mine Detection

Land mine detection is the core task in counter-mine operations. Discovering the locations of hidden mines remains an extremely hazardous task because it puts dismounted troops who are operating hand-held detection equipment close to buried and thus hidden, live, lethal ordnance.

Significant advances have been achieved recently in detection capability, related to the development and fielding of new equipment and training. Current systems are less than perfect, however, and further work on detection is needed to protect our troops and ensure maneuver capability.

The recent deployment of a new hand-held detection system, the Army-Navy/Portable Special Search (AN/PSS)-14 (see figure 1) represents a major technological advance. The first detector to combine two sensors, an electromagnetic induction subsystem, and ground-penetrating radar (GPR), this system has been deployed for use in Operations Enduring Freedom and Iraqi Freedom and has received favorable feedback from its users in the field (82nd Airborne, 2003).

Figure 1. AN/PSS-14 operated near Bagram Airport, Afghanistan, in 2004.

Significant progress has also been made in training troops to operate the AN/PSS-14 and its predecessor, the AN/PSS-12, both of which are employed in current operations. Training programs based on cognitive science research have raised detection rates sufficiently beyond those produced by previous training programs (Staszewski & Davison, 2002), resulting in the Army's adoption of these programs to train AN/PSS-12 and AN/PSS-14 operators. As demonstrated in the initial stages of system development and recently confirmed in the field, the performance of the AN/PSS-14 and dismounted mine detection capability depends crucially on the skills of its operator.

1.1.3 Transfer of Training to the Operational Environment

An in-theater assessment of AN/PSS-14 following its deployment in support of Operation Enduring Freedom addressed issues about the AN/PSS-14's capabilities and use in the operational environment (Maurer, 2003). Evaluators concluded that the equipment was performing to expectations: (a) Soldiers could safely detect very low metal mines from flush emplacement to depths of 4 inches; (b) Soldiers could detect low metal mines close to metal clutter and in metal-laden soils; (c) Soldiers reported confidence that they could detect low metal mines using the AN/PSS-14.

Evaluators' conclusions contained an important caveat related to operator skill, however. In-theater testing showed that the techniques of most operators were deficient after a month or more without system use, resulting in problematic detection rates (73.6%). Fortunately, delivery of refresher training restored performance to desirable levels (98.6%) and increased operators' confidence in their detection capabilities. These observations underscored the critical role of operator training and skill and implied that many operators' skills had deteriorated in the interval between initial training and operational use of the AN/PSS-14. Moreover, evaluators observed that noncommissioned officer (NCO) personnel with supervisory responsibilities who were unfamiliar with operator training and proper operational technique lacked the knowledge required to detect these deficiencies.

Another later in-theater assessment of operator skills conducted by U.S. Army Engineer School (USAES) personnel also showed that Soldiers' detection rates had fallen substantially below the standard for successful completion of AN/PSS-14 training (Mincey, 2005). Evaluation of operators' techniques revealed major deficiencies. This decrement was also attributed to an unspecified interval without practice between Soldiers' completion of initial new equipment training (NET) and subsequent in-theater evaluation.

1.1.4 Skill Decay

The phrase "use it or lose it" accurately describes the fate of skills that go unpracticed. Extensive scientific literature supports this saying (Healy & Bourne, 1995; Farr, 1987; Rose, Czarnolewski, Gragg, Austin, Ford, Doyle, & Hagman, 1985; Shields, Goldberg, & Dressel, 1979). Generally, the longer the interval without practice, the greater the loss in proficiency. Although the length of the retention interval plays a critical role in predicting how much proficiency is likely to suffer, the level of skill at the start of the retention interval is also an important determinant of the deterioration that occurs with the absence of task practice (Anderson & Schunn, 1995; Bahrick & Hall, 1991). It follows that efforts to understand and mitigate skill decay must examine the original level of learning achieved and the effects of denial of practice.

This reasoning applied to the in-theater performance of AN-PSS-14 operators motivated (1) the assessment of operator training reported here and (2) a subsequent experimental investigation of skill retention in progress.

1.2 Problem Statement

Evaluations of Soldiers trained to use the U.S. Army's AN/PSS-14 mine detector in support of ongoing operations suggested that operator skills decayed between completion of original training and operational use. Such losses can compromise our forces' counter-mine capability, threaten mission success, and jeopardize operators and other mission-related personnel. An understanding of the factors contributing to this problem is required for the formulation of mitigating policies. These factors include the level of skill that novice operators acquire in AN/PSS-14 NET.

The U.S. Army Engineer School, Training and Doctrine Command (TRADOC) System Manager for Assured Mobility (TSM-AM), Counter-Explosives Hazards Center (CEHC) provided the AN/PSS-14 NET. The training program consisted of 40 hours' classroom instruction and hands-on training. Typically, three NCOs were in charge of the training, along with training assistance provided by Cyterra or Battelle contractors (or both). The training duration evolved from the initial 40-hour block of training employed for testing the AN/PSS-14 prototype, the Hand-Held Stand-Off Mine Detection System (HSTAMIDS), in 2000. Its effectiveness was confirmed by its inclusion of successful operational tests of the system (Santiago, Locke, & Reidy, 2004). Modifications of the system have followed, including incorporation of an algorithm that supports the aided target recognition function, but the 40-hour duration of training has not been changed. Effects of varying the training time or examining its adequacy or efficiency of AN/PSS-14 training have not been investigated.

1.3 Objectives

The TSM-AM and the USAES Director of Training commissioned this effort to evaluate current AN/PSS-14 NET delivered by USAES, TSM-AM, CEHC and to identify and recommend means to maximize its effectiveness and efficiency. A specific issue for USAES leaders was whether the 40-hour-long training program was needed to train Soldiers to meet the current standards. A related task was to determine the amount of training that Soldiers need to achieve current performance standards for USAES operator certification; current records indicated that these standards were being met with the 40-hour program of instruction.

The scope of inquiry was comprehensive. It included consideration of the training infrastructure, including the site, facilities, training and testing aids, personnel needs, and procedures. Issues for examination included

a. What were the infrastructure requirements needed for training Soldiers to use this mine detector? How did the design of the training site and available resources impact training?

b. How efficient was the training? Were significant amounts of time being lost in teaching topics that were not relevant? Could more efficient ways be established to teach the different tasks and subtasks in mine detection?

c. What areas were being over- or under-taught, and how should that guide reallocation of training time to drills on the basis of need?

1.4 Approach

The evaluation approach was based on an empirical observation of training activities and focused on trainees' skill acquisition and performance and their drivers. A team composed of personnel from the U.S. Army Research Laboratory's (ARL's) Human Research and Engineering Directorate and Carnegie-Mellon University (CMU) executed the evaluation.

Personnel responsible for planning the study first observed 2-week-long training cycles delivered at USAES sites. The purpose was to familiarize themselves with the training in its current form and the training environment. The finding supported planning and preparation for 3 weeks of comprehensive, systematic field observation. This included collection of empirical data about the temporal organization of training activities, the activities of training personnel, and the behavior and performance of trainees. A priority was collection of data that tracked changes in trainee performance as a function of training activities or in other words, learning. These data would document individual trainee performance from initial mine detection efforts to the level of land mine detection performance achieved at the time of certification. The training events driving trainee learning were recorded as well, and evaluation focused on examining how these events related to Soldiers' learning trajectories and the skill levels they attained at the end of NET cycles.

1.5 Indications of Learning

Two common metrics used to investigate and assess learning are success rates and speed of task execution. Success rate is the proportion of opportunities for which an individual achieves a designated goal. Learning is reflected in an increasing proportion of successful trials (to an asymptotic level) as task practice accumulates. The relation between performance and practice takes a curvilinear form typically, as illustrated in the dark green function in figure 2, relating success rates on the y-axis scale on the left of the chart to number of practice trials on the x-axis.

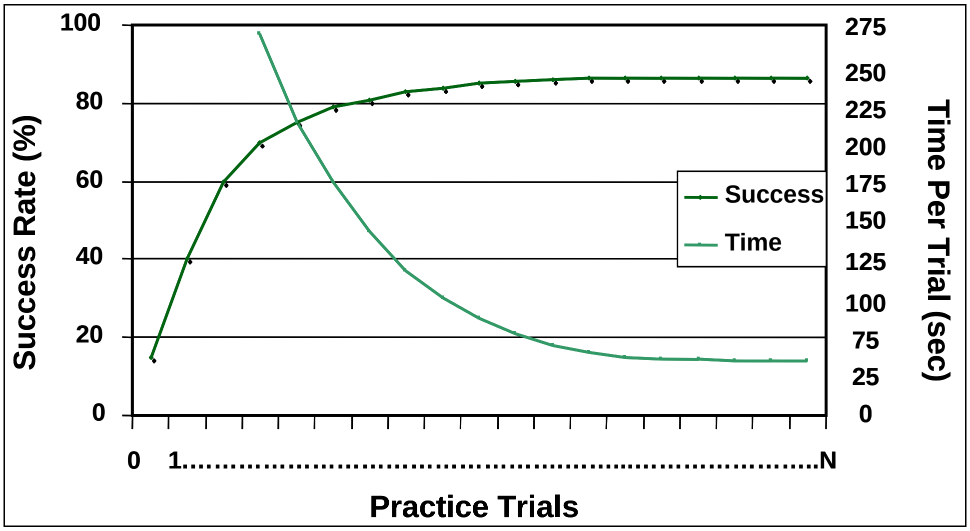

Figure 2. Generic learning curves.

Learning can also be measured as acceleration of task execution with increasing task practice (Newell & Rosenbloom, 1981). According to the Power Law of Practice (Newell & Rosenbloom, 1981), individuals typically demonstrate rapid decreases in task execution time initially but gain more slowly with further practice, thus producing diminishing performance returns. This is illustrated by the light green function in figure 2 relating practice to task execution times (shown on the right-hand y-axis).

It is important to note that these descriptions of learning trajectories make several assumptions about the learning environment. First, the descriptions assume that reliable, accurate, and timely feedback about a learner's performance is available to the learner. The absence of this critical ingredient can impede or negate learning. These characterizations also assume that learners engage in a task for which they have had no prior experience and that the task remains the same throughout the practice period.

This evaluation of mine detection training focused on two measures one can use to infer a mine detector operator's skill acquisition: (1) probability of detection, and (2) task completion time. Additional measures of interest included target and clutter discrimination, operators' subjective ratings of confidence in locating buried mine targets, and rate of advance (ROA).

2. AN/PSS-14 (formerly known as HSTAMIDS)

2.1 Description

The AN/PSS-14 is a lightweight, human-portable, hand-held mine detector that can detect metallic and low-metallic mines (see figure 3). The major components of the AN/PSS-14 are battery case and cable, electronics unit (EU), earpiece and cable, control grip, wand assembly, and sensor head. The AN/PSS-14 is used to support off-road movement of units, clear lanes, and help identify leading edges of minefields. Non-engineer units use the AN/PSS-14 to confirm or deny the presence of mines in support areas and logistics sites.

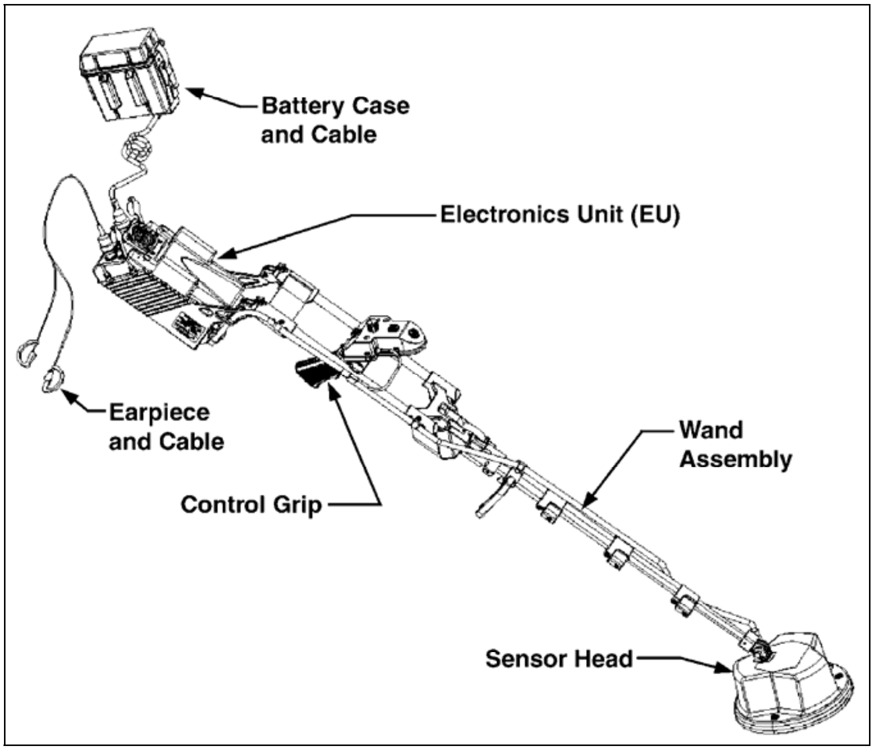

Figure 3. AN/PSS-14.

2.2 Theory of Detection

The AN/PSS-14 uses two different sensors for the detection of mines: electromagnetic induction (EMI) or metal detection (MD), and GPR. Each sensor returns a unique audio signal and can be heard by operators individually or in combination with the other.

MD operates on the principle of EMI, employing components that transmit electromagnetic signals and receive such signals to detect the presence of conductive material. The transmission component sends an electromagnetic signal into the soil, which induces a secondary magnetic field in conductive objects and materials. If the strength of the secondary magnetic field (dependent upon the composition and quantity of the material) is above a set threshold, algorithms that monitor return signals produce an auditory signal indicating the presence of conductive material (Department of the Army, 2003). The metallic components of mines within the range of the EMI signal produce MD responses.

GPR can locate objects buried as deep as 6 inches in the soil by transmitting radar waves into the ground and analyzing the reflected waves. As the search head passes over buried objects whose dielectric constant differs from that of the surrounding soil, changes in the radar returns occur. Algorithms that monitor return signals and register these changes can thus reveal locations of buried objects. The AN/PSS-14's generation of GPR output signals depends upon more than the system's registration of changes in return signals, however. The MD system must also register the presence of conductive material in its sensor field, although the strength of the MD signal does not need to reach the threshold required for an MD output signal.

The sensitivity of the MD and GPR systems to different properties related to mine targets significantly augments the system's detection potential. Co-location of both signals provides highly constrained information for inferring the presence of a buried land mine. Although many buried objects (and terrain features for GPR) can produce output signals on one or the other sensor operating independently, far fewer objects (other than mines) will produce output from both sensors. Moreover, both sensors are sensitive to variation in signal dimensions; the MD subsystem can reveal greater or lesser quantities of conductive material and the GPR subsystem can reveal the spatial dimensions of buried objects. These capabilities provide information that further constrains interpretation of output signals to broad categories of mines. If properly interpreted by a well-trained operator, the AN/PSS-14's responses offer innovative and powerful detection capabilities.

Mine detection with this system depends on its operator's ability to recognize the spatially distributed patterns of auditory output from his equipment produced by land mines. The equipment and the information it provides *when operated correctly* offer enormous potential for land mine detection. However, this potential can only be realized by training operators to (1) produce reliable and valid signals by applying proper operational techniques, and (2) interpret and recognize the spatially distributed patterns of auditory output from the equipment produced by land mines to infer their locations.

2.3 Component Operational Skills

Operators must acquire multiple skills to effectively operate the AN/PSS-14. First, before the system is used for land mine detection, procedures for preparing the system must be performed properly. Two primary operational sub-skills that determine a Soldier’s proficiency with the AN/PSS-14 beyond proper system preparation and calibration are search sweep technique and footprint development. Soldiers must also learn supporting skills such as safety measures and equipment maintenance.

2.3.1 System Preparation and Sensor Calibration

An important functional feature of the AN/PSS-14 is its capability to adapt to varying soil and terrain conditions, which vary widely throughout the world. Exploiting this capability involves training operators to correctly perform preparatory sensor calibration procedures that enable the system’s subsystems to adapt to the characteristics of the environment in which the system will be used (Glumm, Reinhart, Sexton, & Waugh, 2001). Before using the detector, the operator must first prepare and calibrate the AN/PSS-14 to filter soil scatter and eliminate the effects of mineralized soils and “train” the GPR.

After the system is unpacked and assembled, preparation and calibration procedures are performed in the following sequence: (1) attach the earpiece, (2) turn the detector on, (3) allow the detector to warm for 5 minutes, (4) turn the detector off, (5) wait 10 seconds, (6) turn the detector back on, (7) perform noise cancel to establish an environmental noise baseline for the detector, (8) perform ground balance to eliminate soil mineralization effects, (9) train the GPR to filter soil scatter, and (10) verify the calibration process with a test piece to ensure proper signaling and sensitivity. Once the detector is successfully calibrated, the operator is prepared to search for mines. Audio signals alert the operator when a target is present. The operator first finds the origin of the metal signature and then uses GPR to establish whether the target is a mine (returns a GPR signal) or clutter (no GPR signal).

2.3.2 Core Operational Skill Components

2.3.2.1 Search Sweep

Search sweep is the initial technique applied in detection activities. Its purpose is to identify locations in the area to be cleared (USAES training lane dimensions are 1.5 m by 15 m). These locations are identified by an output signal on the MD channel, the GPR channel, or both.

Effective search sweep involves complete spatial coverage of the designated area for search with the sensor head. Complete coverage is necessary but is not a sufficient condition for effective search sweep. Effective search sweep sensor head movements fall within the kinematic ranges needed for effective sensor operation. Violation of these thresholds can compromise the sensitivity of the system sensors and result in missing land mines. Even though the sensor head may pass over a mine, if it is too high or moving too quickly, no return signal will sound.

Proper search sweep technique is the first of the primary operational skills in which Soldiers are trained. The multiple requirements for effective search sweep that an operator must learn to produce are as follow:

- Sensor head must be parallel to the ground.
- Sensor head must be swept as closely as possible to the ground without contact and never in excess of the 2-inch upper limit.
- Sensor head trajectories should be perpendicular to the long axis of training lane in as straight a line as possible. Trainees are explicitly instructed to avoid arc-shaped paths.
- Sensor head velocity with the lane boundaries should be with the 1.0- to 3.6-ft/sec range.
- Lane traversals continue to the point at which one-half of the sensor head extends outside the lane boundary.
- Forward progress should proceed with trajectories that overlap the area covered on the previous traversal by one-third of the sensor head.

Accurately evaluating novice operator movements of the sensor head accurately is an extraordinarily difficult (if not impossible) perceptual task for trainers and observers. Therefore, to provide accurate performance feedback for trainees and evaluative information for trainers, the training aid called the Sweep Monitoring System (SMS) (Herman, McMahill, & Kantor, 2000) was made an integral component of AN/PSS-14 training. This computer-based training aid collects and graphically displays information about these features of an operator’s search sweep for use by trainees and trainers, providing them with critical performance feedback needed for effective and efficient training.

2.3.2.2 Footprint Development

The second critical operational skill that AN/PSS-14 operators must acquire in training is the procedure for “footprint development” and interpretation of the procedural results.

A land mine “footprint” is the spatially organized pattern of auditory signals produced by a hand-held detector when it senses buried land mines. After the origin of an alerting signal obtained in search sweep is located, this location serves as a point of reference for acquiring the localized sensor output from which the pattern or footprint of a potential mine target is constructed by an operator. The operator then compares the resulting pattern to the patterns of mines stored in the operator’s knowledge base from previous encounters. If the pattern developed is recognized as similar to that of a mine pattern, that judgment leads to a mine declaration.

Training includes instruction in the sequence of procedures that are used to build footprints. Repetitive application of these procedures on training mine targets provides practice in their application and familiarizes trainees with the generic patterns of AN/PSS-14 response signals produced by mines. This latter experience builds the knowledge that is the basis upon which operators later recognize mine patterns and make “mine/no mine” decisions in training and in subsequent live operations.

Footprint development procedure involves two sequentially organized steps. The first involves investigation of the area of the alerting signal with the MD sensor and afterward, the GPR sensor. The MD investigation maps an area around the origin of the alerting signal whose contours are defined by the onset or offset of output from the MD sensor. This area defines the region in which the operator will employ the GPR sensor to verify whether the suspected target is a mine.

For MD investigation, operators are instructed to move the detector head in a semi-circular fashion around a suspected target, establishing a small spiral pattern to find the outer boundaries of the target’s signal or halo (see figure 4). These boundaries are defined by the offset or onset of an MD output, depending on the trajectory of the sensor head. When the sensor head is within the MD “halo,” MD output persists; movements that end the response identify a halo edge. MD investigations involve sequentially finding MD onset/offset points at the 3-, 6-, and 9-o’clock positions of the MD halo by continuously tracking its edge between these reference points. At each halo edge point, operators mark each edge position by placing poker chips. These visual markers are intended to support operator learning so that they can later visualize the MD halo without the aid of the physical markers.

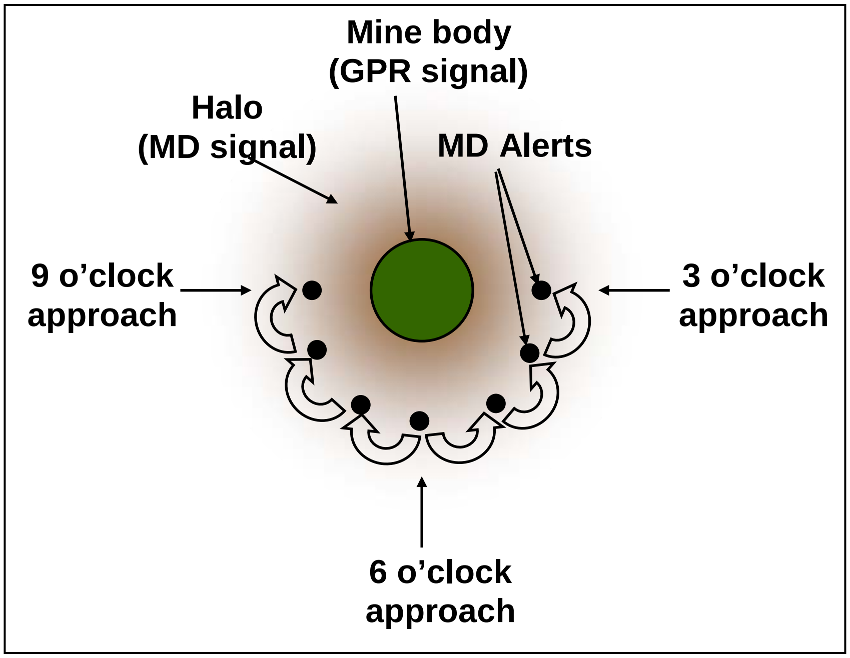

Figure 4. Target investigation.

When the MD halo is completed, its geometry directs the operator where to proceed with GPR investigation. In initial drills, operators are instructed to place a chip at the center of the “clock face” defined by the 3-, 6-, and 9-o’clock edges of the MD halo. If the investigation involves a mine, the strongest MD response should occur at this point. As trainees show proficiency in locating the center of MD halos, trainers remove the requirement of chip placements.

This MD halo center point serves as a reference for the first part of the GPR investigation, GPR “short sweep”. The results of GPR short sweep are the basis for identifying the source of the MD signals as a mine or clutter. Short sweep consists of movements of the sensor head that obey the technique requirements of search sweep but whose length is limited by the spatial extent of the MD halo about the center point. The outer limit for sensor head movement is the MD halo boundary, which should never be exceeded. If GPR signals reliably occur in repeated short sweeps, the decision rule operators are given dictates that they declare a mine. The absence of GPR signals indicates clutter if and only if proper GPR short sweep technique is applied. Violations of proper techniques frequently produce GPR signals, leading to operators making false alarms, that is, declaring clutter as mines. With the proper short sweep technique, many commonly found high metal objects, such as a nail or other metal fragment, are often small enough that the GPR will not detect them, thus allowing an operator to identify such items as clutter.

If short sweep produces GPR output, operators are instructed to extend short sweep farther from the footprint center to identify the outer edges of the mine target at the 3-, 6-, 9-, and 12-o’clock positions. Locating these points, defined by the onset and offset of GPR signals, confirms the likely center of the mine target, which should be spatially coincidental with the MD center point for most mines (and all mine simulants used for training) with no adjacent metallic clutter. Such confirmation increases the likelihood of a declaration being scored as a correct detection or a “hit.” This is because the very stringent accuracy standard for scoring requires that poker chips used to declare mines be placed over or immediately adjacent to the body of a mine.

Mine footprints vary systematically as a function of mine category. Figure 5 shows typical footprints for targets varying in size and purpose, antitank (AT) versus antipersonnel (AP), and varying metallic content, metallic (M) versus low metallic (LM). Note that the variability in the relations of the MD and GPR halos varies considerably across the four major mine categories (ATM, APM, ATLM, and APLM) represented in the set used for training.

In figure 5, the black circles represent outer contours of mine targets (not drawn to scale). Shaded green regions indicate MD halos; red marks indicate where trainees are instructed to place MD halo marker chips. Orange marks indicate GPR return signals and are expected when the sensor head follows the trajectories shown by the thin black lines. Note the coincidence of the centers of the MD and GPR halos at the center of the mines. Also note that the sensor head trajectory for the ATLM (bottom right) extends beyond the MD halo—something that **should not be done operationally** but is illustrated here to demonstrate the location of GPR return signals.

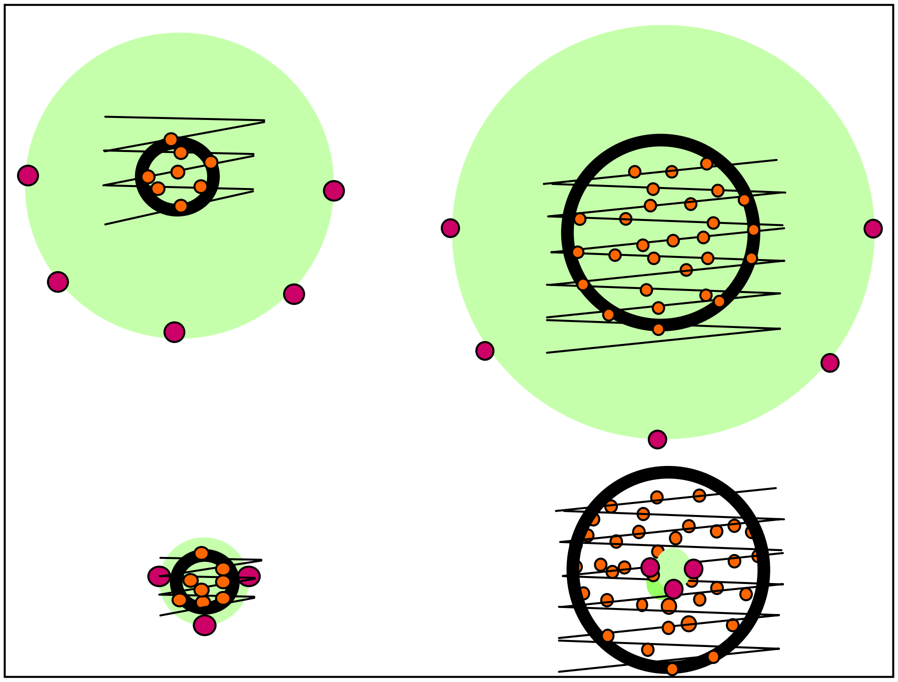

Figure 5. Generic mine footprints: APM (top left), ATM (top right), APLM (bottom left), and ATLM (bottom right).

Adjacent metallic clutter typically distorts the symmetry typical of the MD halos of mines in a clutter-free environment. The degree of distortion is related mainly to the size and shape of the clutter halo and its proximity to a mine's MD halo. The shapes of MD halos for clutter are typically more variable than the MD halos for mines. MD clutter also generates subtly different audio signals (in terms of frequencies and amplitudes) than those produced by the mine simulants used in training. A significant implication of clutter-related distortion to MD footprints is that it increases the difficulty of correctly inferring the location of the MD center point used as a reference point for subsequent GPR investigation and declaration chip placement.

2.4 Training Site

The NET occurred at two different sites at Fort Leonard Wood, Missouri: Training Area 206 and the "pole barn" (see figure 6). The latter was a relatively new site with a one-sided pole barn that provided limited cover from bad weather. Initial observations for planning data collection occurred at both sites. Data collection was conducted only at the pole barn site because training that occurred during the time scheduled for evaluation was performed only at that site. Preparatory observations occurred at both sites.

Figure 6. Pole barn facilities; west facing view.

The pole barn facility included five sterile (non-cluttered) lanes and nine off-route or tactical lanes. All lanes were 1.5 m wide by 15 m long and were divided into 10 equally sized cells. The sterile sand lanes were intended to have no clutter, but several items of clutter could be found in most of these lanes. The tactical lanes were in the wooded area surrounding the site. All had natural soils mostly cleared of surface vegetation. These lanes contained pre-existing clutter and clutter placed by trainers, although clutter locations were not mapped before this study. All lanes contained buried targets that included mine simulants with diameters of 6, 9, and 12 cm (representing APLMs), 20, 25, and 30 cm (representing ATLMs) as well as high metal M15s (ATMs) and M16s (APMs). Although all lanes had nine targets, often with one of each type and two mine simulants (SIM6s), the number of each type varied for some of the lanes. The implications of this lane-to-lane variability in target content, as well as the substantial variability discovered in the number of clutter items between lanes, are discussed later.

2.4.1 Training Aids and Functions

Two training aids are integrated in the training program. One is the SMS mentioned in the earlier discussion of search sweep and illustrated in figure 7. The second are scoring grids, devices used first for emplacing and documenting the locations of mine targets in lanes when they are constructed and later in training for scoring trainees' mine declarations.

The role of the SMS is to accurately and objectively assess the qualities of search sweep technique and provide feedback needed for Soldiers to learn proper technique. The motivation for including this device in the training package stems from the extreme difficulty that even highly skilled human observers experience in reliably and accurately judging whether a trainee's sweep is within acceptable ranges on the multiple parameters listed earlier.

Figure 7. Sweep monitoring system (SMS).

The SMS's two cameras track the motion of the detector sensor head and continually document its position within a lane. When an operator moves the detector too quickly, too slowly, too high from the ground, or creates a gap in lane coverage, the SMS produces a voice message indicating the violation. The SMS records the head position data continuously over time as well as video of the operator sweeping. The data are displayed on a color-coded interface that maps the operator's sweep activities (speed, height, gaps) for the entire drill. This graphical interface enables trainers watching the SMS monitor during the drill to easily detect and diagnose technique flaws and enables an operator to review his search sweep and identify problem areas.

Scoring grids (see figure 8) are used to determine whether mine declarations made by trainees in training and certification testing can be classified as mine detections. The devices consist of a square frame made of plastic tubing with strings spaced at 15-cm intervals and extending vertically and horizontally parallel to the frame components. The matrix arrangement of strings, each labeled with a letter (A through J) on the horizontal axis or a number (1 through 10) on the vertical axis, creates a reference grid. Lanes are constructed with reference pegs along the boundaries so that the scoring grid can be reliably placed in the same location for each of the ten 1.5-m cells that compose a lane. Mine targets are emplaced with their centers at specific intersections of the grid, denoted by a unique letter and number combination for each cell (Cell 2, B-9, for example). Thus, by measuring the distance from a declaration chip to the grid location specifying a target center, adjusting for the target's radius, and applying due diligence with respect to grid placement and measurement, we can accurately and easily categorize the declarations as hits or misses.

Figure 8. Scoring grid.

2.4.2 Training Schedule/Sequence

Training documents list the content and planned delivery sequence for course components as follow:

- Day 1 – Classroom (6 hours), sweep technique demonstration and practical exercise;
- Day 2 – Startup and calibration demonstration, mine footprint demonstration and practical exercise, 1.5 sterile lanes, two 2-minute runs on the SMS;
- Day 3 – Tactical lane practical exercise;
- Day 4 – Tactical lane practical exercise, kneeling and prone mine detection demonstration, written test review;
- Day 5 – Written and performance tests.

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3. Method

Evaluation methods focused on empirical observation of trainees engaged in AN/PSS-14 mine detector operator training. The collection of quantitative data documenting trainee performance was prioritized because learning occurring over the training periods represents arguably the best index of training efficacy. A variety of qualitative observations was collected, some systematically, if they were anticipated based on events and observations encountered in the earlier training familiarization phase. Other unanticipated but significant events that occurred during the formal observation period were noted and described qualitatively in the results that follow.

3.1 Participants

Candidates for detailed observation were drawn from Active Army, Army Reserve, and Army National Guard units from Indiana, Ohio, Alabama, Alaska, and Colorado, who were scheduled for three separate week-long training sessions at Fort Leonard Wood, Missouri. All units but one deployed by January 2005; the remaining unit deployed by August 2005. Six operators from each session were randomly selected for detailed observation for the duration of their training.

Participants' ages ranged from 19 to 47 years with a median age of 29. All Soldiers selected were male except for one female, and their ranks ranged from Private (E-2) to Sergeant First Class (E-7), with a median rank of Sergeant (E-5). Of the 18 Soldiers who were observed, 7 had no previous mine detection experience and the remaining 11 had AN/PSS-12 training. Of the 11 Soldiers with training experience, one had AN/PSS-11, Minelab, and HSTAMIDS training experience, and one had used his AN/PSS-12 experience in a combat environment.

All participants provided informed consent before any observation as prescribed in Army Regulation 70-25 and required by the internal review boards for the protection of human subjects of the authors' institutions, ARL and CMU. A copy of the consent statement is shown in appendix A.

3.2 Apparatus and Materials

Equipment for data collection consisted of digital stop watches used to time and record events in trainees' mine detection drills and certification testing.

Several structured forms tailored for specific purposes and training exercises were designed to facilitate and standardize data collection.

3.2.1 Training Experience Survey

This is a participant survey to collect information about past experience with mine detection systems to include the type of mine detector, training, and if the individual had used the detector in counter-mine operations.

3.2.2 AN/PSS-14 Ergonomics Questionnaire

This is a questionnaire for participants to answer demographic questions and to rate the level of pain or discomfort with certain parts of their bodies before and after training.

3.2.3 Daily Log

This is a form used to record time duration of the daily activities of participants. Activities of participant included arriving and departing site, classroom training, demonstration training, mine detecting, assisting other participants or instructor, breaks, and lunch.

3.2.4 Sweep Drill Worksheet

This is a form used to record the time trainees spent on sweep drills and support “battle buddies” engaged in these drills.

3.2.5 Iteration Cover Sheet

This is a form used to record the participant’s name, detector serial number, starting and stopping times, data collector’s initials, and the lane.

3.2.6 Blind Search Observation Data Worksheet

This is a form used to collect the timed observations of participants while they were operating the mine detector in a lane. The researcher tracked the location of the operator in the lane by cell number. Times were recorded for each activity that the operator completed such as search sweep, MD footprint development, GPR verification, GPR footprint development, or detector recalibration. The location of each target investigation was numbered and recorded on the lane map and data sheet. After each investigation resulting in a mine declaration, data collectors asked their respective operators for a subjective confidence rating on a Likert scale (1 to 5 scale range in which 5 = confident that the target is a mine, 1 = confident that the target is clutter) and recorded their responses. Events such as quick calibration of the system, noise canceling, presence of an instructor or trainer assisting the operator, and any other events or instructor comments deemed significant were recorded.

3.2.7 Mine Lane Maps

These are maps of the mine and clutter locations for each lane.

Copies of all forms are shown in appendix A.

3.3 Procedure

Data collection began in the morning of the first day of each training week. Data collectors initiated recruitment by briefing all assembled trainees about the study’s objectives, the voluntary nature of their participation, and informed consent requirements. Those providing informed consent completed the training experience survey; the ergonomic questionnaire was then administered. Training proceeded with the classroom phase of instruction.

Upon completion of the classroom introduction, six randomly selected volunteers were each introduced to the data collector assigned to observe and document all of that person's training activities. Data collectors recorded information about participants' activities in a daily log. When trainees proceeded to initial drills on sweep techniques, data collectors "shadowed" their respective trainees as unobtrusively as possible to observe component activities, time stamp their starts and stops, and record instructors' comments. At the end of the drill period, another ergonomic questionnaire was given to participants.

On the second day of training, data collectors recorded events for their respective trainees in daily logs, beginning with start-up and calibration demonstration and drills, a demonstration of footprint development by an instructor, and trainees engaging in the footprint development exercises. As initially observed in training familiarization, footprint drills were not performed as focused exercises, as designed in the initial HSTAMIDS training. Instead, the footprint development drill was combined with search sweep to create a "blind search" exercise in the "sterile" lanes. Observations were therefore recorded on the Blind Search Observation Data Worksheets for subsequent practice on the sterile and tactical lanes. To better anticipate trainees' activities and thereby facilitate data recording in blind search exercises, lane maps were constructed showing locations of mine targets and clutter based on data collectors' observations.

After each mine declaration made by each trainee undergoing observation, the data collector asked for a subjective confidence rating using the scale described previously which reflected that operator's confidence that the declaration marked the location of a mine of any type. Following a trainee's completion of blind search on a given lane, data collectors observed instructors' scoring of declarations, noting the observations associated with successful detections and missed targets.

The fifth day of training consisted of a certification test. Data collectors again used the same procedures and forms for events as those used in previous blind search exercises. Trainees were assigned a tactical lane that they had not previously completed in training and were required to successfully detect all the mines in the lane in order to pass. If, after completing the test lane, the participant did not detect all the mines, the participant was assigned another tactical lane for retesting. Only perfect detection performance in the first or second test met certification requirements.

Following completion of field observations, data collectors entered all hand-coded observations into computer files for subsequent analyses. Anticipating later analyses by target type (APLM, APM, ATLM, ATM) or clutter, data collectors added appropriate categorical labels.

3.4 Anticipated Results

Several results were anticipated. First, based on performance in AN-PSS-14 operational tests (Santiago, Locke, & Reidy, 2004), one of the authors' prior experience with HSTAMIDS operator training, and anecdotal reports about training effectiveness, the tracking of trainees' detection rates over the course of blind search practice was expected to reveal learning curves that peaked in the 97% to 100% range. Because the training was expected to provide trainees with prior knowledge and experience at footprint development before blind search exercises, it was anticipated that this prior experience would produce initial trial probability of detection (PD) well above where it would be expected to be, if no prior training had been given in those sub-skills (as suggested by the functions in figure 2). It was expected that first trial PD would be in the 70% to 80% range and would increase with practice to the 97% to 100% range.

With feedback and review of any missed targets with trainers present to provide coaching, trainees' increasing familiarity with the patterns of information that defined mine targets led to the expectation that they would gradually begin to distinguish mine targets from clutter.

Trainee ability to recognize the patterns of AN-PSS-14 output that defined mine targets was expected to increase with practice, and with the feedback and coaching they were expected to receive, gains in operators' confidence ratings were anticipated as a function of practice.

Regarding the tracking of trainee MD and GPR investigation times for mine targets, a trajectory conforming to the power law of practice (illustrated in figure 2) was expected; however, specific ranges were not expected for starting times or ending times for either of the measures since these measures had never before been collected systematically.

4. Results

4.1 Time Distribution

Data from the daily log worksheet were aggregated over the three observation periods to create a weekly time distribution to examine time allocations to events and activities occurring within the 40-hour block of instruction. A summary of time allocation to various events is shown in figure 9.

Lane time is defined as the duration an operator was in a lane engaged in blind search for mine targets. "Calibrate" or "sweep" was the time spent in calibrating the AN/PSS-14 or performing sweep drills without investigating targets (the detector was turned off for the drills). "Chip" or "observe" was the time spent in placing chips for another operator's footprint development of targets during blind search or watching another operator use the detector. "Class" was time spent by participants in the classroom, listening to lectures or performing preventive maintenance checks and services. "Demo" was the organized time that all operators spent watching the instructors demonstrate specific techniques. "Lunch" reflects time spent on the daily meal break. "Break" or "waiting" was time spent warming on a cold day, standing around and talking with buddies, waiting for an instructor to grade a completed lane, waiting for a lane to open, and so forth.

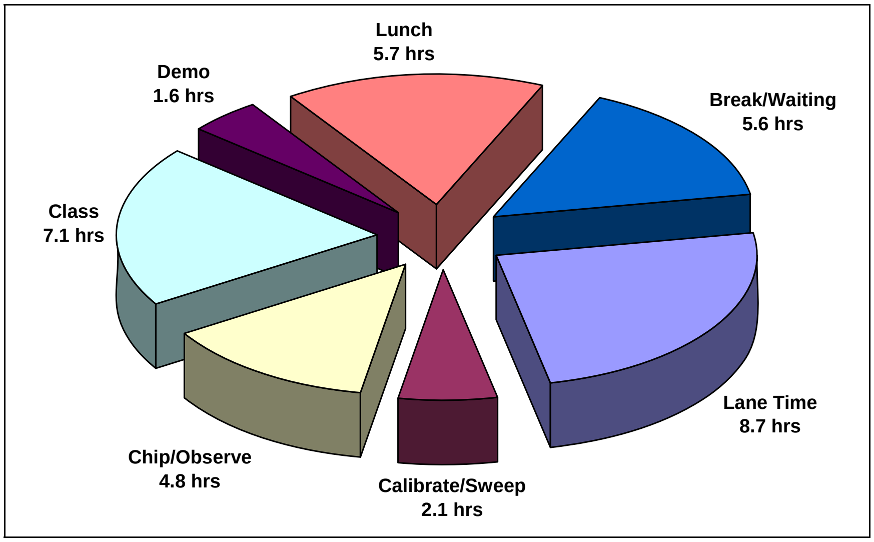

Figure 9. Median weekly time distribution.

These activities took 35.6 hours of the available training period on average. Of the 4.5-day training week, more than 30% of the time was consumed by lunch periods (4), breaks, and waiting periods. *The proportion of time in non-training activities exceeded that spent practicing mine detection in the test lanes*; note that the lane time for individual trainees ranged from a minimum of 7.2 hours for one operator to a maximum of 16.0 hours for another. Chipping and observing time, whose instructional value is suspect, also varied widely, from 1.4 hours to 9.0 hours for individuals. Time allotments for remaining event categories showed relatively little variability.

4.2 Probability of Detection

PD measures the capability of an operator to detect the locations of mines and in this case, mine simulants. PD is the proportion created when the number of mine declarations scored as hits is divided by total number of mines encountered.

Figure 10 displays overall PD for all trainees in the observed sample as a function of practice. The authors created the dimension of practice by ordering blind search trials in which all trainees engaged, noting that in most cases, the first two trials were labeled Footprint Development in the program of instruction (POI) but in effect, constituted blind search trials performed in the "sterile" lanes. Trial 7, also performed on a tactical lane in which a trainee had not practiced, represents each trainee's first attempt at qualifying for certification. Results of re-test trials given to those who failed the first test are not shown. Error bars indicate the 95% confidence interval of the proportion (PD) as calculated with the modified Wald method (Agresti & Coull, 1998). Caution should accompany the interpretation of the PD and confidence intervals because of measurement issues, discussed next, which threaten their validity.

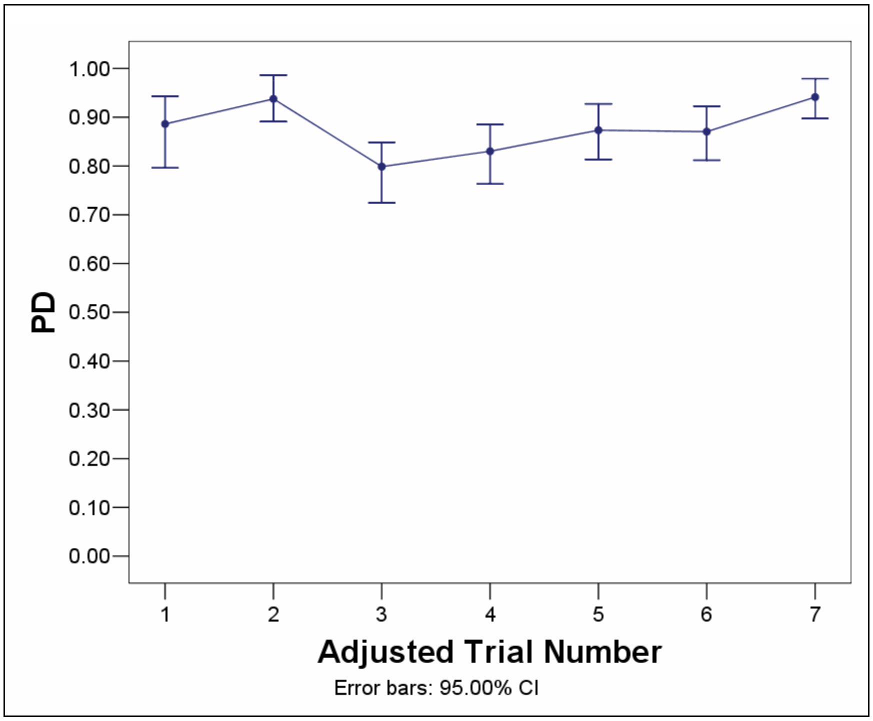

Figure 10. Probability of detection versus trial number for all mine types.

Two features of the function shown in figure 10 are noteworthy. The first is the surprisingly high initial trial PD. The second is the decline between the first two trials and the third. Differences in PD between Trials 1 and 3 were statistically reliable (z^2, N = 233, = 5.39, $p < .02$), as were those between Trials 2 and 3 (z^2, N = 282, = 11.3, $p < .001$).

These features of trainee performance were examined as a function of mine category because the footprints that are the basis for accurate mine detection with the AN/PSS-14 differ considerably across categories. PD as a function of practice for APLM, ATLM, APM, and ATM targets is shown in figure 11. Trial 1 detection rates again show high performance levels, with the slightly lower performance for low metal targets (more difficult to find) versus high metal targets (expected). Differences between second and third trial performance vary considerably for different target categories. PD for ATMs show the form of classic learning curves, curvilinear monotonic increasing functions. In contrast, sharp declines of 30% and 20% are shown for APLMs and APMs, respectively, between Trials 2 and 3.

The declines in PD between Trials 2 and 3 motivated examination of PD as a function of sterile versus tactical lanes (see appendix B for a detailed description of PD as a function of trials and lanes). A striking contrast was the difference in between-lane ranges in PD for the sterile (.05) and tactical lanes (.14). An analysis of the differences between the tactical lane with the highest overall PD (Lane I, PD = .93) and the three tactical lanes with the lowest PDs that were completed by more than one trainee, produced reliable differences between this lane and H (PD = 0.93, N = 187, $z^2 = 6.13$, $p < .05$), M (PD = 0.82, N = 151, $z^2 = 4.95$, $p < .05$), and F ($z^2 = 3.55$, $p < .05$).

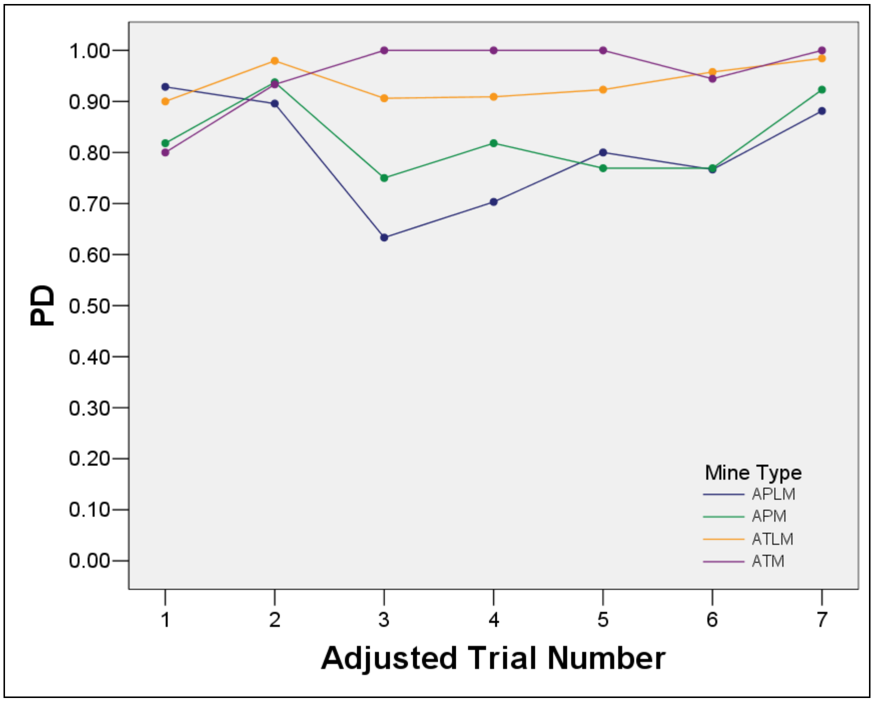

Figure 11. Mean probability of detection versus adjusted trial number by mine type.

Observations of training and testing produced two significant qualitative findings relevant to interpretation of PD and the related confidence intervals, which raised concern about their reliability. First, trainers or trainers in training often interrupted trainees while they were performing footprint development exercises and blind search drills in the tactical lanes in order to model the procedures and proper technique. The interruptions frequently consisted of the trainer (or a trainer assistant) seizing control of the AN/PSS-14 sensor head, performing the component steps of footprint development, and placing the declaration chips on targets. All declarations were scored and recorded, however, as if they were produced by the operator. This practice represents a source of measurement error likely to inflate PD for initial trials artifactually.

A second source of measurement error was observed related to scoring conducted by trainers and trainers in training in the tactical lanes. Scorers were observed to score trainees' declarations on most occasions by visually estimating the distance between a placed chip and a target's reference point on the scoring grid placed on a lane from distances of 4 to 8 feet away, rather than using a tape or ruler to measure distance. An instance of this practice was captured on a video, and it shows a trainer making "eyeball" estimates of declaration-target distances at speeds (mean 4.4 seconds, min = 2, max = 7 sec per "measurement"), hardly conducive to accurate measurement.

Scoring accuracy was challenged by trainees on occasions. In three observed cases, declarations judged as misses by trainers performing scoring and protested by the operators involved were later shown to be hits upon a later careful re-examination by observers. Such lax scoring practices, whose incidence beyond the observed samples is unknown, invite measurement error in scoring. Such errors raise doubts about the accuracy of PD measures *and produce inaccurate* *feedback upon which trainee learning depends.* The scoring errors documented here had negative consequences for the morale of the trainees involved.

4.3 Confidence Ratings

Figure 12 summarizes subjective confidence ratings given by each observed trainee for all mine declarations as a function of practice, distinguishing ratings given for mine targets and those given for false alarms (clutter mistaken for a mine). Error bars in this figure represent the 95% confidence interval for each mean. Confidence as a function of practice for each of the four target categories is shown in figure 13.

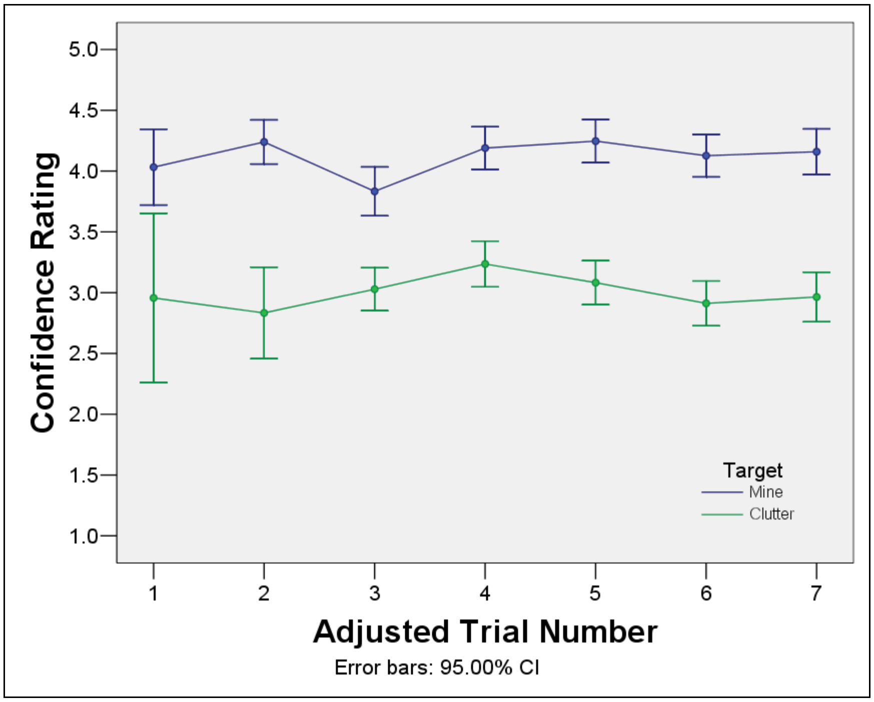

Figure 12. Mean confidence rating versus trial number: all mines versus clutter.

The salient feature of the functions shown for mines in figure 12 is their negligible slopes. These functions and related summary statistics in table C-1 show that the mine detection practice provided over the course of training does not reliably increase an operator's self-assessed confidence in his or her capability to detect targets—an effect contrary to the gains expected from training. Although the obvious differences in confidence ratings for targets and clutter items suggest that operators should develop some sensitivity to the signals that distinguish targets from clutter early in training, subsequent practice does not improve this sensitivity from its baseline level. Note that the value of 5 represents that an operator feels "confident" that a given declaration marks the location of a mine target.

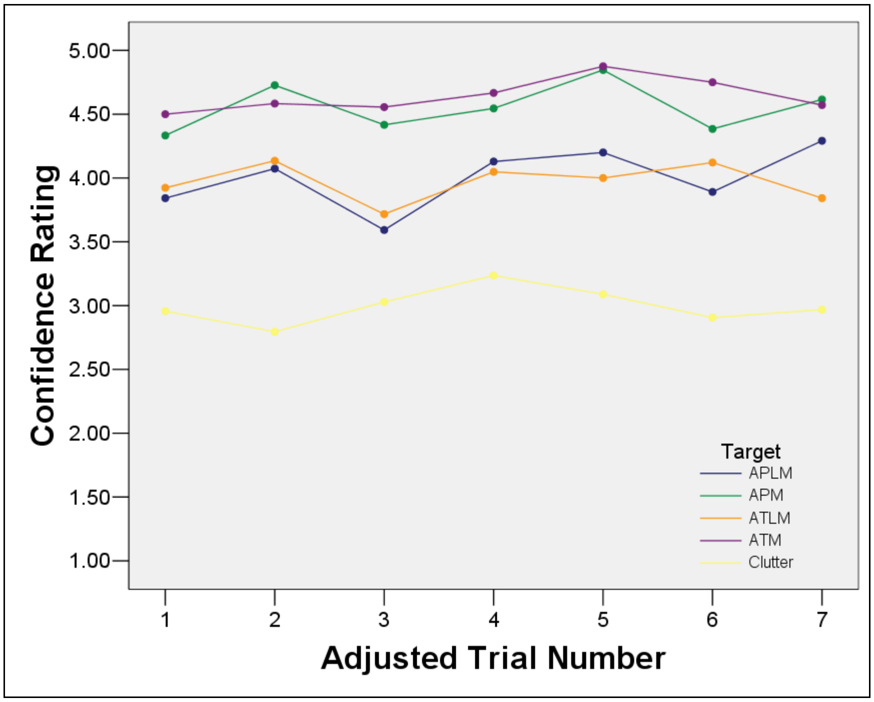

Figure 13. Mean confidence rating versus adjusted trial number by mine type.

Figure 13 shows differences between operator confidence for declarations related to metallic and low metallic targets, with high metal targets consistently receiving higher confidence ratings over the course of blind search trials. Examination of the summary statistics for confidence ratings in table C-1 confirms no effect of practice for ratings for APLM or ATLM targets, the threats that heavily motivated the development of the AN/PSS-14.

4.4 Investigation Times

An investigation event was defined as an operator's sequential application of MD techniques and GPR techniques to an area where an alerting signal occurred. This definition ignores the order of technique application, noting that trainees are instructed to first perform an MD investigation on a suspected target and then use its findings to guide GPR investigation. Because investigation times include sensor-specific investigation activities as well as acts such as quick calibration or grip adjustment, investigation time in such instances exceeds the sum of MD and GPR investigation times.

Figure 14 illustrates investigation times, MD investigation times, and GPR investigation times as a function of practice. Medians summarize the temporal measures attributable to the consistently skewed form of these time distributions. Medians were calculated after removal of outliers, defined as times that were greater than three times the value of the fourth spread beyond the 75th percentile value (Hoaglin, Mosteller, & Tukey, 1983). Additionally, the lowest percentile and other clearly erroneous times, such as investigation time with zero duration, were trimmed before median calculations.

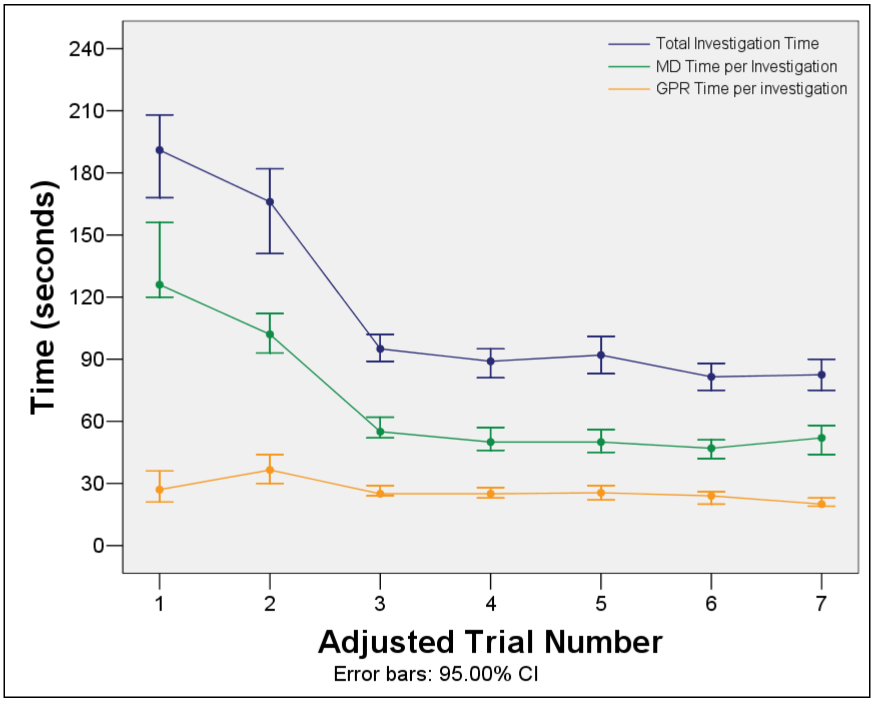

Figure 14. Median investigation times (total, MD, and GPR) versus trial number for all mine types and clutter.

Investigation time for all targets (mines and clutter) decreases substantially (57%) with practice, also showing a curvilinear trend consistent with the power law of practice (Newell & Rosenbloom, 1981). This general description, as well as the magnitude of the apparent training effect, applies to the functions for investigation times for targets and clutter and for the durations of MD investigations for targets and clutter. Decreases for GPR investigation times as a function of practice tend to be much more modest, about half the percentage decrease seen for investigation and MD investigation times.

Results from fitting the power curve function ($y = Cx^b$) to the temporal investigation time measures are shown in appendix D in tables D-4, D-5, and D-6, and in figures D-4 through D-18. Despite high variability resulting in relatively poor fits, three noteworthy consistencies emerge. First, comparative examination of R^2 values in tables D-4, D-5, and D-6 shows that the best fits are achieved for investigation times and MD times related to mine targets. Second, fits of GPR investigation times are quite poor across all target types and clutter. Third, fits to the investigation times, MD times, and GPR times for clutter are poor. Examination of slope estimate (b) magnitudes in tables D-1, D-2, and D-3 shows that the lowest values are related to the functions for GPR investigation and clutter targets. Inspection of figures D-4 through D-18 shows consistently greater dispersion of individual data points from the predicted values at each practice level for the poorer fitting functions, with one noted exception: high dispersion is characteristic of investigation, MD investigation, and GPR investigation times for metallic targets.

4.5 Rate of Advance

One measure of operator performance that is of considerable operational importance is ROA. ROA measures the speed with which a given area can be cleared of mines and made safe for maneuver. Slow mine detection and clearance compromises operational tempo and threatens to desynchronize various tactical elements of mission and disrupt plans.

The areas or lanes on which participants performed blind search exercises were 1.5 m wide by 15 m long, whose perimeters were marked and whose interiors were divided into ten 1.5-m by 1.5-m cells. Not all cells were swept on all trials, e.g., Trial 1 typically involved a search of five contiguous cells, but trainers sometimes truncated the first and latter trials on an arbitrary basis. To measure advancement, taking into account the different areas actually covered in trials, ROA values are presented in units of square meters covered per minute (m^2/min), making ROA values independent of the specific area covered.

Figure 15 illustrates the median rate of advance for all participants as a function of practice. The medians displayed were computed after the removal of outliers, defined as values greater than three times the fourth spread from the 75th percentile (Hoaglin, Mosteller, & Tukey, 1983). Error bars indicate the 95% confidence intervals for the resulting central tendency estimates. Despite the absence of any speed requirements, a trend indicating increased coverage speed is seen through Trial 6. A regression in speed was observed for the final trial, which represents a trainee’s initial attempt to qualify for operator certification.

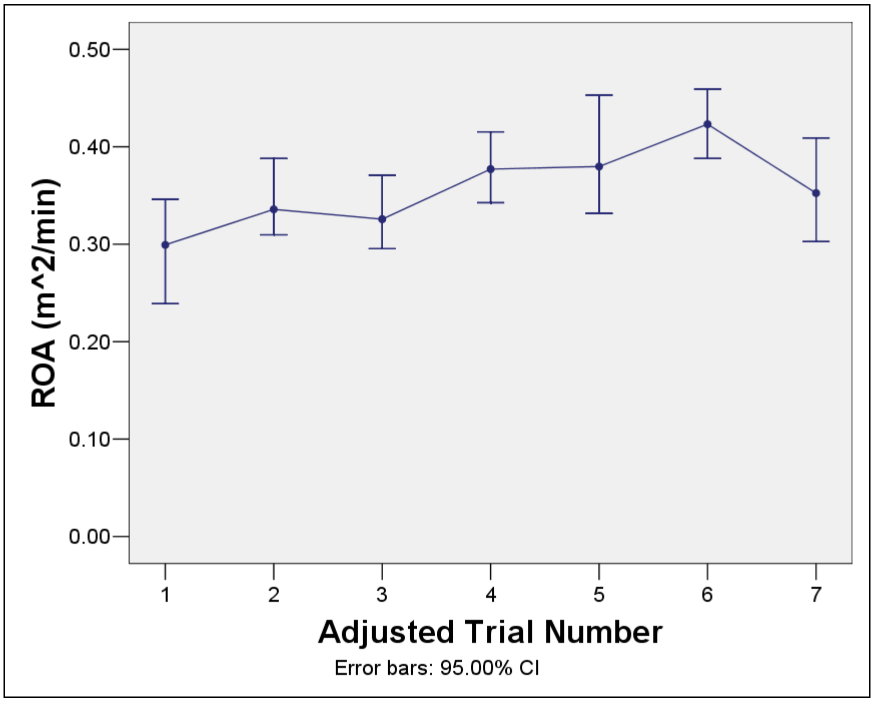

Figure 15. Median rate of advance versus trial number.

Summaries of ROA as a function of variables other than practice are presented in appendix E. Included are descriptive statistics for ROA by lane (table E-1) and by participants who passed the first test (Trial 7) and those who did not (table E-2). The information is also presented graphically in figures E-1 and E-2.

A noteworthy finding shown in figure E-2 is that ROA functions diverge after Trial 3 for trainees who pass the initial certification trial (Trial 7) and those who fail, with the successful operators showing faster ROAs. The unsuccessful operators also show a greater reduction in ROA between Trials 6 and 7, with Trial 7 falling slightly below the ROA that this group demonstrated in its initial trial.

Noting that no time limit was imposed on testing and operators were told to take all the time that was needed, extreme differences among operators were observed. Some completed their lanes in as few as 35 minutes, but one took 3 hours 45 minutes to complete one lane.

4.6 Qualitative Observations

The number of trainers varied substantially from week to week. For the first training week, the three regular NCO trainers were supplemented by two civilian contractor trainers from Cyterra, the manufacturer of the AN/PPS-14. For the second training week, there were no civilian trainers. In the third training week, three civilian trainers were supplied by Battelle Corporation. In addition, as many as ten trainer assistants (TAs) in one week and as few as one in another functioned as trainers by observing, critiquing, and coaching trainees.

The quantity and quality of training that trainees received varied substantially within weeks and between weeks for several reasons. First, TAs were Soldiers who had trained and qualified for operator certification only the previous week and so possessed relatively little experience with the AN/PSS-14. Their training skills varied considerably as well. Numerous instances were observed in which a TA seized the detector head from an operator who was thought to exhibit poor technique, proceeded to investigate a target from a kneeling position using poor technique, and then ended his demonstration lesson with comments such “see that?” or “get it?” Different TAs also gave contradictory advice about technique to trainees, which often resulted in trainee confusion and frustration.

Problems with the operation of the SMS, which occurred frequently, reduced the pool of appropriately qualified trainers available to observe and coach trainees. Only the regular trainers had sufficient familiarity with the SMS to diagnose and (sometimes) fix the problems.

Simultaneous responsibility given to the resident NCOs for supervising, coaching, and evaluating the TAs further reduced their availability to work with the trainees.

Supervision of trainees fell dramatically once training exercises moved to the tactical lanes for several reasons. One is that the tactical lanes were dispersed in the wooded area around the pole barn, requiring a trainer to be close to an operator to observe his technique. Because as many as six operators might be engaged on different lanes simultaneously, experienced trainers, especially when their numbers were low, could only split time among operators by walking from lane to lane. Because trainers scored completed lanes, this task further reduced their availability for observing trainees.

Finally, during test and practice trials on the tactical lanes, the experienced trainers showed a marked tendency to congregate under and around the pole barn, venturing out occasionally to observe and coach (if deemed necessary) trainees for short periods. This tendency to congregate under the shelter of the barn was exaggerated during conditions of harsh and inclement weather, which dominated for the three observed weeks. In fairness, longer periods of observation and often excellent coaching were devoted to trainees regarded as needing coaching on the basis of their performance. At the same time, during substantial portions of trainee activity on the tactical lanes, observers frequently noted deficient technique as well as safety violations that went unnoticed by trainers, *even during certification testing*.

Regarding SMS usage, reliability problems resulted in frequent down time, limiting the amount of time that it could be used to provide trainees with the feedback needed for achieving proficiency. This shifted the burden of accurately assessing trainee technique (a difficult task for even the most experienced personnel) and providing feedback to the available trainers. When the number of trainees engaged in sweep drills exceeded the number of available trainers, they were denied consistent feedback.

5. Discussion

This study was undertaken with the assumption that the AN-PSS-14 training conducted at the USAES was effective and that efforts focused on identifying means to improve its efficiency. Our observations have raised doubt about the validity of our assumption and issues about the effectiveness of AN/PSS-14 training as it is being delivered.

The remainder of this section discusses the bases for questioning training effectiveness found in the results, organized by sequence of results reported in the previous section. Following discussion of results, recommendations for changes are made whose implementation, we believe, can raise the quality of AN/PSS-14 operator training to the standards of the USAES and the capability of operators to the level demanded by the current mine threat.

5.1 Time Distribution

A major concern related to the Army’s adoption of the AN/PSS-14 is the costly 40-hour block of training required for its operators. Individual operators, however, do not receive 40 hours of training. Results from this small sample of training sessions show that the average operator spends but a fraction (22%) of the 40 hours on the most important component of training: mine detection drills (blind search). A larger proportion of each cycle's training time is expended on lunch, waiting, and breaks. Realistic task practice *accompanied with accurate and timely performance feedback and coaching* is essential for skill acquisition. Because maximizing task practice (within the available boundaries) is the key to maximizing learner capabilities, and maximizing the returns of practice requires a prior base of knowledge and basic skills, increased individual detection practice time following essential preparatory instruction and drills should improve training.

Surprisingly, little time was spent on footprint development, the core and most complex component of AN/PSS-14 operation. The extent of instruction focused explicitly on this critical subskill was a 15- to 20-minute demonstration, although in one week, roughly half of that time was used to demonstrate footprint development for only two of the four mine types. Moreover, footprint development exercises were eliminated. Instead, as described earlier, footprint development practice was merged with search sweep into blind search drills with sporadic and often inconsistent instructor guidance while the operator practiced. Few Soldiers appeared to execute the techniques involved correctly without direct instruction from trainers. In the case of the training period with a severely shortened instructional demonstration, observers from the Night Vision and Electronic Sensors Directorate of the U.S. Army Research, Development, and Engineering Command who were present (an NCO and a civilian) intervened and initiated individualized footprint development tutoring for trainees in response to the obvious confusion they exhibited in executing this task in the context of blind search drills.

The time allocated for sweep and system calibration drills appeared sufficient, based on trainee performance, although the amount of time spent on the SMS during sweep drills was sharply limited because of the unreliable operation of this system. Because the performance feedback that the SMS provides (when working properly) is likely far more accurate than that a trainer can provide, maximizing the proportion of SMS time with the current limits of that allocated for sweep drills is desirable. Given the purchase cost of this equipment and the sunken costs related to its deployment, its limited use provides a very low return on investment.

The 7-hour block of time of classroom environment, even with interleaved breaks, challenged Soldiers' ability to maintain concentration and to acquire and retain the volume of detailed information presented. Much of this information had to be represented outside the classroom to enable all Soldiers to perform drills correctly, which suggests information overload in the classroom.

Although breaks in training are needed for recovery from physical fatigue and relief from intense concentration that AN/PSS-14 operation demands, a disproportionate amount of trainee time was spent off-task for lunch, hourly breaks, and waiting. Chipping or observation time provided limited benefit to participants; often, the time was spent watching surrounding activities or chatting with a buddy.

5.2 Probability of Detection

Detection rates are the core measure of operator skill and the effects of training. Interpretation of detection rates in the results section in order to evaluate training effectiveness is problematic for several reasons. Two reasons described in the results are the tendency for trainers (or assistant trainers) to intervene in blind search drills and make declarations for trainees, and the outrageously imprecise declaration scoring procedures used. These raise questions about the accuracy of the PD measures recorded.

In addition, PD, especially in test trials (Trial 7), is likely inflated by some operator strategy of lowering the criterion for making a mine declaration and increasing the number of declarations placed, thus increasing the likelihood of hits along with the false alarm rate. Trainees talked openly about using this strategy to “pass the test” and receive certification. In one observed instance, a participant placed multiple chips near each declaration in hopes that at least one chip would be near enough to count as a hit. It worked; 63 chips were laid to mark the nine mines (and miscellaneous clutter), enabling the participant to pass the test. Another test strategy involved exploiting speed/accuracy; the ROA results show a distinct decrease in ROA from Trial 6 to Trial 7, while PD for APLMs and ATLMs shows an upward inflection at the same point. The absence of performance standards for false alarm rates or ROA invites a test-wise shift in operator strategy. The strategies that appear to have been implemented confound interpreting changes in PD as a function of practice as a reflection of trainee learning.

Still another issue challenging the interpretation of PD measures as indicators of training effectiveness involves test conditions. Test lanes differed not only in the number of clutter items but also in the proximity of that clutter to targets. Observations reveal that the presence of clutter adjacent to low metallic targets increases the difficulty of their detection. Thus, the tests taken by some operators were more difficult than the tests taken by others. It follows that an operator who can successfully detect all targets in a lane with few clutter items adjacent to the LM targets would have a much easier time meeting the certification criterion and could do so with a lesser level of skill than if he had been assigned a lane for testing on which clutter items were adjacent to LM targets.

Acknowledging the scoring and test strategy issues, 6 of the 18 operators missed mines on the first test (Trial 7)—a costly attrition rate. In addition, PD for the group on low metallic APs and ATs on Trial 7 is well below the certification criterion. These observations, plus the suspiciously shallow slope of PD function between Trials 3 and 6, raise concerns about training effectiveness. PD is the primary basis for operator certification. The observed measurement and scoring problems raise concerns about the validity of the certification process.

5.3 Confidence Ratings

The unchanging confidence ratings for clutter and mines through the week indicates that participants perceived little change in their capability to detect targets or distinguish target from clutter as a result of the instruction and practice they received.

The clear separation between the functions for mines and clutter in figure 12 indicates that trainees acquired some sensitivity to the difference between the signals produced by mine targets and those produced by clutter. However, clutter confidence hovering around the value of 3 suggests that participants were “confident” that clutter items were targets but less so than for actual targets. Participants frequently stated a confidence rating of 3 accompanied by the comment “There’s something there; I just don’t know what it is.”

One of the purposes in transitioning from the AN/PSS-12 to the AN/PSS-14 was the added ability to discriminate mines from clutter through the use of GPR and to consequently reduce the number of targets that must be confirmed as mines by probing. Instructions to trainees stated that GPR signals occurring over the center of a metallic halo confirmed a mine target. Conversely, if no GPR output occurred over a metal signature, then the target was probably clutter. However, if the operators were unsure about the identity of a target, they were instructed to mark it as a mine.

Beyond this decision rule, clearly specified characteristics for correct GPR investigation techniques were not given to trainees. In fact, different NCO trainer demonstrations of this technique over targets showed wildly different search head velocities; this variability was reflected in trainee techniques, often with the consequence that the swings artificially produced GPR signals over clutter items.

Another phenomenon confused trainees about GPR operation and interpretation of GPR signals. Even over mine targets, the production of GPR signals varied from swing to swing with the variability clearly related to two factors: the characteristics of the sensor head movement and the metallic content of targets. Regarding sensor head movement, increases in swing velocity and length unheeded by the operator could often produce GPR output where previously he had received none. For metallic targets, longer GPR investigations over the high metal targets often produced an increasing number of GPR returns over a larger area than occurred initially. Execution of a quick calibration operation followed by resumption of GPR investigation of the target returned GPR output to the original levels and area. This variability in GPR response appeared to confuse operators.

Signs suggesting confusion included statements by trainees such as “What’s wrong with the system?” or “What’s going on?” Less explicit signs took several forms. Observation showed numerous occasions when an operator received no GPR signal but marked the target as a mine nevertheless because “there must be something there.” In other instances (even seen on Trial 7, the certification test), operators performed investigations with MD only, without any GPR investigation, thus ignoring the functions of GPR sensing and using the AN/PSS-14 essentially as a metal detector.

We attribute the inferred confusion, consistent with the differential confidence ratings for M and LM targets in figure 13, primarily to three factors: (1) lack of explicit training guidelines for GPR investigation technique, (2) absence of explicit footprint development drills, and (3) absence of timely performance feedback telling an operator if a mine declaration was a target. Changes in training addressing these factors are included in the recommendations discussed in section 6.3.

5.4 Investigation Time

One approach to identifying and evaluating operator skill development throughout the training week was to examine changes in performance and subjective confidence as a function of accumulated task practice. The expected form for time-based performance measures is the exponential decrease illustrated earlier in figure 2, i.e., large reductions in task execution times in early practice trials followed by continuously diminishing reductions as task practice accumulates.

Results show that learning curves of this form are observed for investigation times and MD investigation times. The GPR functions, on the other hand, suggest minimal learning on this component of AN/PSS-14 operation. We therefore attribute the gains in overall investigation times largely to increasing proficiency in MD investigation with practice.

Why might gains in MD investigation skill occur but not in GPR investigation? Part of the answer was discussed earlier; training content and procedures offer little support for learning to use GPR effectively. In contrast, the robustness of the MD system produces output more reliably. MD signals are far more consistent in yielding the results described in instruction and demonstrated by trainers, thus providing implicit feedback needed to support learning. The performance feedback given after each trial is likely to lead trainees who rely heavily on MD signals to make declaration that such a strategy can yield acceptable performance and enable them to meet the certification standard (especially in the absence of any false alarm criterion).

In short, training content and practice may unintentionally lead trainees to operate the advanced, very capable AN/PSS-14 much in the same fashion as its predecessor the AN/PSS-12 and other EMI detectors in the Army’s inventory.

5.5 Rate of Advance

Several factors appear to contribute to improvements in ROA that occur with practice. The improvements seen in MD investigation times are one factor; increased efficiency in search sweep is likely another.

It is unclear, however, how well ROA measures reflect learning. On one hand, the divergence of tactical lane ROAs for trainees passing their first attempt at certification suggests that ROA is predictive of skill. Evidence for a speed-accuracy trade-off in Trial 7 suggests otherwise, noting that the trainee with the longest lane time (3 hr 45 min) passed the first test. It is reasonable to ask whether individuals whose lane coverage times exceed those of other successful operator really understand the fundamentals of AN/PSS-14 operation. A negative feature of exceptionally slow ROAs is that lengthy trials stifle the flow of training and leave operators who are scheduled for the occupied lanes waiting idly and unproductively for extended periods.

Another problem in interpreting ROA as a measure of an operator’s skill is the variability among lanes in the amount of clutter they contain. The mean number of clutter items per lane is 25, but the count ranges from 11 (Lane N) to 42 (Lane H). Generally speaking, more clutter items demand more investigations, which result in longer trial durations and lower ROAs. This is reflected in an inverse relation between number of clutter items in lanes and median ROAs. In short, the practical implication is that any valid comparison or interpretation of individual ROAs must control at least for the number of clutter items in a lane.

5.6 Performance Feedback

A number of results, including those suggesting successful learning (MD investigation times), questionable learning (PD), and negligible learning (GPR investigation times), can be explained in terms of the performance feedback provided. Performance feedback (i.e., information about the success or failure to achieve the goal set for a task) is critical for effective and efficient learning. Task practice without accurate and timely feedback yields negligible learning.

In blind search trials, feedback consisted mainly of an operator receiving information about the number of mines missed after scoring occurred. Locations of missed targets were marked and the operator returned to each and conducted another investigation in the area of the marker, supervised and critiqued by a trainer. Unless a target was missed, operators had little opportunity to associate the patterns of signals produced by individual investigations with targets. This policy provided little useful feedback to trainees to support development of mine detection skills. This would account for little improvement in PD over the course of practice on the tactical lanes and the flat confidence functions. The limited feedback provided minimal opportunity for learning to differentiate the patterns of signals produced by mine targets and those produced by clutter. Trainees were uncertain whether declarations should be marked as targets or as clutter, as was evidenced by the confidence ratings they gave to clutter items.

The paucity of feedback also appeared to cause morale problems that likely impeded the learning of some. Expressions and signs of frustration as to what was in the ground were abundant. Doubt and frustration often turned into an attitude of indifference.

In contrast, for MD investigations, implicit feedback about performance was available, and trainees’ exhibited learning curves were of the sort expected.

The negligible improvement in GPR investigation times can be interpreted in terms of the feedback available. The inconsistency with which GPR signals could be produced and trainees’ lack of knowledge about the buried items producing GPR signals denied implicit feedback. The absence of clear, objective criteria for what constituted proper GPR short sweep technique made it impossible for trainers or operators to assess the quality of the search head movements executed.

5.7 Certification Standards

USAES certification of trainees is based primarily on PD, the accurate measurement of which involves several standards. First, the performance standard requires that an operator find all nine targets in his first or second test. Measurement of performance (i.e., PD) is based on a scoring standard: to be scored as hits, a declaration marker (a poker chip) must be placed so that it overlaps or is adjacent to the body of a given target. Valid scoring of declarations depends on meeting a measurement accuracy standard: that the distance from the edge of a marking chip to the nearest edge of a target's body is accurately measured.

Problems observed and related to each of these standards call the validity of the certification process into question. The practical implications of this situation are that "certified" operators can vary considerably in their capability to operate the AN/PSS-14 effectively and safely and that some may actually fall below the desired level of proficiency that certification procedures were instituted to ensure.

Obtaining accurate target-chip measurements was problematic for several reasons. First, as described earlier, quick visual estimation rather than careful measurement predominated. Such procedures surely introduce error, especially if they are made in 4 seconds by a grader standing 8 feet away from and 5 to 6 feet above the points to be measured. Second, one of these reference points is the intersection of two strings on a scoring grid. The accuracy of any measurement using that intersection point depends on accurate placement of the scoring grid. Careful placement of the scoring grid was inconsistent. Third, mines tend to migrate beneath the ground surface after burial and there are several indications that some targets did so. Care must be taken to locate their actual centers and record their position on grading sheets; these new positions should serve as reference points for measurement. No such notations were found on the grade sheets. Instead, in some cases, graders probed the ground to find the mine and estimate its center point. Two draw-backs make this solution untenable; the ground can only be probed when it is not frozen, which it was for several days during the last week of observations. Successful probing, when possible, creates another problem; it leaves visible cues indicating the locations of targets for later trials. Some graders obscured the probe marks by scuffing the ground surface, thus substituting visible scuff marks for signs of probing! Such marks were noticed and clearly used by trainees, with the likely consequence that it made the targets in question easier to detect.

In short, very stringent accuracy standards have been adopted for scoring and laudably so; equally stringent standards and quality assurance should apply to chip-target measurement distances. Indeed, accurate feedback needed to support trainee learning depends first upon accurate measurements and scoring.

A second issue arises regarding the scoring criteria adopted. A far more liberal scoring criterion that adds a 6-inch halo to the perimeter of target bodies was employed by USAES and for operational testing of the AN/PSS-14. The current, stringent scoring criterion could account for the failure to observe the PD achieved in operational testing and reported by Santiago, Locke, and Reidy (2004).

Issues were also discovered regarding the criteria used for certification. Specifically, the absence of false alarm rate or test time standards puts at risk the certification of operators who may not be qualified to operate the AN/PSS-14 in operational environments. Omission of standards for these measures invites strategies for operators to “game” their way to certification. Trading speed for detection accuracy, as observed and noted earlier, can produce certification under the current standards. However, application of this strategy in the operational environment would be likely to compromise operational tempo, possibly threatening mission success. A strategy that accepts high false alarm rates to achieve 100% PD in the test environment would likely pose a similar problem in live operations, since the time needed to confirm declarations via probing would absorb prohibitive amounts of time.

Finally, application of existing certification standards to trainees tested on different lanes applies the same standard to tasks of differential difficulty. This is because the lanes used for testing differed in the number of clutter items they contained by a factor of more than 3; the test lane with the lowest number of clutter items contained 11 (lane N), and the test lane with the highest number had 36 (lane K). If, as it appears, clutter placements adjacent to low metal targets increase the difficulty of their detection, lanes with higher clutter counts are more likely to produce this condition (assuming random placement of clutter), making such test environments more difficult than lanes with less clutter. One practical, hypothetical consequence of *de facto* differential standards is that meeting the 100% PD standard on tests that are easy may certify operators who lack the skills needed to accomplish missions in an operational environment. Alternatively, testing on excessively difficult lanes may results in operators failing to receive certification, who have the skills needed to successfully execute counter-mine operations. The latter “error” scenario reduces the pool of operators available and wastes resources invested in training the individuals who are erroneously denied certification.

Apart from the PD criterion for certification, safety violations committed by trainees constitute grounds for denial of certification. Such violations committed by trainees, some of whom received certification, were observed in training and testing, although many were not noticed by trainers.

5.8 SMS Equipment

The problems experienced with the SMS resulted in the use of this training at a level lower than planned. The SMS offers a very powerful tool for providing feedback critical to trainees’ learning of effective search sweep technique and providing trainers and trainees with information to identify and diagnose technique problems.

The reliability problems observed had two negative consequences. First, the problems denied trainees feedback, which even experienced trainers are challenged to provide. Second, time devoted to system setup, diagnosis and solution of its operational problems by NCO trainers reduced the number of experienced trainers available to observe trainees in ongoing sweep drills and to provide feedback and diagnose problems.

Considering the purchase cost of the SMS and the sunken costs related to its deployment, its limited usage represents a poor return on investment.

5.9 Limitations

Limitations of this research include two main issues. The first is the issue of generality. Quantitative data were collected from a relatively small sample of 18 operators participating in three different training sessions, of the approximately 150 Soldiers trained each year. Second, the collection of data outdoors in challenging weather was arduous and demanding. Although all involved sought the highest levels of accuracy, some errors of commission and omission in recording and transcription must be expected. To counteract threats to validity that such errors might introduce and to mitigate their effect by statistical means, we have attached confidence intervals to the applicable results. When measurement error was beyond our control, that is, in PD measures, we have explicitly noted the problems posed for interpreting the results in the text.

Regarding the issue of generality, it is important to note that many of the significant qualitative observations made during the 3-week sampling window (e.g., PD scoring issues, minimal focused footprint development instruction, SMS problems and under-use) were seen not only in the 2 weeks of preparatory observation at the USAES but also in a training session conducted for USMC trainees at Camp Lejeune, North Carolina, by Cyterra trainers in which one of the authors participated. This convergence undermines arguments that the observations reported in this study cannot generalize beyond their narrow sampling context.

6. Recommendations

6.1 Curriculum: Content and Time Allocations

The recommended distribution of time for tasks throughout the week should include an additional category for footprint development and eliminate time for chipping and observing. Figure 16 shows the proposed time allotment for tasks. The 6 recommended hours for footprint instruction should include multiple demonstrations, practice time in a sterile area, experimentation time where multiple targets can be laid in proximity, and practical time when instructors can observe operators in an unmarked, low-clutter lane. Actual lane time should be increased by 5.5 hours to 14.2 hours. Class time should be reduced; shorter, spaced classroom sessions interspersed with hand-on exercises will help operators to better remember the information needed to practice proper techniques and develop sweep and footprint skills. Chipping and observing should be eliminated in favor of practical exercises. “Wasted” time for lunch, especially the usual inflation of allotted time related to travel off site, can be eliminated if the lunch break is limited to 30 minutes and trainees are required to bring lunches. More disciplined administration can easily reduce time wasted on inflated break times and waiting for lanes or equipment to become available. Time allocations for demonstrations and calibrate or sweep drills should stay the same.

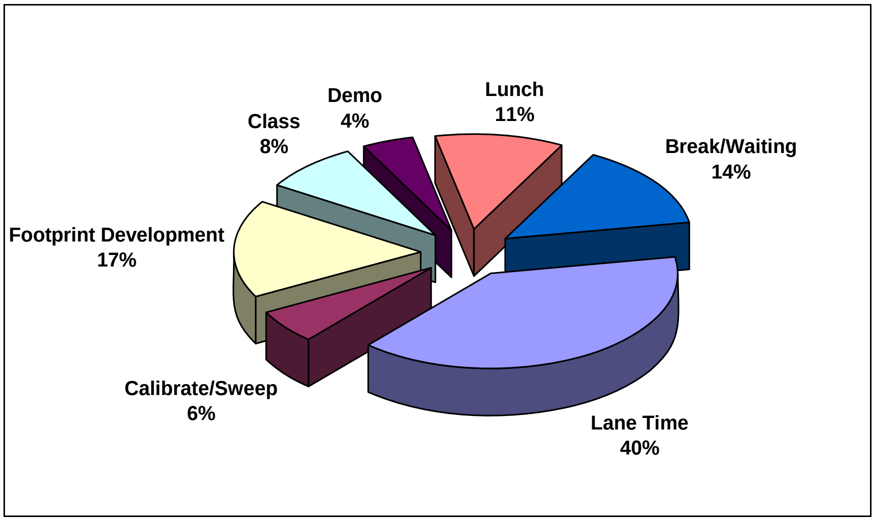

Figure 16. Recommended weekly time distribution.

6.2 Performance Feedback

Operators need more supervision. Part of the difficulty in increasing supervision and the delivery of immediate feedback is the limited availability of instructors, but that does not diminish the need for prompt feedback on what the operator is doing, right or wrong. Effective and efficient skill acquisition demands it.

These statements equate feedback with accurate feedback. The scoring problems and SMS problems observed need to be fixed to provide trainees with the needed feedback.

6.3 Training Content

The most important substantive change recommended in training content is the inclusion of footprint development and allocation of time to its instruction and practice. Absent footprint development drills, trainees can rarely, if ever, know that the MD and GPR signals received in an investigation are those produced by a mine, unless they have missed a target. Denial of information impedes a trainee’s learning and undermines effective and efficient acquisition of mine detection skill. The suggested time distribution invests 6 hours of the 40-hour instruction week to footprint development instruction and practice.

Training content needs to be standardized. One of the largest difficulties encountered across the 3 weeks of observed training was the variability with which instructors were present. Each of the instructors had different ideas about how much information to present, how the detector worked, which technique to use, and what content should be emphasized. As an example, several instances of instruction promoted the use of chipping an inner halo on high metal targets to facilitate finding the center of the target. The outer halo that is normally chipped is located at the first audible sound the detector produces surrounding the target (for high metal mines, this halo can be 30 inches in diameter). The inner halo is located where the detector tone distinctly jumps from a low pitch to a high pitch. The trouble with the inner halo technique is that if the operator in any way misunderstands or forgets that the area between the outer and inner halos is not assuredly safe, someone may step on a “hidden” mine, a low metal mine whose signature is hidden within that of the high metal target. Techniques must be standardized to prevent these mistakes and the hazards they create.

As another example, instructors differ in what constitutes proper sensor head velocity for GPR short sweep technique. In the absence of clear and accurate specification of an effective and acceptable range, trainers and trainees have only their intuition to rely upon to assess technique. Unfortunately, such intuitions can be contradictory and simply wrong.

The long continuous block of classroom instruction on the initial day of training should be shortened, with its contents redistributed and interspersed with hands-on activities. Doing so would better support operators’ retention of the theory and procedures presented, which are necessary to practice and learn effective techniques. In addition, efficiency would be gained; we found that much of the content presented in the continuous block of instruction was being repeated before hands-on exercises because trainees had not retained it. Following an overview of training and an overview of the system and its operation, the content of each subsequent instructional segment should be limited to just the information needed to support trainees’ proper execution and practice of the activities covered.

An explicitly “scaffolded” approach to instruction (also expressed as the “crawl, walk, run” instructional strategy) will facilitate skill development, and we recommend its adoption. Basic, component skills should be taught in isolation. Tests should follow each instructional unit to assess trainees’ proficiency in these sub-skills. Testing at each stage or level of training would help instructors determine which operators are struggling early in the week so that focused diagnosis, remediation, and additional practice can be given. Such early intervention allows struggling operators to clarify task requirements while the instructor is present, specifically to answer questions, coach proper technique, and provide feedback. Most participants did not seek instructors with questions; they only asked if instructors were conveniently near or if an instructor had already engaged them in conversation—events that were too infrequent. Practicing improper or weak techniques led to the acquisition of “bad habits,” which are difficult and costly to reverse later.

Trainers’ effectiveness is diluted by the dual responsibilities assigned; they are to instruct, coach, and assess new operators, and when TAs are present, they are to instruct, evaluate, and test TAs. Training personnel should be assigned and dedicated to one instructional task or the other. Implementing this recommendation carries nontrivial immediate costs: it would require additional qualified trainers. We believe that the benefits that would accrue by enhancing the training of new operators and new trainers could offset and justify the cost, especially if it decreases the trainee failure rate.

There are two elements of training in which instructors and trainees are handicapped by a lack of information about AN/PSS-14 operation: system calibration procedures and GPR short sweep. In both cases, the gaps in knowledge result in (1) trainees lacking clear descriptions of the techniques that become their goals to acquire and practice, and (2) trainees and trainers lacking clear standards for assessing trainee performance of these significant functions. Trainers can only "eyeball" an operator's technique and guess whether it is good or bad, lacking clear and specific guidelines for distinguishing between techniques that prepare the sensor systems for effective use and those that do not. The validity of any feedback they provide is therefore suspect, if any feedback is given to a trainee.

Instructions describe system calibration procedures as critical for safe and effective operation of the AN/PSS-14. However, no objective empirical standards are available for reliably and validly assessing whether the procedures executed have effectively prepared the system for use.

Acquiring the needed information to assess system calibration and documenting the procedures for doing so, beyond its benefits for training, could resolve a chronically controversial issue with regard to system preparation procedures. Some parties have advocated checking sensor response by burying the test piece that comes with the system. Others have argued for performing these checks with the test piece on the ground surface. Procedures for objectively describing the state of the system, following along with delineation of states that produce acceptable sensor responses and those that compromise sensor performance, could provide measures that resolve the controversy experimentally.

Trainers have been observed to give operators contradictory information about appropriate sensor head velocities for GPR short sweep, as related earlier. This situation arises because no explicit specification of the velocity ranges required for optimal and valid GPR sensor response is available to trainers. These operating thresholds for GPR short sweep should be established and validated empirically (if they have not been already) and disseminated to trainers. We note that an experimental investigation of this issue should involve a factorial design that includes manipulation of the variables of sensor head roll and head height because our observations suggest that increases in these dimensions are correlated with increasing velocities. Training personnel describe this phenomenon as "cupping," which some sources speculate produces artifactual GPR responses, which in turn, lead to false alarms.

A final issue related to operation of AN/PSS-14 GPR is the changing response observed during lengthy investigations of high metal targets. An accelerating frequency of GPR response occurs over an area growing in size around a target's location. Trainers report observing this phenomenon in previous training sessions. One of the authors has experienced it while operating the system in training at Camp Lejeune. Indeed, training personnel described "unofficial" techniques for mitigating the difficulties it created for accurate declaration placements. These latter observations suggest a generality that extends beyond the context of this study.

The features of this phenomenon are similar to those that are observed when GPR sensitivity is increased manually. Regardless of the underlying mechanisms, if this phenomenon can be shown to occur with any regularity, trainers and trainees should be clearly informed of the features by which it can be recognized, its consequences, procedures for preventing it, and appropriate responses to its appearance. Otherwise, confusion and loss of confidence in the equipment are the likely responses of new operators.

A final issue with regard to training content is whether instruction for discriminating mines from clutter should be included in the POI. This is a controversial policy issue whose resolution is a matter for USAES leadership. How it is settled has important implications for the content and duration of AN/PSS-14 operator training.

Training operators to distinguish clutter from mines is feasible. Experienced operators have demonstrated in test settings that a low false alarm rate can be achieved while extraordinarily high detection rates are maintained. In addition, an enormous body of scientific knowledge has established effective procedures for training discrimination skills. In many instances, it has been applied in military training, notably in training personnel to make friend/foe decisions. Moreover, Biederman and Schiffrar (1987) have demonstrated that techniques used to analyze expertise in discriminating between complex perceptual categories produce knowledge shown as highly effective for training novices. This same approach has been applied to designing the currently used AN/PSS-12 and AN/PSS-14 training programs and will be applied to a proposed study of the best AN/PSS-14 operator.

Although we believe that Soldiers can be trained to develop clutter discrimination skills without sacrificing high detection rates (and safety), the costs of doing so are unknown. If the recommendations proposed here are implemented, however, especially those that can increase training efficiency, these costs can be reduced.

6.4 Certification Standards

Several changes should be implemented to achieve the effects intended by instituting an operator certification policy.

First, procedures for measuring target-declaration distances must be specified, monitored for quality assurance, and enforced with standards as stringent as the accuracy standards demanded of trainee declarations. Greater use of tape measures, careful placement of scoring grids, accurate recording of distances, and professionalism in the application of all costs will minimize measurement error.

Second, regarding scoring standards, we urge adoption of principled distance criteria for computing PD that would resolve the discrepancy between two apparently arbitrary standards applied by USAES and discussed earlier. One reasonable basis for developing the needed standard involves the distances between declaration and mines of various sizes that maximize the safety, effectiveness, and efficiency of probing. Allowing that “to err is human,” an extra “cushion” for unavoidable errors in taking measurements should be incorporated in setting the standard.

Third, related to the testing environment, testing should take place on lanes equated for difficulty. Although imposing the same design standard, especially with regard to the density and placement of clutter, to all training is not necessary, such uniformity should be required of lanes used for certification testing.

Fourth, operators can adopt strategies to “game” testing and achieve certification by exploiting the absence of any time limit or false alarms. We recommend setting and applying reasonable standards for these performance dimensions to ensure that certification procedures validly distinguish between trainees who have the capability to safely and efficiently accomplish counter-mine missions and those who lack such capability.

Introducing reasonable time limits in training as well as for testing holds two other potential benefits. First, limiting lane time will facilitate more accurate scheduling and lane use by reducing the unproductive waiting time that occurs when a trainee takes extraordinary amounts of time to complete a lane. Second, lane traversal times exceeding 1.5 to 1.75 hours appear to produce levels of mental and physical fatigue that result in trainees’ practicing sloppy techniques, leading to skepticism about the quantity and quality of learning that occurs beyond these durations. We propose that more productive practice time would result for such operators if such excessively long trials are truncated and the operator resumes practice on another lane after a mentally and physically refreshing break.

6.5 Equipment

Effective demonstrations of AN/PSS-14 operations require that trainees see the detector’s movements relative to targets and hear its output. The latter often proved to be a problem when a full complement of trainees (12) gathered around the trainer giving the demonstration, and especially when noise from other sources (e.g., wind, machinery, traffic, aircraft) was present. The use of attaching equipment (e.g., amplifier, speaker) capable of clearly broadcasting the detector’s auditory output over a wider area and other interfering sources would remedy the problem and enhance the instruction.

Quality assurance issues are chronically reported for the low metallic training mines. Effective and efficient training requires targets that function reliably. If the vendor for these training aids cannot or will not remedy the problems experienced with these very expensive targets, we recommend searching for a supplier who will provide targets of the quality needed.

The SMS was underused, being used only for 4 minutes per operator, two runs of 2 minutes each. In order to receive full benefit from this device, it should be used several minutes every day to provide accurate and objective feedback to support trainees' learning and to assess the development of their sweep skills. Its potential training benefits are considerable, but they can only be realized if the system is used. Chronic reliability problems have made trainers (USAES as well as Cyterra) justifiably reluctant to invest the time needed for setup, only to find that breakdowns prevent its use and diagnosing and fixing the problems divert time that could be spent more productively observing trainees. If the vendor for this system cannot or will not fix these problems, we recommend that USAES look elsewhere for other equipment that can serve the function of the SMS.

De-milled mines produce responses from the AN/PSS-14, which differ from those produced by mine simulants. The availability of samples of de-milled mines for use in training to supplement the use of simulants can help familiarize trainees with the subtle differences between mines and training simulants and thereby promote transfer of the skills developed in training to the detection of live mines in actual counter-mine operations.

6.6 Training Facilities

Many features of the new pole barn site at Fort Leonard Wood make it an excellent training facility. The following recommendations are made with the goal of making an even more effective environment for mine detection training. While some are specific to this site, the majority are more generally applicable.

- Results of several measures suggest that lanes differ considerably in difficulty. For implementing a "crawl, walk, run" instructional approach, we advocate lane designs that differ systematically in their clutter content. For initial blind search trials, sterile lanes are desirable. Trainees who demonstrate proficiency in these lanes should graduate to lanes with clutter, half of which is placed adjacent to targets. Still another set of lanes should pose a greater challenge with more clutter items and more challenging placements. Implementing this recommendation will likely involve construction of additional lanes.

- To promote transfer of training to natural environments, we recommend selection and use of clutter items likely to be found in the operational environment (e.g., brass, cartridge chain links, barbed wire) in the orientations in which they are likely to be found (as opposed to driving 10 penny nails straight into the ground, as has been done in pole barn lanes). In addition, the positions of all emplaced clutter should be recorded on maps; such maps facilitate evaluation of trainees' skills and especially identification and diagnosis of problems that they experience in detecting mines and clutter.

- Sterile lanes need to be sterile. This means ensuring that lanes designated as sterile should be thoroughly cleared when constructed and maintained in this state by regular monitoring.

- Several lanes need improved drainage. For example, sterile lanes C, D, E flood after heavy rains, making them unusable for training. In several other lanes standing water collects, precipitating repeated built-in test (BIT) failures in the older model AN/PSS-14s used for training. Subsequent use of the system after BIT failure requires the time-consuming processes of start-up and sensor calibration. Repeated BIT failures multiply these costs and frustrate operators.

- High densities of natural clutter at the staring points of several lanes required trainees to expend time searching for a clutter-free area to ground balance the MD subsystem. Clearing the area in front of each lane would eliminate this unproductive time spent in doing so and thus increase the time available for productive training.

6.7 Program of Instruction, Efficiency, Costs, and Skill Retention

The recommendations from this research have been incorporated into a new POI. Priority in its design has been given to achieving a level of training effectiveness consistent with USAES standards of excellence. The recommended changes in training incorporated in the proposed program borrow time saved by the elimination of discovered inefficiencies observed, allocating the savings to increased practice time for trainees.

With regard to training efficiency and costs, the redesign still assumes a 40-hour training period for training as many as 12 operators. If and when empirical evaluation demonstrates that the POI achieves the training standards of USAES, efforts to maximize its efficiency and minimize its cost should be pursued. The recommendations also entail added costs; adding lanes entails acquiring more targets. Increasing the number of appropriate qualified trainers imposes a non-trivial personnel cost.

Are such costs justifiable? The true effects of NET training on mission capability for operators of the AN/PSS-14 (and its cost effectiveness) need to be assessed and studied in a context that extends beyond the terminal performance of trainees completing training successfully and the costs involved in producing it. The skill retention functions shown in figure 17 suggest that initial investments that produce the highest levels of skill may reduce requirements for refresher training and may be offset in the long run by lower resource expenditure requirements to maintain operator and mission capability.

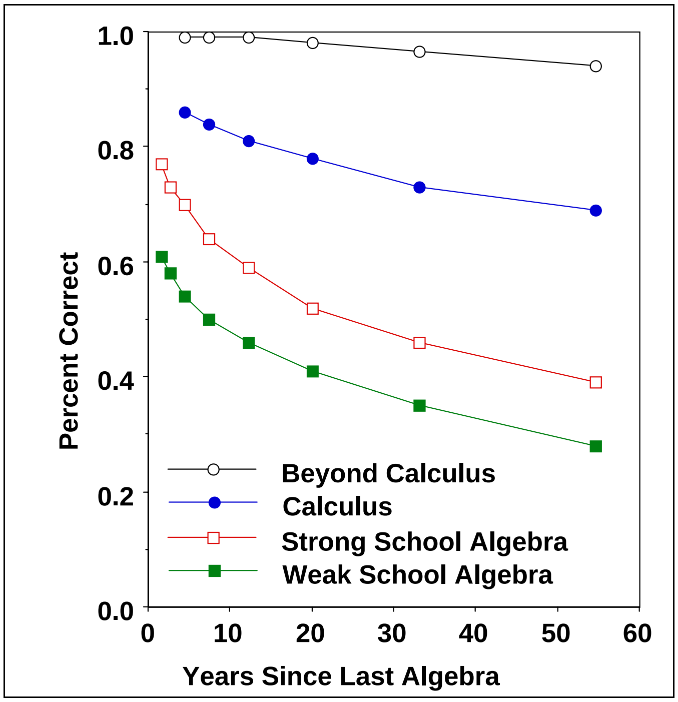

Figure 17. Skill retention functions.

6.8 Future Research

Understanding GPR response to kinematic variations in the movement of the search head in the context of GPR short sweep will benefit training. We recommend that the appropriate experimental studies be undertaken. A clear and specific understanding of the movement parameters that optimize the reliability and validity of GPR output will provide trainees with clear goals for training. It will also provide trainees and trainers with information needed to assess the quality of trainees' GPR short sweep and fix any deficiencies.

Research should be undertaken to establish criteria for determining when the MD and GPR subsystems have been properly calibrated by operators and when they have not. Results should strengthen efforts to establish procedures for doing so in the context of training. Once the procedures have been validated, they should be disseminated immediately to trainers and certified operators.

The changes in the training recommended here and incorporated in the POI need to be tested to ensure that they deliver the expected gains. We emphasize that rigorous evaluation would need to involve evaluation of trainer implementation of the POI; training content cannot achieve its goals if it is not delivered effectively.

We recommend establishment of criteria for scoring mine declaration, which are principled and based on consideration of how different criteria interact with subsequent doctrinal procedures for mine clearance. A level of accuracy, that is, the distance(s) between mine targets and operators' declaration, that best accomplishes mission requirements should be the basis. Studies of probing effectiveness and efficiency should provide critical information.

We have recommended that changes in operator certification criteria be considered. Cost/benefit analyses of any such changes ordered and implemented should be undertaken to ensure that the expected benefits accrue and that they are justified by the investments required.

Following any changes made in USAES AN/PSS-14 training, skill retention studies should be performed. The true effects of NET training on mission capability for operators of the AN/PSS-14 and its cost effectiveness need to be assessed and studied in a context that extends beyond the terminal performance of trainees completing training successfully and the costs involved in producing it. Initial investments that produce the highest levels of skill may reduce requirements for refresher training and may be offset in the long run by lower resource expenditure requirements to maintain operator and mission capability.

7. Conclusion

The objective of this effort was to examine what was assumed to be an effective training program for ways to increase its efficiency. In the pursuit of this goal, deficiencies in AN/PSS-14 training were discovered, which we argue undermine its effectiveness, raise doubt about the validity of operator certification, and could have contributed to training and mission capability issues identified by two in-country evaluations of AN/PSS-14 operator capability.

In addition to the identification of training problems, principled recommendations for changes in the AN/PSS-14 POI that represent potential solutions are offered for the consideration of USAES leadership and other stakeholders. These recommendations describe tactics for enhancing effectiveness and they do so by exploiting time gained by minimizing the inefficiencies discovered in the current training program implementation. Priority has been given to achieving a level of training effectiveness consistent with USAES standards in making recommendations; effort to maximize efficiency and minimize costs can and should be pursued after this standard is achieved.

The AN/PSS-14 represents an important technological advance that holds potential to substantially improve the counter-mine capability of U.S. ground forces. Multiple studies have underscored the critical roles played by operator skill and operator training in achieving this potential. The findings and recommendations reported here offer a path for advancing toward that goal that is cognizant of needs and the resource limitations under which USAES works in meeting these needs.

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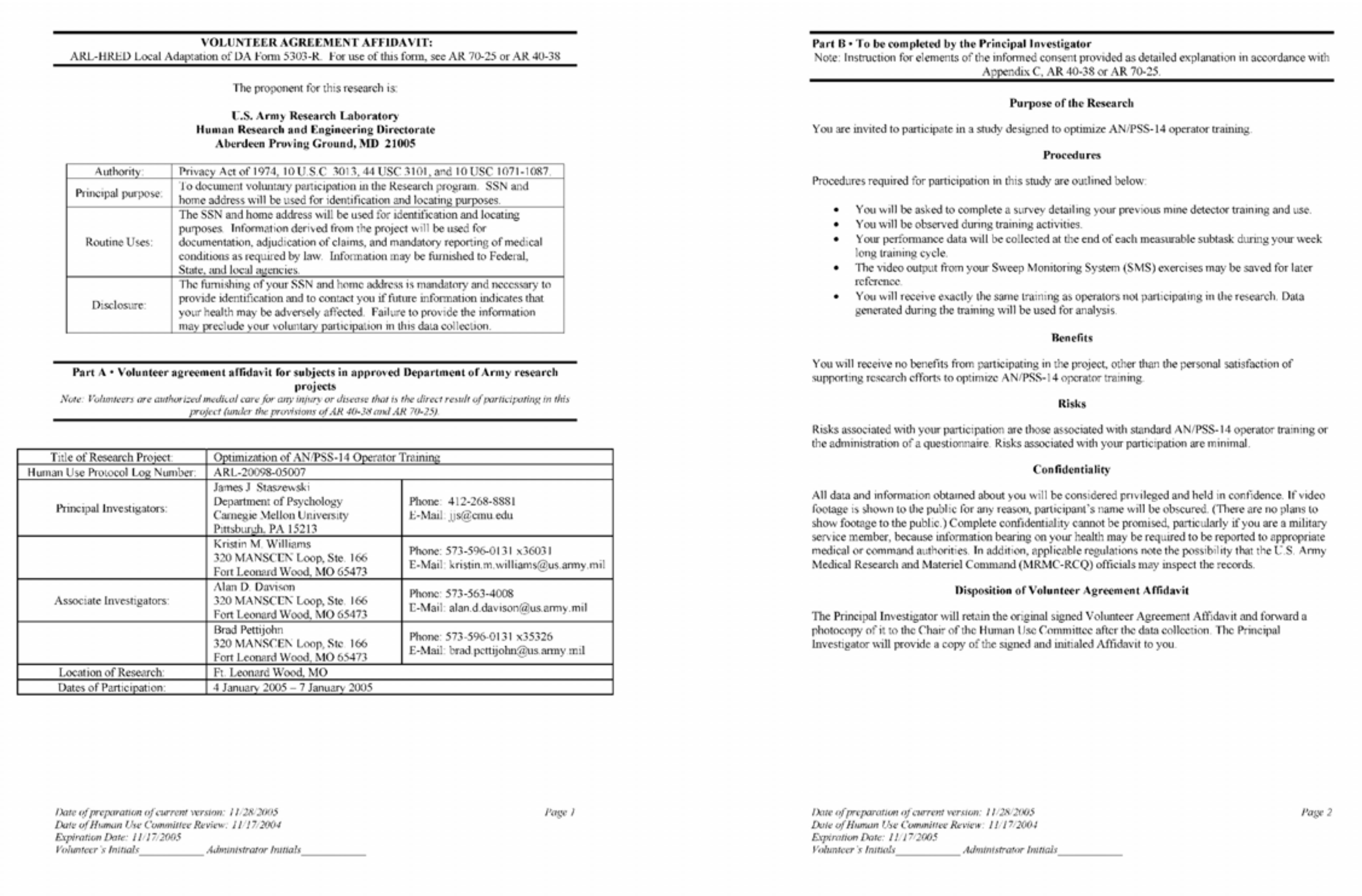
Appendix A. Data Collection Forms

Volunteer Agreement Affidavit



VOLUNTEER AGREEMENT AFFIDAVIT:
ARL-HRED Local Adaptation of DA Form 5303-R. For use of this form, see AR 70-25 or AR 40-38

The proponent for this research is:

U.S. Army Research Laboratory
Human Research and Engineering Directorate
Aberdeen Proving Ground, MD 21005

Authority:	Privacy Act of 1974, 10 U.S.C. 3013, 44 USC 3101, and 10 USC 1071-1087.
Principal purpose:	To document voluntary participation in the Research program. SSN and home address will be used for identification and locating purposes.
Routine Uses:	The SSN and home address will be used for identification and locating purposes. Information derived from the project will be used for documentation, adjudication of claims, and mandatory reporting of medical conditions as required by law. Information may be furnished to Federal, State, and local agencies.
Disclosure:	The furnishing of your SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this data collection.

Part A • Volunteer agreement affidavit for subjects in approved Department of Army research projects

Note: Volunteers are authorized medical care for any injury or disease that is the direct result of participating in this project (under the provisions of AR 40-38 and AR 70-25).

Title of Research Project:	Optimization of AN/PSS-14 Operator Training	
Human Use Protocol Log Number:	ARL-20098-05007	
Principal Investigators:	James J. Staszewski Department of Psychology Carnegie Mellon University Pittsburgh, PA 15213	Phone: 412-268-8881 E-Mail: jjs@cmu.edu
	Kristin M. Williams 320 MANSCEN Loop, Ste. 166 Fort Leonard Wood, MO 65473	Phone: 573-596-0131 x36031 E-Mail: kristin.m.williams@us.army.mil
Associate Investigators:	Alan D. Davison 320 MANSCEN Loop, Ste. 166 Fort Leonard Wood, MO 65473	Phone: 573-563-4008 E-Mail: alan.d.davison@us.army.mil
	Brad Pettijohn 320 MANSCEN Loop, Ste. 166 Fort Leonard Wood, MO 65473	Phone: 573-596-0131 x35326 E-Mail: brad.pettijohn@us.army.mil
Location of Research:	Ft. Leonard Wood, MO	
Dates of Participation:	4 January 2005 – 7 January 2005	

Date of preparation of current version: 11/28/2005
Date of Human Use Committee Review: 11/17/2004
Expiration Date: 11/17/2005
Volunteer's Initials___________ Administrator Initials___________

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Part B • To be completed by the Principal Investigator
Note: Instruction for elements of the informed consent provided as detailed explanation in accordance with Appendix C, AR 40-38 or AR 70-25.

Purpose of the Research

You are invited to participate in a study designed to optimize AN/PSS-14 operator training.

Procedures

Procedures required for participation in this study are outlined below:

- You will be asked to complete a survey detailing your previous mine detector training and use.
- You will be observed during training activities.
- Your performance data will be collected at the end of each measurable subtask during your week long training cycle.
- The video output from your Sweep Monitoring System (SMS) exercises may be saved for later reference.
- You will receive exactly the same training as operators not participating in the research. Data generated during the training will be used for analysis.

Benefits

You will receive no benefits from participating in the project, other than the personal satisfaction of supporting research efforts to optimize AN/PSS-14 operator training.

Risks

Risks associated with your participation are those associated with standard AN/PSS-14 operator training or the administration of a questionnaire. Risks associated with your participation are minimal.

Confidentiality

All data and information obtained about you will be considered privileged and held in confidence. If video footage is shown to the public for any reason, participant's name will be obscured. (There are no plans to show footage to the public.) Complete confidentiality cannot be promised, particularly if you are a military service member, because information bearing on your health may be required to be reported to appropriate medical or command authorities. In addition, applicable regulations note the possibility that the U.S. Army Medical Research and Materiel Command (MRMC-RCQ) officials may inspect the records.

Disposition of Volunteer Agreement Affidavit

The Principal Investigator will retain the original signed Volunteer Agreement Affidavit and forward a photocopy of it to the Chair of the Human Use Committee after the data collection. The Principal Investigator will provide a copy of the signed and initialed Affidavit to you.

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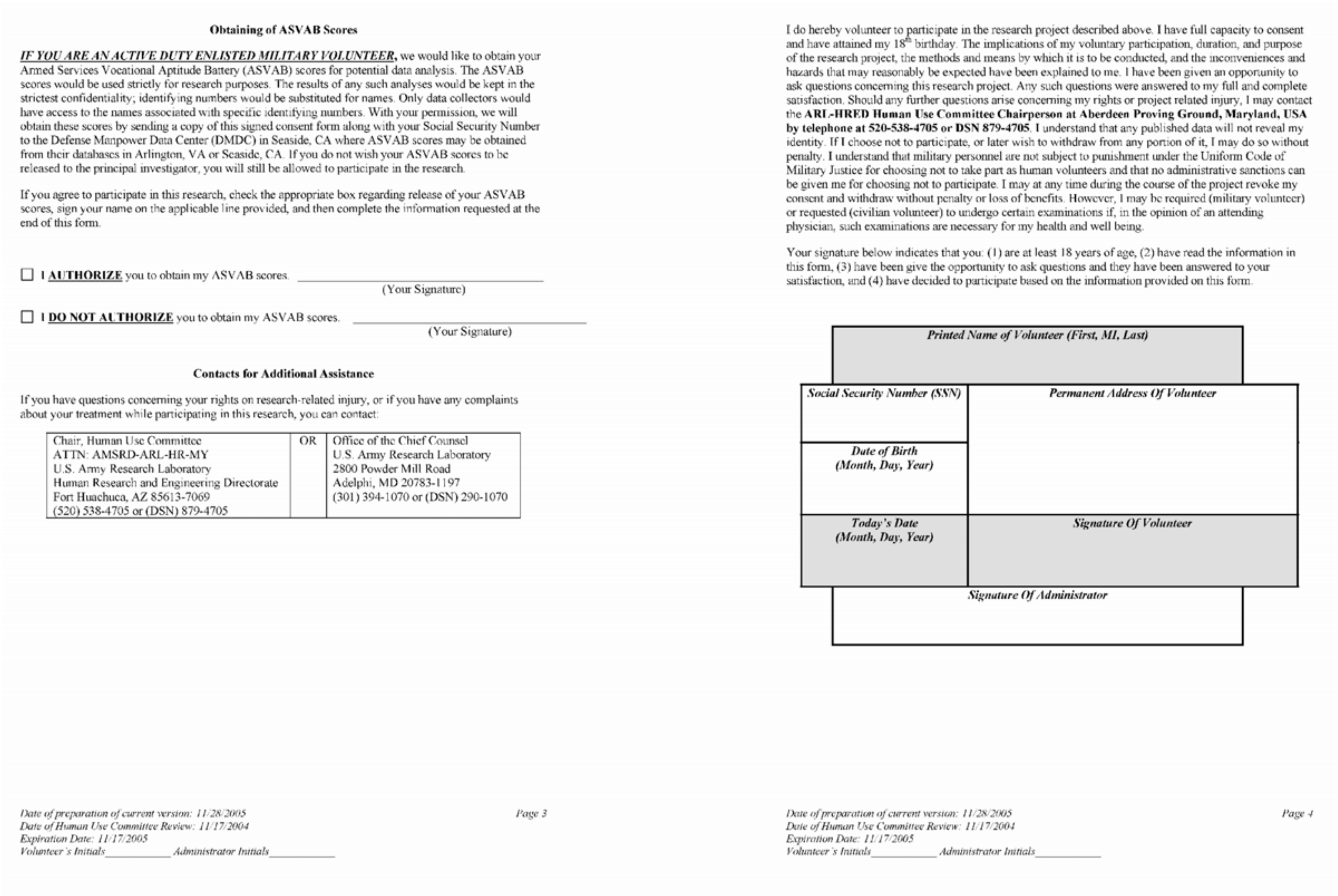

Obtaining of ASVAB Scores

***IF YOU ARE AN ACTIVE DUTY ENLISTED MILITARY VOLUNTEER*,** we would like to obtain your Armed Services Vocational Aptitude Battery (ASVAB) scores for potential data analysis. The ASVAB scores would be used strictly for research purposes. The results of any such analyses would be kept in the strictest confidentiality; identifying numbers would be substituted for names. Only data collectors would have access to the names associated with specific identifying numbers. With your permission, we will obtain these scores by sending a copy of this signed consent form along with your Social Security Number to the Defense Manpower Data Center (DMDC) in Seaside, CA where ASVAB scores may be obtained from their databases in Arlington, VA or Seaside, CA. If you do not wish your ASVAB scores to be released to the principal investigator, you will still be allowed to participate in the research.

If you agree to participate in this research, check the appropriate box regarding release of your ASVAB scores, sign your name on the applicable line provided, and then complete the information requested at the end of this form.

☐ I **AUTHORIZE** you to obtain my ASVAB scores. ______________________________
(Your Signature)

☐ I **DO NOT AUTHORIZE** you to obtain my ASVAB scores. ______________________________
(Your Signature)

Contacts for Additional Assistance

If you have questions concerning your rights on research-related injury, or if you have any complaints about your treatment while participating in this research, you can contact:

Chair, Human Use Committee ATTN: AMSRD-ARL-HR-MY U.S. Army Research Laboratory Human Research and Engineering Directorate Fort Huachuca, AZ 85613-7069 (520) 538-4705 or (DSN) 879-4705	OR	Office of the Chief Counsel U.S. Army Research Laboratory 2800 Powder Mill Road Adelphi, MD 20783-1197 (301) 394-1070 or (DSN) 290-1070

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*Volunteer's Initials*__________ *Administrator Initials*__________

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I do hereby volunteer to participate in the research project described above. I have full capacity to consent and have attained my 18th birthday. The implications of my voluntary participation, duration, and purpose of the research project, the methods and means by which it is to be conducted, and the inconveniences and hazards that may reasonably be expected have been explained to me. I have been given an opportunity to ask questions concerning this research project. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights or project related injury, I may contact the **ARL-HRED Human Use Committee Chairperson at Aberdeen Proving Ground, Maryland, USA by telephone at 520-538-4705 or DSN 879-4705**. I understand that any published data will not reveal my identity. If I choose not to participate, or later wish to withdraw from any portion of it, I may do so without penalty. I understand that military personnel are not subject to punishment under the Uniform Code of Military Justice for choosing not to take part as human volunteers and that no administrative sanctions can be given me for choosing not to participate. I may at any time during the course of the project revoke my consent and withdraw without penalty or loss of benefits. However, I may be required (military volunteer) or requested (civilian volunteer) to undergo certain examinations if, in the opinion of an attending physician, such examinations are necessary for my health and well being.

Your signature below indicates that you: (1) are at least 18 years of age, (2) have read the information in this form, (3) have been give the opportunity to ask questions and they have been answered to your satisfaction, and (4) have decided to participate based on the information provided on this form.

Printed Name of Volunteer (First, MI, Last)	
Social Security Number (SSN)	***Permanent Address Of Volunteer***
Date of Birth (Month, Day, Year)	
Today's Date (Month, Day, Year)	***Signature Of Volunteer***
Signature Of Administrator	

Date of preparation of current version: 11/28/2005
Date of Human Use Committee Review: 11/17/2004
Expiration Date: 11/17/2005
*Volunteer's Initials*__________ *Administrator Initials*__________

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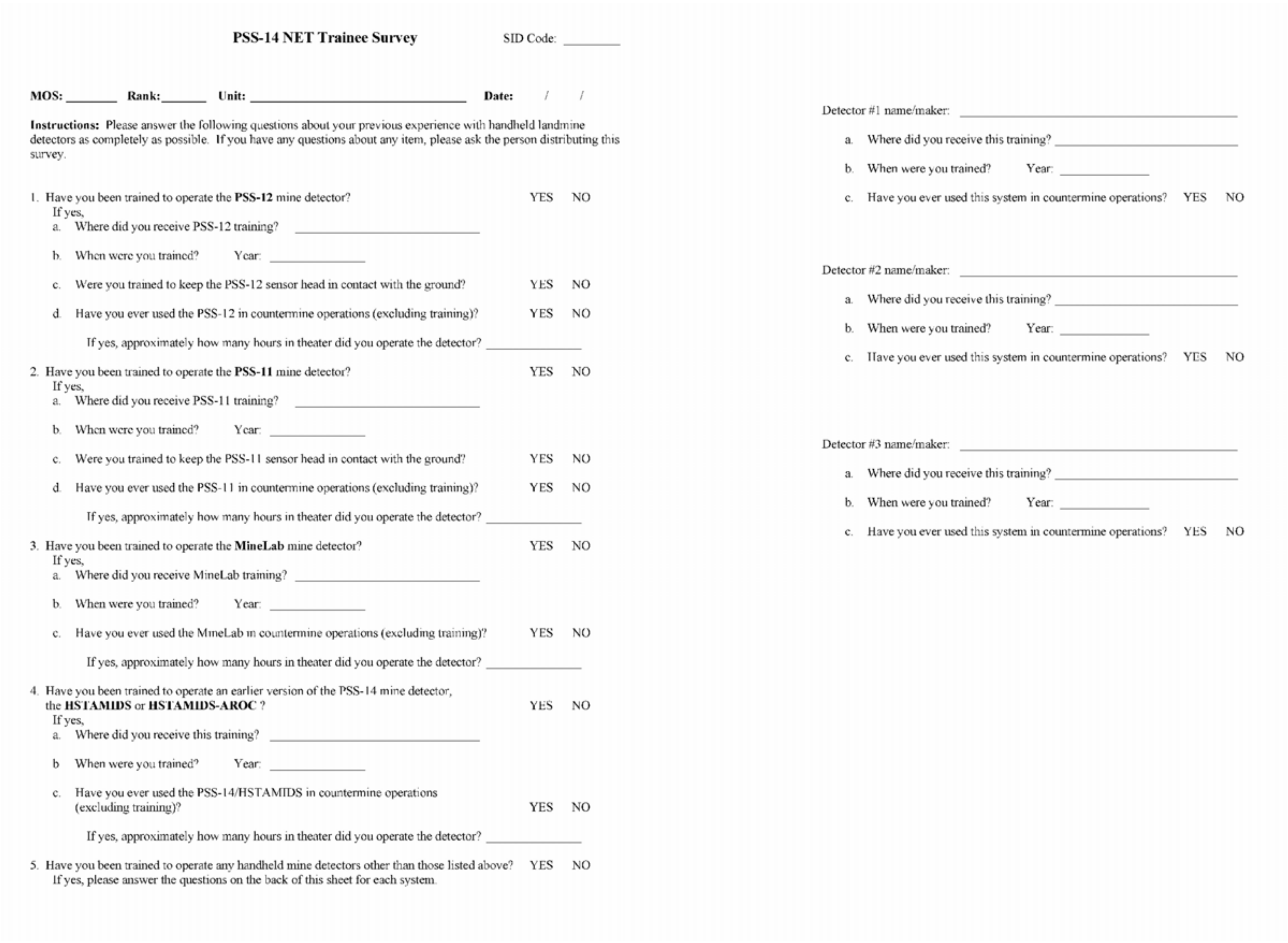
Training Experience Survey



PSS-14 NET Trainee Survey

SID Code: ________

MOS: ________ **Rank:** _______ **Unit:** ______________________________ **Date:** / /

Instructions: Please answer the following questions about your previous experience with handheld landmine detectors as completely as possible. If you have any questions about any item, please ask the person distributing this survey.

1. Have you been trained to operate the **PSS-12** mine detector? YES NO
   If yes,
   a. Where did you receive PSS-12 training? __________________________
   b. When were you trained? Year: ______________
   c. Were you trained to keep the PSS-12 sensor head in contact with the ground? YES NO
   d. Have you ever used the PSS-12 in countermine operations (excluding training)? YES NO
   If yes, approximately how many hours in theater did you operate the detector? ______________

2. Have you been trained to operate the **PSS-11** mine detector? YES NO
   If yes,
   a. Where did you receive PSS-11 training? __________________________
   b. When were you trained? Year: ______________
   c. Were you trained to keep the PSS-11 sensor head in contact with the ground? YES NO
   d. Have you ever used the PSS-11 in countermine operations (excluding training)? YES NO
   If yes, approximately how many hours in theater did you operate the detector? ______________

3. Have you been trained to operate the **MineLab** mine detector? YES NO
   If yes,
   a. Where did you receive MineLab training? __________________________
   b. When were you trained? Year: ______________
   c. Have you ever used the MineLab in countermine operations (excluding training)? YES NO
   If yes, approximately how many hours in theater did you operate the detector? ______________

4. Have you been trained to operate an earlier version of the PSS-14 mine detector, the **HSTAMIDS** or **HSTAMIDS-AROC** ? YES NO
   If yes,
   a. Where did you receive this training? ______________________________
   b. When were you trained? Year: ______________
   c. Have you ever used the PSS-14/HSTAMIDS in countermine operations (excluding training)? YES NO
   If yes, approximately how many hours in theater did you operate the detector? ______________

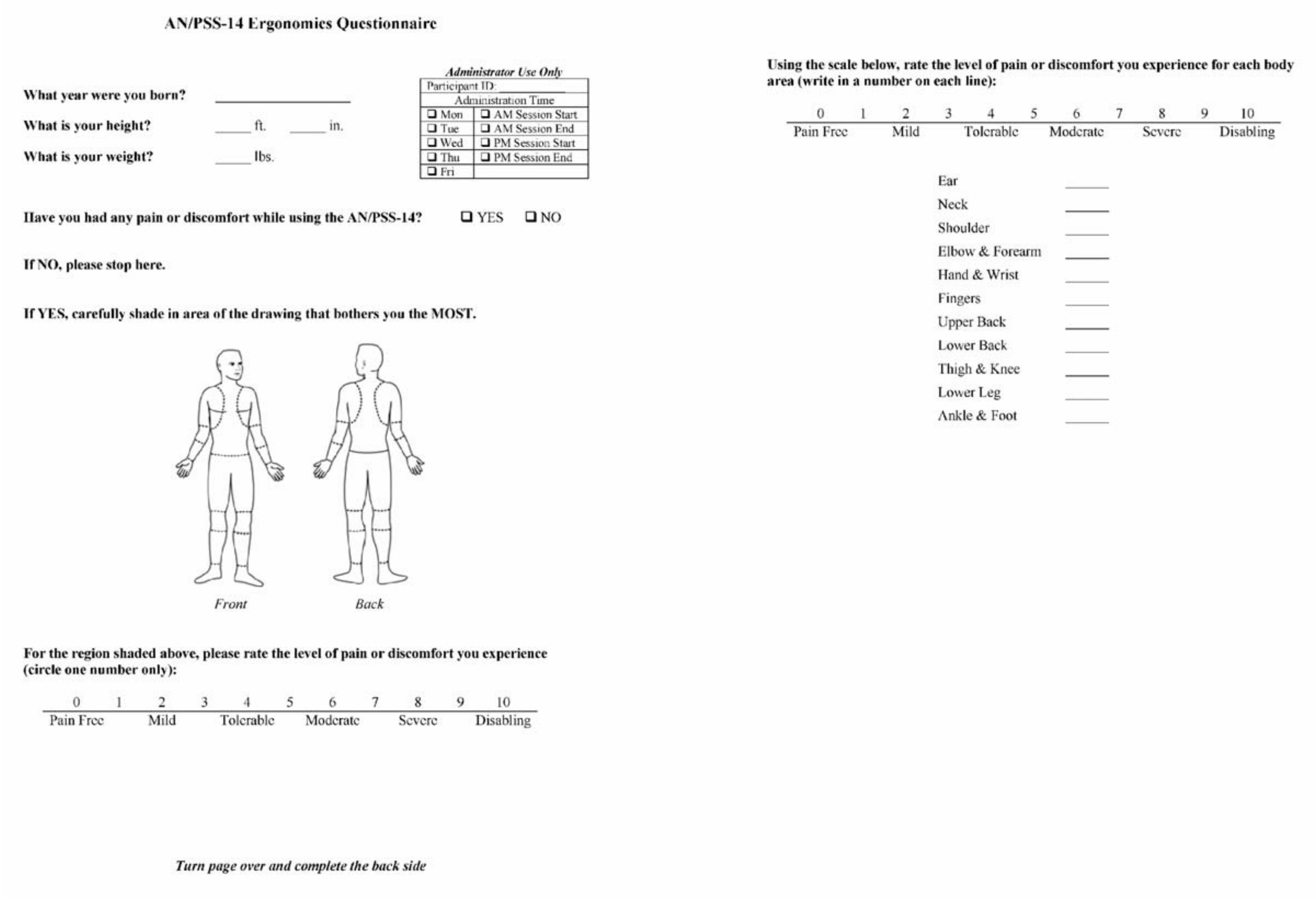
5. Have you been trained to operate any handheld mine detectors other than those listed above? YES NO
   If yes, please answer the questions on the back of this sheet for each system.

Detector #1 name/maker: ____
a. Where did you receive this training? __________________________
b. When were you trained? Year: ____________
c. Have you ever used this system in countermine operations? YES NO

Detector #2 name/maker: ____
a. Where did you receive this training? __________________________
b. When were you trained? Year: ____________
c. Have you ever used this system in countermine operations? YES NO

Detector #3 name/maker: ____
a. Where did you receive this training? __________________________
b. When were you trained? Year: ____________
c. Have you ever used this system in countermine operations? YES NO

AN/PSS-14 Ergonomics Questionnaire



AN/PSS-14 Ergonomics Questionnaire

Administrator Use Only

Participant ID:	
Administration Time	
☐ Mon	☐ AM Session Start
☐ Tue	☐ AM Session End
☐ Wed	☐ PM Session Start
☐ Thu	☐ PM Session End
☐ Fri	

What year were you born? ________________

What is your height? _____ ft. _____ in.

What is your weight? _____ lbs.

Have you had any pain or discomfort while using the AN/PSS-14? ☐ YES ☐ NO

If NO, please stop here.

If YES, carefully shade in area of the drawing that bothers you the MOST.

For the region shaded above, please rate the level of pain or discomfort you experience (circle one number only):

0	1	2	3	4	5	6	7	8	9	10
Pain Free		Mild		Tolerable		Moderate		Severe		Disabling

Turn page over and complete the back side

Using the scale below, rate the level of pain or discomfort you experience for each body area (write in a number on each line):

0	1	2	3	4	5	6	7	8	9	10
Pain Free		Mild		Tolerable		Moderate		Severe		Disabling

Ear _____
Neck _____
Shoulder _____
Elbow & Forearm _____
Hand & Wrist _____
Fingers _____
Upper Back _____
Lower Back _____
Thigh & Knee _____
Lower Leg _____
Ankle & Foot _____

Time Log Worksheet

AN/PSS-14 Training: Time Log

Operator ID: ____________________ **Date:** __________

Location examples: inside, SMS, tactical lane **206B** | **Pole Barn**
(circle one)

Action #	Location	Clock start time	Clock finish time	Activity/Comments
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
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23				
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25				
26				
27				
28				
29				
30				

Sweep Drill Worksheet

AN/PSS-14 Training: Sweep Technique

Operator ID: ____________________
Battle buddy: ____________________

Date: ____________
Clock start time: ____________
Clock finish time: ____________

Sweep location: lines, lane, free
Common sweep errors: arc, cup, fast, slow, high, gap, level

206B | **Pole Barn**
(circle one)

Action #	Location	Start time	Finish time	Instr. initials	Inter-vention	Problem fixed?	Comments
1		: :	: :		Y / N	Y / N	
2		: :	: :		Y / N	Y / N	
3		: :	: :		Y / N	Y / N	
4		: :	: :		Y / N	Y / N	
5		: :	: :		Y / N	Y / N	
6		: :	: :		Y / N	Y / N	
7		: :	: :		Y / N	Y / N	
8		: :	: :		Y / N	Y / N	
9		: :	: :		Y / N	Y / N	
10		: :	: :		Y / N	Y / N	
11		: :	: :		Y / N	Y / N	
12		: :	: :		Y / N	Y / N	
13		: :	: :		Y / N	Y / N	
14		: :	: :		Y / N	Y / N	
15		: :	: :		Y / N	Y / N	
16		: :	: :		Y / N	Y / N	
17		: :	: :		Y / N	Y / N	
18		: :	: :		Y / N	Y / N	
19		: :	: :		Y / N	Y / N	
20		: :	: :		Y / N	Y / N	
21		: :	: :		Y / N	Y / N	
22		: :	: :		Y / N	Y / N	
23		: :	: :		Y / N	Y / N	
24		: :	: :		Y / N	Y / N	
25		: :	: :		Y / N	Y / N	
26		: :	: :		Y / N	Y / N	
27		: :	: :		Y / N	Y / N	
28		: :	: :		Y / N	Y / N	
29		: :	: :		Y / N	Y / N	
30		: :	: :		Y / N	Y / N	

Iteration Cover Sheet

Cover Sheet

Data Collector Initials: ________________

Operator ID: ________________

Battle Buddy: ________________

Date: ________________

Start Time: ________________

End Time: ________________

Location: **206B / Pole Barn**

AN/PSS-14 Serial Number: ________________

Task: ________________

Observation Data Entry

Cell	Start Time (h:mm:ss)	Sweep	MD	GPR	Target "Declared" (Match with # on map)	Operator Confidence	Footprint Chipped?	Quick Cal		Noise Cancel	Instructor / Trainer Initials	Comments
								"Cal Mode" (operator select)	"Quick Cal" (detector desig)			
	: :	☐	☐	☐			☐	☐	☐	☐		
	: :	☐	☐	☐			☐	☐	☐	☐		
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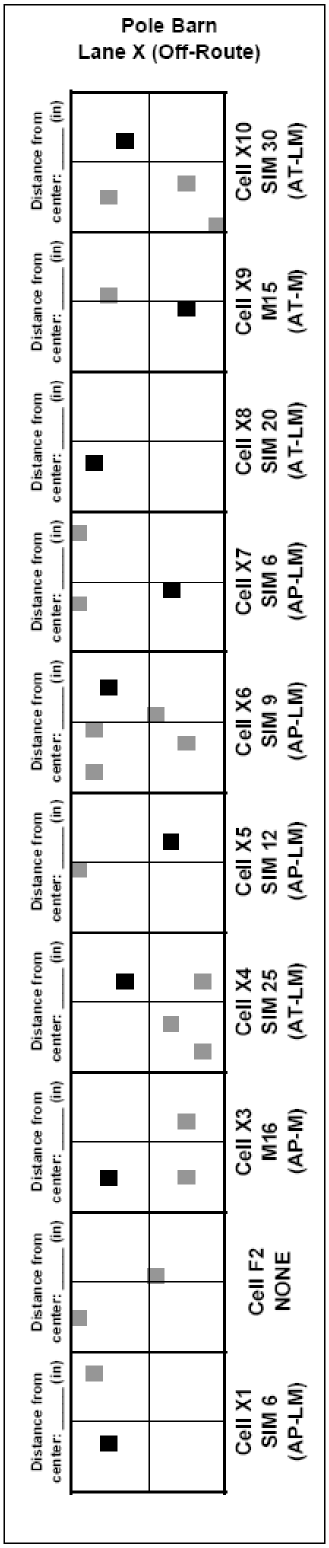
Mine Lane Map



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Appendix B. Probability of Detection

Table B-1. Descriptive statistics: probability of detection by target type.

	Adjusted Trial Number																											
	1				*2*				*3*				*4*				*5*				*6*				*7*			
			95% CI				95% CI				95% CI				95% CI				95% CI				95% CI				95% CI	
Mine	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**
Overall	79	0.89	0.94	0.79	128	0.94	0.97	0.88	154	0.80	0.85	0.73	159	0.83	0.88	0.76	150	0.87	0.92	0.81	162	0.87	0.91	0.81	153	0.94	0.97	0.89
Low Metal Mines	58	0.91	0.97	0.81	97	0.94	0.97	0.87	124	0.77	0.84	0.69	130	0.81	0.87	0.73	120	0.87	0.92	0.79	131	0.87	0.92	0.80	123	0.93	0.97	0.87
APLM Type Mines	28	0.93	0.99	0.76	48	0.90	0.96	0.77	60	0.63	0.74	0.51	64	0.70	0.80	0.58	55	0.80	0.89	0.67	60	0.77	0.86	0.64	59	0.88	0.94	0.77
Sim 6	9	0.89	1.00	0.54	0	0.86	0.99	0.03	22	0.50	0.69	0.31	21	0.67	0.83	0.45	16	0.81	0.94	0.56	19	0.74	0.88	0.51	22	0.86	0.96	0.66
Sim 9	13	1.00	1.00	0.73	21	0.86	0.96	0.64	18	0.67	0.84	0.44	22	0.73	0.87	0.51	16	0.69	0.86	0.44	19	0.89	0.98	0.67	16	0.94	1.00	0.69
Sim 12	6	0.83	0.98	0.42	13	1.00	1.00	0.73	20	0.75	0.89	0.53	21	0.71	0.86	0.50	23	0.87	0.96	0.67	22	0.68	0.84	0.47	21	0.86	0.96	0.64
ATLM Type Mines	30	0.90	0.97	0.73	49	0.98	1.00	0.88	64	0.91	0.96	0.81	66	0.91	0.96	0.81	65	0.92	0.97	0.83	71	0.96	0.99	0.88	64	0.98	1.00	0.91
Sim 20	10	0.80	0.95	0.48	16	0.94	1.00	0.69	26	0.85	0.94	0.66	24	0.92	0.99	0.73	24	0.83	0.94	0.63	27	0.89	0.97	0.71	23	1.00	1.00	0.83
Sim 25	13	1.00	1.00	0.73	19	1.00	1.00	0.80	20	1.00	1.00	0.81	25	0.96	1.00	0.79	19	1.00	1.00	0.80	24	1.00	1.00	0.83	24	0.96	1.00	0.78
Sim 30	7	0.86	0.99	0.46	14	1.00	1.00	0.74	18	0.89	0.98	0.66	17	0.82	0.94	0.58	22	0.95	1.00	0.76	20	1.00	1.00	0.81	17	1.00	1.00	0.78
Metal Mines	21	0.81	0.93	0.59	31	0.94	0.99	0.78	30	0.90	0.97	0.73	29	0.93	0.99	0.77	30	0.90	0.97	0.73	31	0.87	0.95	0.70	30	0.97	1.00	0.82
ATM Type Mines	10	0.80	0.95	0.48	15	0.93	1.00	0.68	18	1.00	1.00	0.79	18	1.00	1.00	0.79	17	1.00	1.00	0.78	18	0.94	1.00	0.72	17	1.00	1.00	0.78
M15 Sim	10	0.80	0.95	0.48	15	0.93	1.00	0.68	18	1.00	1.00	0.79	18	1.00	1.00	0.79	17	1.00	1.00	0.78	18	0.94	1.00	0.72	17	1.00	1.00	0.78
APM Type Mines	11	0.82	0.96	0.51	16	0.94	1.00	0.69	12	0.75	0.91	0.46	11	0.82	0.96	0.51	13	0.77	0.92	0.49	13	0.77	0.92	0.49	13	0.92	1.00	0.64
M16 Sim	11	0.82	0.96	0.51	16	0.94	1.00	0.69	12	0.75	0.91	0.46	11	0.82	0.96	0.51	13	0.77	0.92	0.49	13	0.77	0.92	0.49	13	0.92	1.00	0.64

Table B-2. Descriptive statistics: probability of detection by lane.

	Adjusted Trial Number																											
	1				*2*				*3*				*4*				*5*				*6*				*7*			
			95% CI				95% CI				95% CI				95% CI				95% CI				95% CI				95% CI	
Lane	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**
A	17	0.88	0.98	0.64	32	0.94	0.99	0.79	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	13	0.92	1.00	0.64	27	0.93	0.99	0.75	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	9	0.67	0.88	0.35	34	0.97	1.00	0.84	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	18	0.94	1.00	0.72	9	1.00	1.00	0.65	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E	22	0.91	0.98	0.71	26	0.88	0.97	0.70	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	33	0.82	0.92	0.65	27	0.74	0.87	0.55	18	0.89	0.98	0.66	18	0.78	0.91	0.54	27	0.93	0.99	0.75
G	-	-	-	-	-	-	-	-	9	0.67	0.88	0.35	27	0.78	0.90	0.59	26	0.92	0.99	0.75	18	0.89	0.98	0.66	36	0.97	1.00	0.84
H	-	-	-	-	-	-	-	-	44	0.73	0.84	0.58	27	0.81	0.92	0.63	9	0.89	1.00	0.54	27	0.85	0.95	0.67	-	-	-	-
I	-	-	-	-	-	-	-	-	17	0.76	0.91	0.52	9	1.00	1.00	0.65	9	1.00	1.00	0.65	27	0.96	1.00	0.80	18	0.94	1.00	0.72
J	-	-	-	-	-	-	-	-	9	0.89	1.00	0.54	42	0.83	0.92	0.69	14	0.93	1.00	0.66	18	1.00	1.00	0.79	18	0.94	1.00	0.72
K	-	-	-	-	-	-	-	-	15	0.93	1.00	0.68	18	1.00	1.00	0.79	27	0.78	0.90	0.59	27	0.78	0.90	0.59	27	1.00	1.00	0.85
L	-	-	-	-	-	-	-	-	-	-	-	-	9	0.78	0.94	0.44	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	18	0.89	0.98	0.66	-	-	-	-	35	0.80	0.90	0.64	18	0.78	0.91	0.54	-	-	-	-
N	-	-	-	-	-	-	-	-	9	0.78	0.94	0.44	-	-	-	-	12	1.00	1.00	0.71	9	1.00	1.00	0.65	27	0.85	0.95	0.67

Table B-3. Descriptive statistics: probability of detection by participants' test result.

	Adjusted Trial Number																											
	1				*2*				*3*				*4*				*5*				*6*				*7*			
			95% CI				95% CI				95% CI				95% CI				95% CI				95% CI				95% CI	
Test Outcome	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**	**n**	**PD**	**Upper**	**Lower**
Pass	53	0.94	0.99	0.84	91	0.95	0.98	0.87	105	0.81	0.87	0.72	108	0.85	0.91	0.77	101	0.86	0.92	0.78	108	0.89	0.94	0.81	99	1.00	1.00	0.95
Fail	26	0.77	0.89	0.58	37	0.92	0.98	0.78	49	0.78	0.87	0.64	51	0.78	0.88	0.65	49	0.90	0.96	0.78	54	0.83	0.91	0.71	54	0.83	0.91	0.71

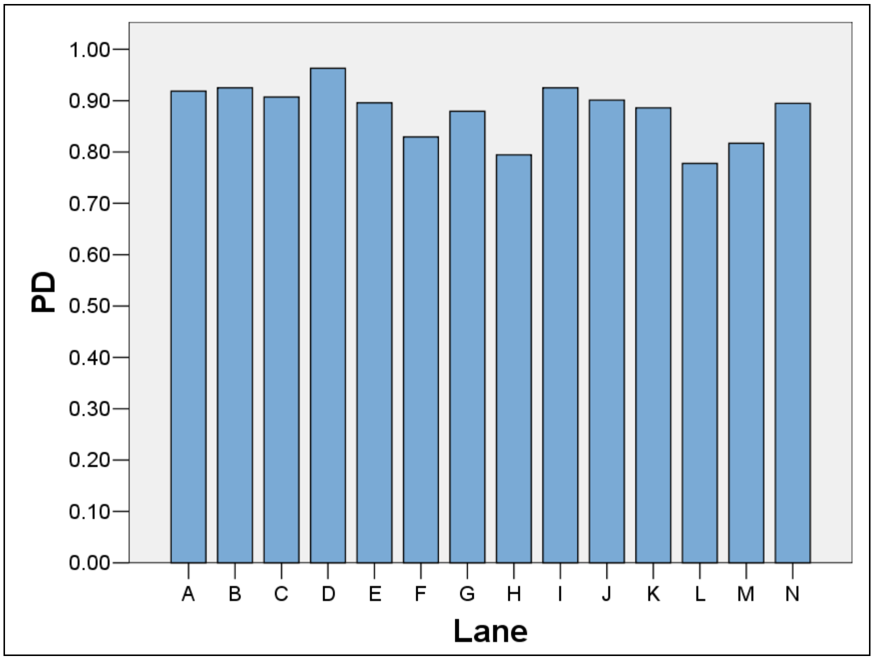


Figure B-1. Mean probability of detection versus lane for all trials.

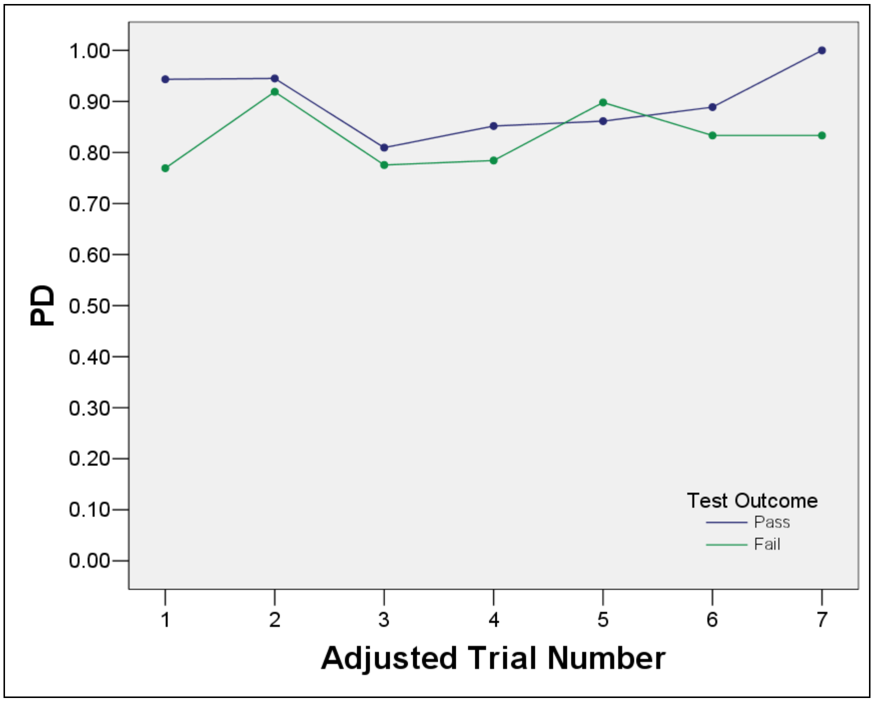
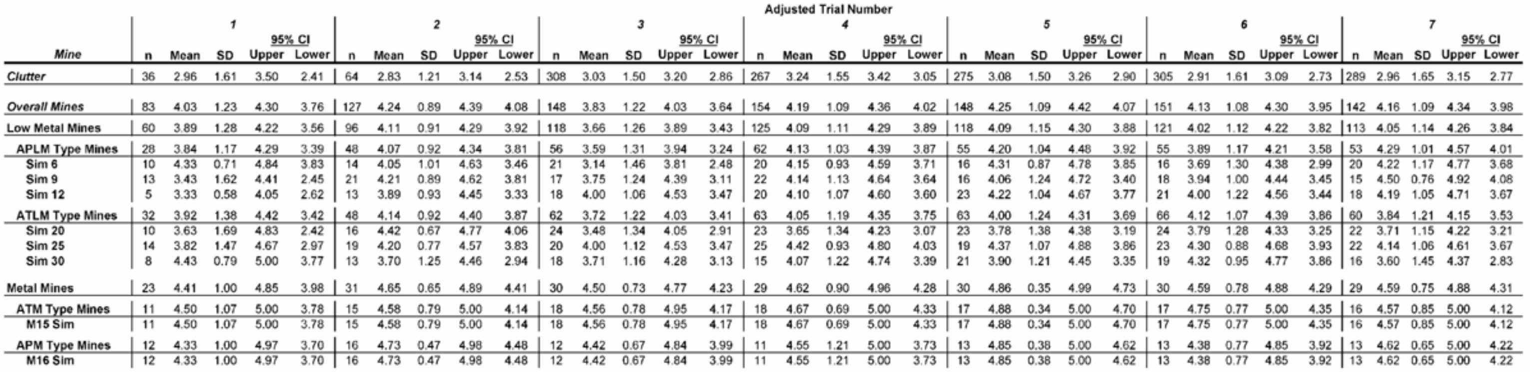


Figure B-2. Mean probability of detection versus adjusted trial number by participants' test result.

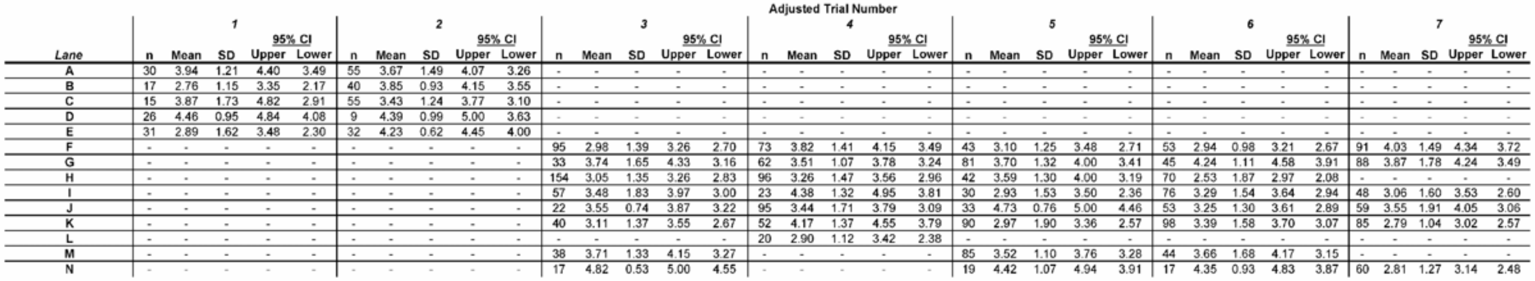
Appendix C. Confidence Rating

Table C-1. Descriptive statistics: confidence rating by target type.



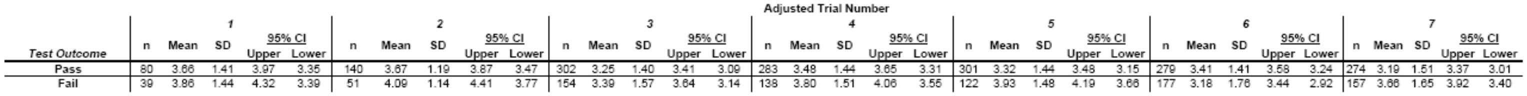
	Adjusted Trial Number																																		
	1					2					3					4					5					6					7				
				95% CI					95% CI					95% CI					95% CI					95% CI					95% CI					95% CI	
Mine	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower
Clutter	36	2.96	1.61	3.50	2.41	64	2.83	1.21	3.14	2.53	308	3.03	1.50	3.20	2.86	267	3.24	1.55	3.42	3.05	275	3.08	1.50	3.26	2.90	305	2.91	1.61	3.09	2.73	289	2.96	1.65	3.15	2.77
Overall Mines	83	4.03	1.23	4.30	3.76	127	4.24	0.89	4.39	4.08	148	3.83	1.22	4.03	3.64	154	4.19	1.09	4.36	4.02	148	4.25	1.09	4.42	4.07	151	4.13	1.08	4.30	3.95	142	4.16	1.09	4.34	3.98
Low Metal Mines	60	3.89	1.28	4.22	3.56	96	4.11	0.91	4.29	3.92	118	3.66	1.26	3.89	3.43	125	4.09	1.11	4.29	3.89	118	4.09	1.15	4.30	3.88	121	4.02	1.12	4.22	3.82	113	4.05	1.14	4.26	3.84
APLM Type Mines	28	3.84	1.17	4.29	3.39	48	4.07	0.92	4.34	3.81	56	3.59	1.31	3.94	3.24	62	4.13	1.03	4.39	3.87	55	4.20	1.04	4.48	3.92	55	3.89	1.17	4.21	3.58	53	4.29	1.01	4.57	4.01
Sim 6	10	4.33	0.71	4.84	3.83	14	4.05	1.01	4.63	3.46	21	3.14	1.46	3.81	2.48	20	4.15	0.93	4.59	3.71	16	4.31	0.87	4.78	3.85	16	3.69	1.30	4.38	2.99	20	4.22	1.17	4.77	3.68
Sim 9	13	3.43	1.62	4.41	2.45	21	4.21	0.89	4.62	3.81	17	3.75	1.24	4.39	3.11	22	4.14	1.13	4.64	3.64	16	4.06	1.24	4.72	3.40	18	3.94	1.00	4.44	3.45	15	4.50	0.76	4.92	4.08
Sim 12	5	3.33	0.58	4.05	2.62	13	3.89	0.93	4.45	3.33	18	4.00	1.06	4.53	3.47	20	4.10	1.07	4.60	3.60	23	4.22	1.04	4.67	3.77	21	4.00	1.22	4.56	3.44	18	4.19	1.05	4.71	3.67
ATLM Type Mines	32	3.92	1.38	4.42	3.42	48	4.14	0.92	4.40	3.87	62	3.72	1.22	4.03	3.41	63	4.05	1.19	4.35	3.75	63	4.00	1.24	4.31	3.69	66	4.12	1.07	4.39	3.86	60	3.84	1.21	4.15	3.53
Sim 20	10	3.63	1.69	4.83	2.42	16	4.42	0.67	4.77	4.06	24	3.48	1.34	4.05	2.91	23	3.65	1.34	4.23	3.07	23	3.78	1.38	4.38	3.19	24	3.79	1.28	4.33	3.25	22	3.71	1.15	4.22	3.21
Sim 25	14	3.82	1.47	4.67	2.97	19	4.20	0.77	4.57	3.83	20	4.00	1.12	4.53	3.47	25	4.42	0.93	4.80	4.03	19	4.37	1.07	4.88	3.86	23	4.30	0.88	4.68	3.93	22	4.14	1.06	4.61	3.67
Sim 30	8	4.43	0.79	5.00	3.77	13	3.70	1.25	4.46	2.94	18	3.71	1.16	4.28	3.13	15	4.07	1.22	4.74	3.39	21	3.90	1.21	4.45	3.35	19	4.32	0.95	4.77	3.86	16	3.60	1.45	4.37	2.83
Metal Mines	23	4.41	1.00	4.85	3.98	31	4.65	0.65	4.89	4.41	30	4.50	0.73	4.77	4.23	29	4.62	0.90	4.96	4.28	30	4.86	0.35	4.99	4.73	30	4.59	0.78	4.88	4.29	29	4.59	0.75	4.88	4.31
ATM Type Mines	11	4.50	1.07	5.00	3.78	15	4.58	0.79	5.00	4.14	18	4.56	0.78	4.95	4.17	18	4.67	0.69	5.00	4.33	17	4.88	0.34	5.00	4.70	17	4.75	0.77	5.00	4.35	16	4.57	0.85	5.00	4.12
M15 Sim	11	4.50	1.07	5.00	3.78	15	4.58	0.79	5.00	4.14	18	4.56	0.78	4.95	4.17	18	4.67	0.69	5.00	4.33	17	4.88	0.34	5.00	4.70	17	4.75	0.77	5.00	4.35	16	4.57	0.85	5.00	4.12
APM Type Mines	12	4.33	1.00	4.97	3.70	16	4.73	0.47	4.98	4.48	12	4.42	0.67	4.84	3.99	11	4.55	1.21	5.00	3.73	13	4.85	0.38	5.00	4.62	13	4.38	0.77	4.85	3.92	13	4.62	0.65	5.00	4.22
M16 Sim	12	4.33	1.00	4.97	3.70	16	4.73	0.47	4.98	4.48	12	4.42	0.67	4.84	3.99	11	4.55	1.21	5.00	3.73	13	4.85	0.38	5.00	4.62	13	4.38	0.77	4.85	3.92	13	4.62	0.65	5.00	4.22

Table C-2. Descriptive statistics: confidence rating by lane.



	Adjusted Trial Number																																		
	1					2					3					4					5					6					7				
				95% CI					95% CI					95% CI					95% CI					95% CI					95% CI					95% CI	
Lane	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower	n	Mean	SD	Upper	Lower
A	30	3.94	1.21	4.40	3.49	55	3.67	1.49	4.07	3.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	17	2.76	1.15	3.35	2.17	40	3.85	0.93	4.15	3.55	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	15	3.87	1.73	4.82	2.91	55	3.43	1.24	3.77	3.10	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	26	4.46	0.95	4.84	4.08	9	4.39	0.99	5.00	3.63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E	31	2.89	1.62	3.48	2.30	32	4.23	0.62	4.45	4.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	-	-	95	2.98	1.39	3.26	2.70	73	3.82	1.41	4.15	3.49	43	3.10	1.25	3.48	2.71	53	2.94	0.98	3.21	2.67	91	4.03	1.49	4.34	3.72
G	-	-	-	-	-	-	-	-	-	-	33	3.74	1.65	4.33	3.16	62	3.51	1.07	3.78	3.24	81	3.70	1.32	4.00	3.41	45	4.24	1.11	4.58	3.91	88	3.87	1.78	4.24	3.49
H	-	-	-	-	-	-	-	-	-	-	154	3.05	1.35	3.26	2.83	96	3.26	1.47	3.56	2.96	42	3.59	1.30	4.00	3.19	70	2.53	1.87	2.97	2.08	-	-	-	-	-
I	-	-	-	-	-	-	-	-	-	-	57	3.48	1.83	3.97	3.00	23	4.38	1.32	4.95	3.81	30	2.93	1.53	3.50	2.36	76	3.29	1.54	3.64	2.94	48	3.06	1.60	3.53	2.60
J	-	-	-	-	-	-	-	-	-	-	22	3.55	0.74	3.87	3.22	95	3.44	1.71	3.79	3.09	33	4.73	0.76	5.00	4.46	53	3.25	1.30	3.61	2.89	59	3.55	1.91	4.05	3.06
K	-	-	-	-	-	-	-	-	-	-	40	3.11	1.37	3.55	2.67	52	4.17	1.37	4.55	3.79	90	2.97	1.90	3.36	2.57	98	3.39	1.58	3.70	3.07	85	2.79	1.04	3.02	2.57
L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	20	2.90	1.12	3.42	2.38	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	-	-	38	3.71	1.33	4.15	3.27	-	-	-	-	-	85	3.52	1.10	3.76	3.28	44	3.66	1.68	4.17	3.15	-	-	-	-	-
N	-	-	-	-	-	-	-	-	-	-	17	4.82	0.53	5.00	4.55	-	-	-	-	-	19	4.42	1.07	4.94	3.91	17	4.35	0.93	4.83	3.87	60	2.81	1.27	3.14	2.48

Table C-3. Descriptive statistics: confidence rating by participants' test result.



	Adjusted Trial Number																																		
	1					2					3					4					5					6					7				
	n	Mean	SD	95% CI		n	Mean	SD	95% CI		n	Mean	SD	95% CI		n	Mean	SD	95% CI		n	Mean	SD	95% CI		n	Mean	SD	95% CI		n	Mean	SD	95% CI	
Test Outcome				Upper	Lower				Upper	Lower				Upper	Lower				Upper	Lower				Upper	Lower				Upper	Lower				Upper	Lower
Pass	80	3.66	1.41	3.97	3.35	140	3.67	1.19	3.87	3.47	302	3.25	1.40	3.41	3.09	283	3.48	1.44	3.65	3.31	301	3.32	1.44	3.48	3.15	279	3.41	1.41	3.58	3.24	274	3.19	1.51	3.37	3.01
Fail	39	3.86	1.44	4.32	3.39	51	4.09	1.14	4.41	3.77	154	3.39	1.57	3.64	3.14	138	3.80	1.51	4.06	3.55	122	3.93	1.48	4.19	3.66	177	3.18	1.76	3.44	2.92	157	3.66	1.65	3.92	3.40

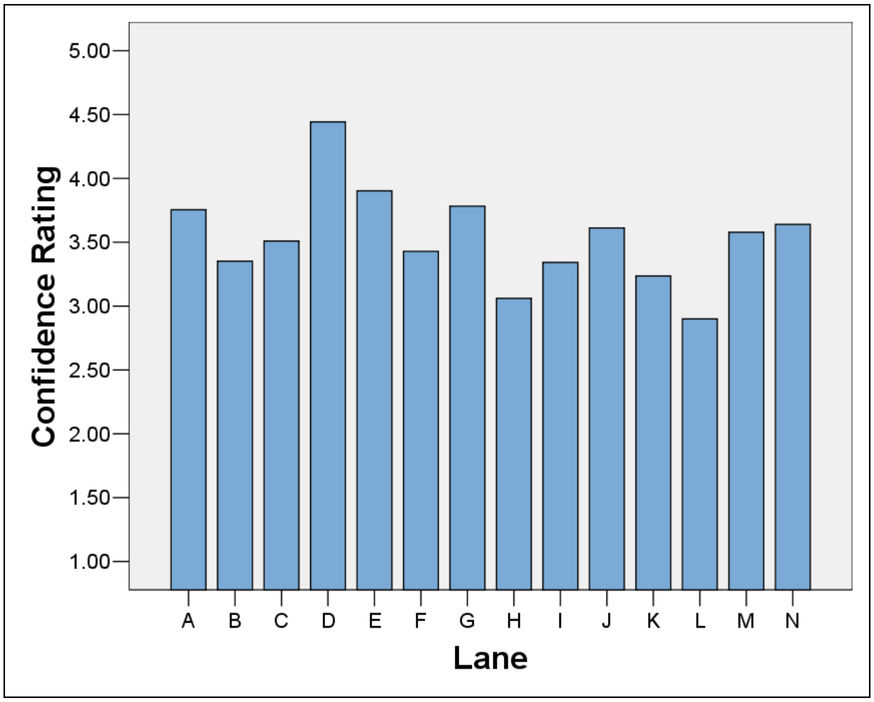


Figure C-1. Mean confidence rating versus lane for all trials.

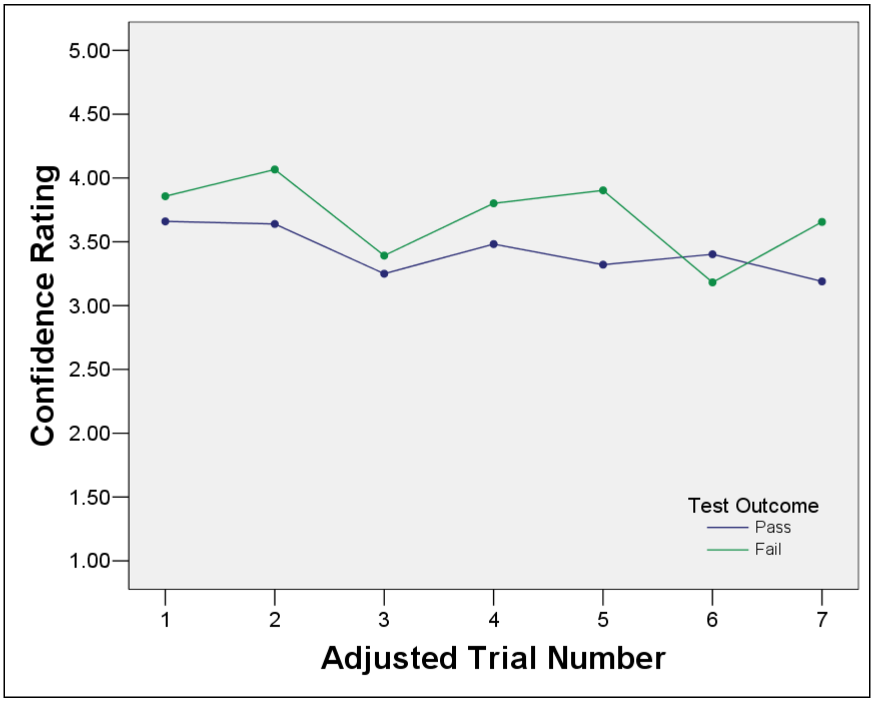


Figure C-2. Mean confidence rating versus adjusted trial number by participants' test result.

Appendix D. Investigation Time

Table D-1. Descriptive statistics: total investigation time (seconds) by target type.

	Adjusted Trial Number																											
	1				2				3				4				5				6				7			
Mine	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD
Clutter	22	165.00	178.91	55.48	52	162.50	164.38	81.44	259	95.00	109.11	66.19	228	90.50	100.74	58.54	235	90.00	103.63	64.83	249	80.00	92.17	55.35	247	81.00	95.85	63.20
Overall Mines	69	195.00	216.65	111.29	100	167.50	181.02	104.73	134	95.50	114.81	75.74	143	86.00	102.18	70.10	133	100.00	114.60	81.92	129	82.00	98.35	68.81	127	88.00	102.66	68.19
Low Metal Mines	48	187.50	190.25	86.27	77	157.00	163.78	84.06	109	90.00	105.76	62.63	116	76.00	90.85	60.58	106	95.00	105.12	59.79	104	75.00	88.27	59.44	102	80.50	93.64	56.39
APLM Type Mines	23	175.00	167.52	68.35	41	155.00	161.51	84.29	52	89.00	99.75	53.40	59	70.00	83.25	49.32	48	82.50	96.42	56.46	45	78.00	85.07	40.58	50	80.50	92.90	50.25
Sim 6	9	155.00	163.33	59.57	12	140.50	171.08	96.27	19	72.00	106.00	72.48	19	68.00	86.79	58.52	14	85.50	87.00	39.94	14	66.50	75.21	40.36	19	90.00	89.00	39.63
Sim 9	9	175.00	175.44	84.02	18	127.00	153.50	86.83	16	84.50	93.94	41.66	22	70.00	88.41	50.78	12	63.00	111.00	73.32	14	83.50	87.86	36.24	15	79.00	94.00	52.08
Sim 12	5	184.00	160.80	65.11	11	168.00	164.18	71.93	17	94.00	98.24	38.31	18	65.00	73.22	36.52	22	89.00	94.45	56.10	17	83.00	90.88	44.84	16	71.00	96.50	61.63
ATLM Type Mines	25	199.00	211.16	96.65	36	165.00	166.36	84.92	57	92.00	111.25	70.03	57	85.00	98.72	69.94	58	100.00	112.33	61.97	59	72.00	90.71	70.79	52	79.50	94.35	62.20
Sim 20	7	194.00	177.43	91.17	13	200.00	199.00	111.74	22	83.50	111.14	83.47	22	92.00	124.41	94.57	21	100.00	115.05	72.11	23	86.00	100.96	64.21	19	100.00	118.95	80.43
Sim 25	13	176.00	193.69	88.88	14	136.00	134.36	55.68	20	120.50	129.65	70.43	21	86.00	88.29	48.66	17	135.00	126.65	70.30	20	57.50	68.95	43.32	18	64.50	70.78	41.14
Sim 30	5	285.00	303.80	78.54	9	197.00	169.00	65.22	15	90.00	86.87	36.25	14	65.50	74.00	32.13	20	88.00	97.30	38.17	16	72.50	103.19	99.98	15	90.00	91.47	46.67
Metal Mines	21	248.00	277.00	138.30	23	188.00	238.74	142.92	25	125.00	154.24	110.21	27	117.00	150.85	87.05	27	118.00	151.81	133.51	25	113.00	140.28	88.42	25	105.00	139.48	96.30
ATM Type Mines	10	243.50	280.40	141.16	9	260.00	278.56	158.03	13	125.00	154.62	97.81	17	127.00	168.35	99.56	16	116.00	163.31	159.10	14	141.50	163.64	95.46	15	113.00	150.47	105.85
M15 Sim	10	243.50	280.40	141.16	9	260.00	278.56	158.03	13	125.00	154.62	97.81	17	127.00	168.35	99.56	16	116.00	163.31	159.10	14	141.50	163.64	95.46	15	113.00	150.47	105.85
APM Type Mines	11	280.00	273.91	142.47	14	152.00	213.14	131.89	12	125.00	153.83	126.73	10	107.50	121.10	52.04	11	119.00	135.09	88.65	11	110.00	110.55	71.98	10	87.50	123.00	82.45
M16 Sim	11	280.00	273.91	142.47	14	152.00	213.14	131.89	12	125.00	153.83	126.73	10	107.50	121.10	52.04	11	119.00	135.09	88.65	11	110.00	110.55	71.98	10	87.50	123.00	82.45

Table D-2. Descriptive statistics: MD time per investigation (seconds) by target type.

	Adjusted Trial Number																											
	1				2				3				4				5				6				7			
Mine	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD
Clutter	22	123.00	128.00	52.60	52	101.50	98.73	53.62	259	53.00	64.69	44.71	228	49.50	58.73	43.45	235	46.00	61.88	49.29	249	47.00	55.67	40.10	247	49.00	59.17	45.41
Overall Mines	69	147.00	145.61	65.12	100	102.50	117.02	69.46	134	59.00	75.69	60.48	143	51.00	66.83	54.63	133	56.00	74.86	69.57	129	47.00	62.61	59.76	127	55.00	70.64	57.82
Low Metal Mines	48	120.00	131.69	60.78	77	101.00	109.17	61.71	109	56.00	67.02	43.46	116	48.00	56.96	40.05	106	54.00	67.15	51.35	104	44.00	53.39	46.89	102	55.00	63.78	44.37
APLM Type Mines	23	113.00	115.17	46.46	41	101.00	108.66	61.13	52	51.50	63.75	41.63	59	42.00	50.10	33.70	48	46.50	60.96	48.25	45	42.00	48.07	36.83	50	55.00	64.98	45.67
Sim 6	9	113.00	114.00	43.82	12	99.50	101.00	72.07	19	50.00	67.05	51.95	19	44.00	52.58	40.33	14	35.00	50.14	37.88	14	30.50	40.86	33.00	19	45.00	59.32	38.47
Sim 9	9	143.00	119.67	49.49	18	97.50	112.28	59.98	16	52.00	59.44	32.82	22	42.50	50.82	33.63	12	47.50	66.92	51.97	14	42.00	53.07	40.45	15	55.00	64.47	38.24
Sim 12	5	100.00	109.20	55.15	11	106.00	111.09	54.92	17	58.00	64.12	38.05	18	38.50	46.61	27.13	22	58.50	64.59	52.86	17	44.00	49.88	38.02	16	58.50	72.19	59.80
ATLM Type Mines	25	148.00	146.88	68.94	36	104.00	109.75	63.22	57	58.00	70.00	45.22	57	52.00	64.05	44.90	58	56.50	72.28	53.65	59	47.00	57.46	53.27	52	50.50	62.63	43.49
Sim 20	7	148.00	140.71	73.87	13	110.00	127.00	76.13	22	50.00	66.32	47.55	22	66.50	78.14	60.19	21	58.00	78.10	58.72	23	48.00	66.83	54.50	19	60.00	74.47	53.88
Sim 25	13	120.00	135.08	66.24	14	72.50	88.07	51.84	20	67.00	85.00	52.93	21	50.00	54.57	27.63	17	55.00	77.12	64.61	20	32.50	44.90	30.53	18	45.00	53.11	35.37
Sim 30	5	220.00	186.20	68.69	9	136.00	118.56	55.08	15	56.00	55.40	20.36	14	51.50	56.14	33.31	20	55.00	62.05	36.37	16	41.00	59.69	71.29	15	47.00	59.07	36.32
Metal Mines	21	170.00	177.43	64.88	23	106.00	143.30	87.27	25	83.00	113.48	99.73	27	81.00	109.22	83.09	27	64.00	105.11	112.84	25	76.00	100.96	87.82	25	73.00	98.60	90.84
ATM Type Mines	10	167.50	177.70	55.25	9	162.00	152.78	74.00	13	94.00	120.62	86.93	17	91.00	122.59	98.63	16	72.00	113.38	130.25	14	89.00	117.29	95.44	15	86.00	111.73	102.86
M15 Sim	10	167.50	177.70	55.25	9	162.00	152.78	74.00	13	94.00	120.62	86.93	17	91.00	122.59	98.63	16	72.00	113.38	130.25	14	89.00	117.29	95.44	15	86.00	111.73	102.86
APM Type Mines	11	171.00	177.18	75.30	14	96.00	137.21	97.05	12	56.50	105.75	115.46	10	73.50	86.50	41.73	11	41.00	93.09	85.95	11	72.00	80.18	76.28	10	57.00	78.90	69.50
M16 Sim	11	171.00	177.18	75.30	14	96.00	137.21	97.05	12	56.50	105.75	115.46	10	73.50	86.50	41.73	11	41.00	93.09	85.95	11	72.00	80.18	76.28	10	57.00	78.90	69.50

Table D-3. Descriptive statistics: GPR time per investigation (seconds) by target type.

	Adjusted Trial Number																											
	1				2				3				4				5				6				7			
Mine	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD
Clutter	22	32.00	32.32	20.19	52	38.00	47.04	35.94	259	29.00	36.83	29.10	228	28.00	34.65	26.10	235	27.00	34.28	26.09	249	24.00	30.16	23.47	247	21.00	29.34	23.88
Overall Mines	69	26.00	38.77	34.34	100	35.50	46.10	34.16	134	24.00	30.40	24.02	143	21.00	28.27	23.99	133	22.00	31.53	26.84	129	23.00	29.82	26.03	127	19.00	25.02	19.86
Low Metal Mines	48	25.00	33.90	28.90	77	35.00	43.21	31.53	109	24.00	30.63	23.94	116	20.50	27.50	23.07	106	21.50	30.66	27.00	104	22.00	28.97	25.63	102	18.50	24.16	18.45
APLM Type Mines	23	25.00	33.91	31.36	41	29.00	38.68	32.60	52	24.50	30.12	21.71	59	20.00	28.24	24.72	48	21.00	30.19	26.44	45	23.00	31.60	25.92	50	18.50	22.26	13.74
Sim 6	9	25.00	28.78	15.92	12	37.00	47.75	39.90	19	25.00	31.05	22.68	19	21.00	24.84	18.59	14	34.50	33.14	22.07	14	22.00	32.07	21.48	19	21.00	24.37	11.64
Sim 9	9	27.00	41.11	42.23	18	19.00	30.22	29.54	16	23.00	29.75	23.74	22	22.00	35.50	31.09	12	17.00	35.50	37.11	14	23.50	28.57	22.85	15	14.00	20.13	13.55
Sim 12	5	20.00	30.20	33.81	11	38.00	42.64	27.78	17	23.00	29.41	19.83	18	16.00	22.94	20.34	22	15.00	25.41	22.27	17	23.00	33.71	32.18	16	15.50	21.75	16.51
ATLM Type Mines	25	25.00	33.88	27.09	36	40.50	48.36	29.87	57	24.00	31.11	25.99	57	21.00	26.74	21.43	58	21.50	31.05	27.69	59	19.00	26.97	25.44	52	19.00	25.98	22.04
Sim 20	7	18.00	24.71	17.81	13	52.00	56.15	32.89	22	23.50	30.73	26.23	22	31.00	33.32	25.91	21	21.00	26.71	26.51	23	28.00	27.48	25.96	19	29.00	35.63	27.34
Sim 25	13	23.00	31.15	30.27	14	35.50	43.71	27.73	20	25.50	33.45	27.74	21	23.00	27.81	19.10	17	36.00	40.41	35.34	20	17.50	22.30	20.74	18	13.00	16.78	11.93
Sim 30	5	65.00	53.80	22.60	9	40.00	44.33	29.62	15	21.00	28.53	24.70	14	11.50	14.79	10.18	20	21.00	27.65	19.91	16	24.00	32.06	30.20	15	18.00	24.80	19.96
Metal Mines	21	38.00	49.90	43.12	23	50.00	55.78	41.13	25	23.00	29.36	24.83	27	27.00	31.59	27.81	27	27.00	34.93	26.39	25	23.00	33.36	27.89	25	20.00	28.52	24.94
ATM Type Mines	10	40.00	46.10	32.13	9	30.00	54.33	51.32	13	18.00	25.92	20.68	17	28.00	33.24	31.25	16	36.50	39.06	24.75	14	30.50	36.86	26.58	15	18.00	24.40	25.02
M15 Sim	10	40.00	46.10	32.13	9	30.00	54.33	51.32	13	18.00	25.92	20.68	17	28.00	33.24	31.25	16	36.50	39.06	24.75	14	30.50	36.86	26.58	15	18.00	24.40	25.02
APM Type Mines	11	27.00	53.36	52.55	14	52.00	56.71	35.20	12	28.00	33.08	29.14	10	22.50	28.80	22.02	11	17.00	28.91	28.71	11	15.00	28.91	30.16	10	37.00	34.70	24.77
M16 Sim	11	27.00	53.36	52.55	14	52.00	56.71	35.20	12	28.00	33.08	29.14	10	22.50	28.80	22.02	11	17.00	28.91	28.71	11	15.00	28.91	30.16	10	37.00	34.70	24.77

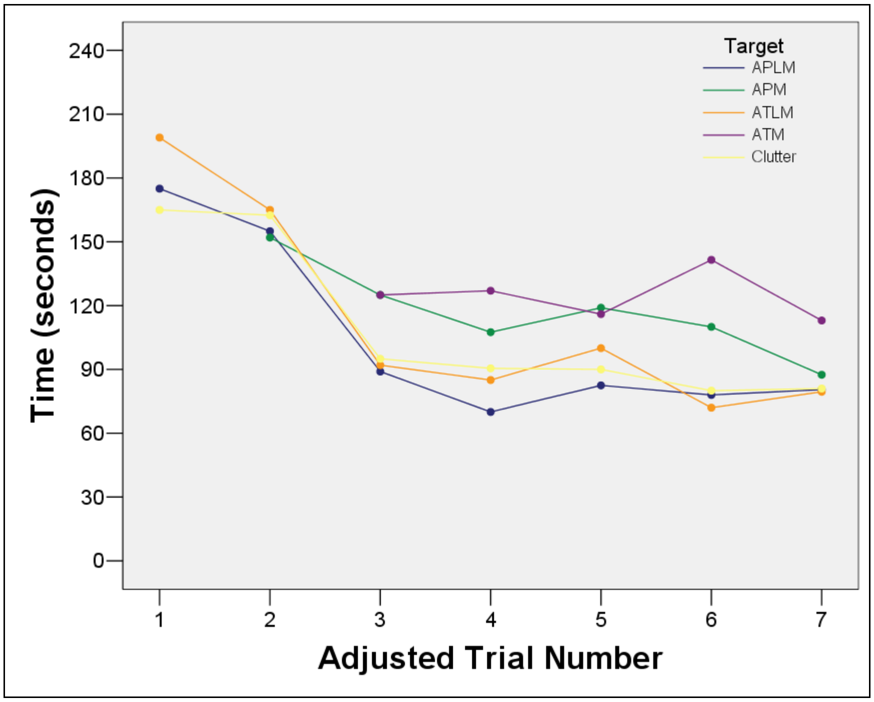


Figure D-1. Median total investigation time versus adjusted trial number by mine type.

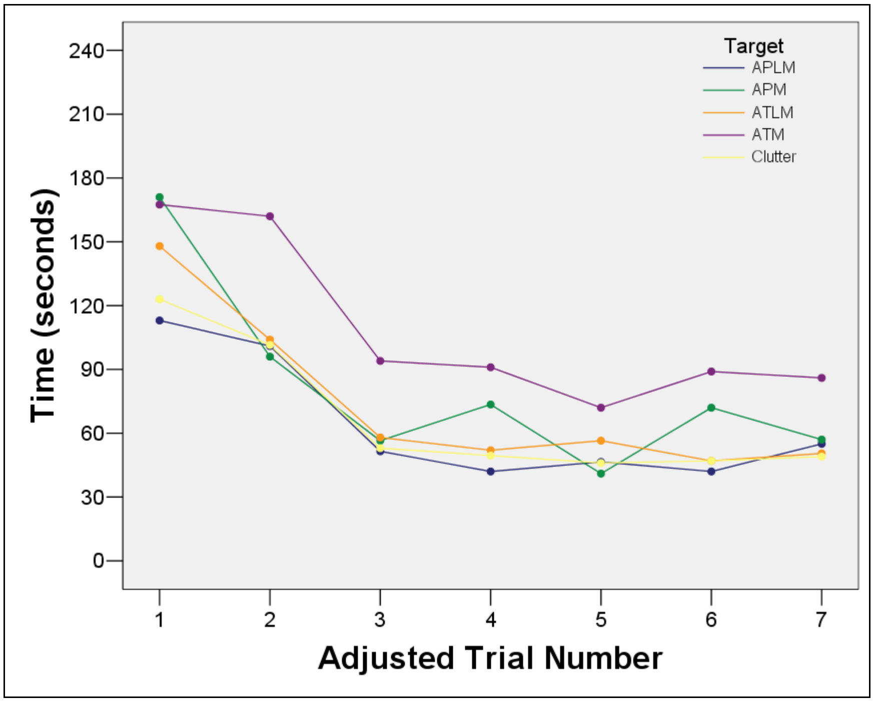


Figure D-2. Median MD time per investigation versus adjusted trial number by mine type.

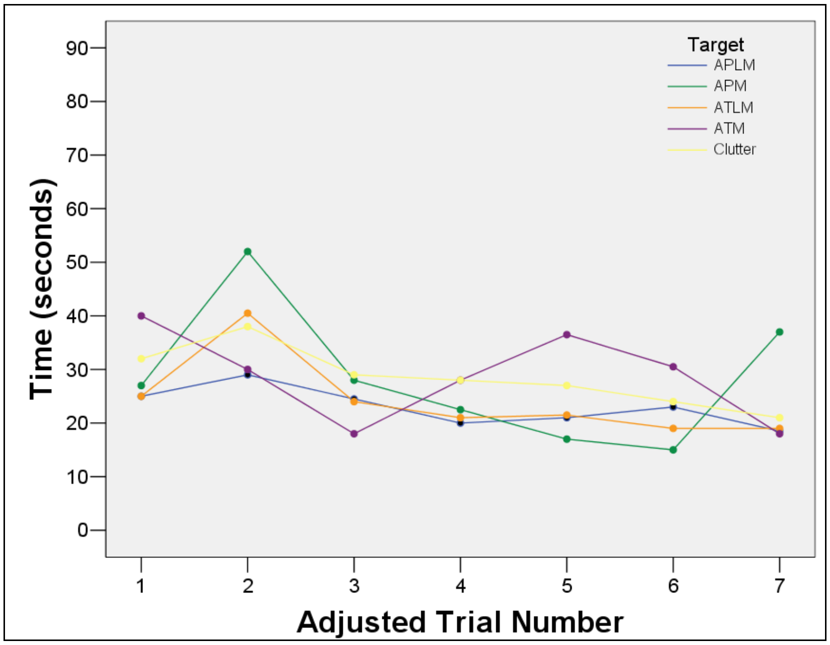


Figure D-3. Median GPR time per investigation versus adjusted trial number by mine type.

Table D-4. Power curve ($y = Cx^b$) model summary: investigation time (y) versus adjusted trial number (x).

Target Type	**Model Summary**					**Parameter Estimates**	
	R^2	**F**	**df1**	**df2**	**Sig.**	***C***	***b***
APLM	0.122	44.088	1	316	0.000	149.887	-0.394
APM	0.181	17.052	1	77	0.000	230.628	-0.489
ATLM	0.151	60.751	1	342	0.000	178.576	-0.467
ATM	0.115	11.917	1	92	0.001	248.733	-0.393
Clutter	0.044	59.928	1	1,290	0.000	142.806	-0.333

Table D-5. Power curve ($y = Cx^b$) model summary: MD time per investigation (y) versus adjusted trial number (x).

Target Type	**Model Summary**					**Parameter Estimates**	
	R^2	**F**	**df1**	**df2**	**Sig.**	***C***	***b***
APLM	0.116	41.472	1	316	0.000	101.523	-0.517
APM	0.165	15.262	1	77	0.000	153.729	-0.563
ATLM	0.129	50.532	1	342	0.000	116.750	-0.524
ATM	0.098	9.997	1	92	0.002	170.595	-0.458
Clutter	0.034	45.976	1	1,290	0.000	83.189	-0.377

Table D-6. Power curve ($y = Cx^b$) model summary: GPR time per investigation (y) versus adjusted trial number (x).

Target Type	Model Summary					Parameter Estimates	
	R^2	**F**	**df1**	**df2**	**Sig.**	***C***	***b***
APLM	0.012	3.695	1	316	0.055	26.804	-0.173
APM	0.057	4.619	1	77	0.035	39.587	-0.345
ATLM	0.033	11.739	1	342	0.001	32.771	-0.319
ATM	0.028	2.649	1	92	0.107	35.218	-0.240
Clutter	0.011	14.642	1	1,290	0.000	34.450	-0.221

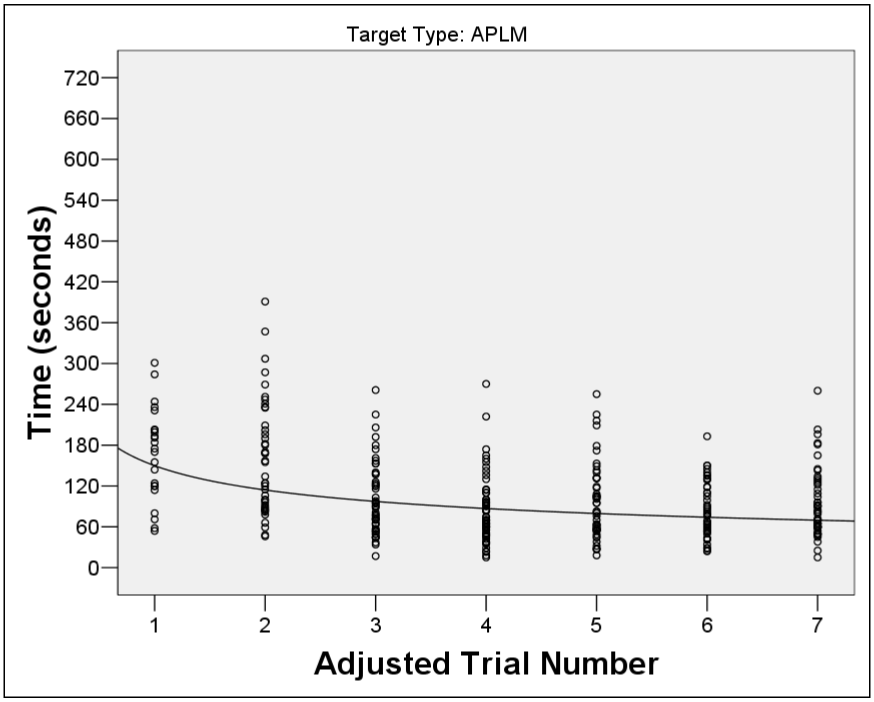


Figure D-4. Total investigation time versus adjusted trial number for APLM type mines.

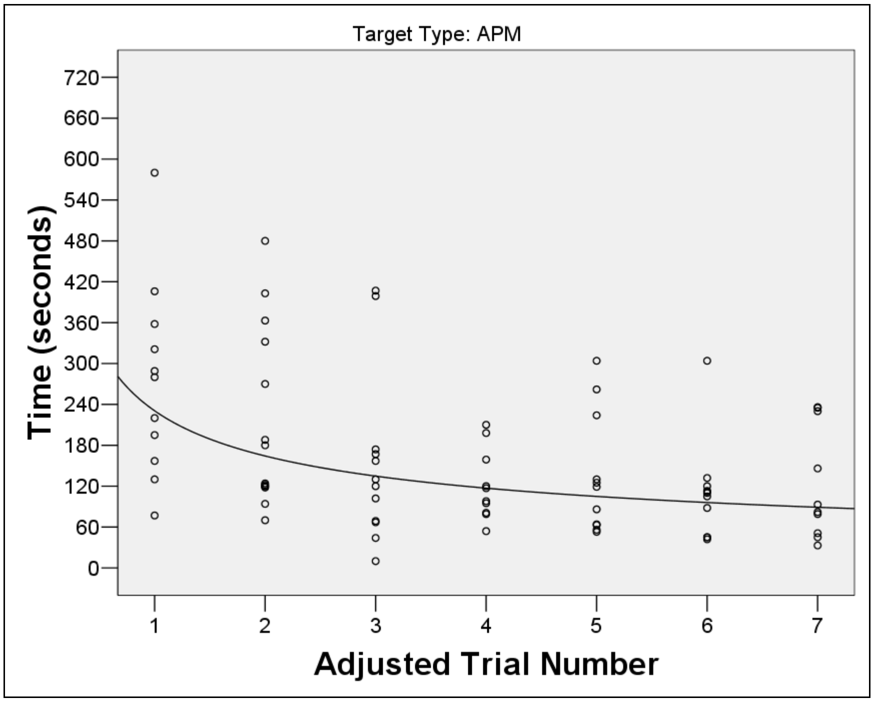


Figure D-5. Total investigation time versus adjusted trial number for APM type mines.

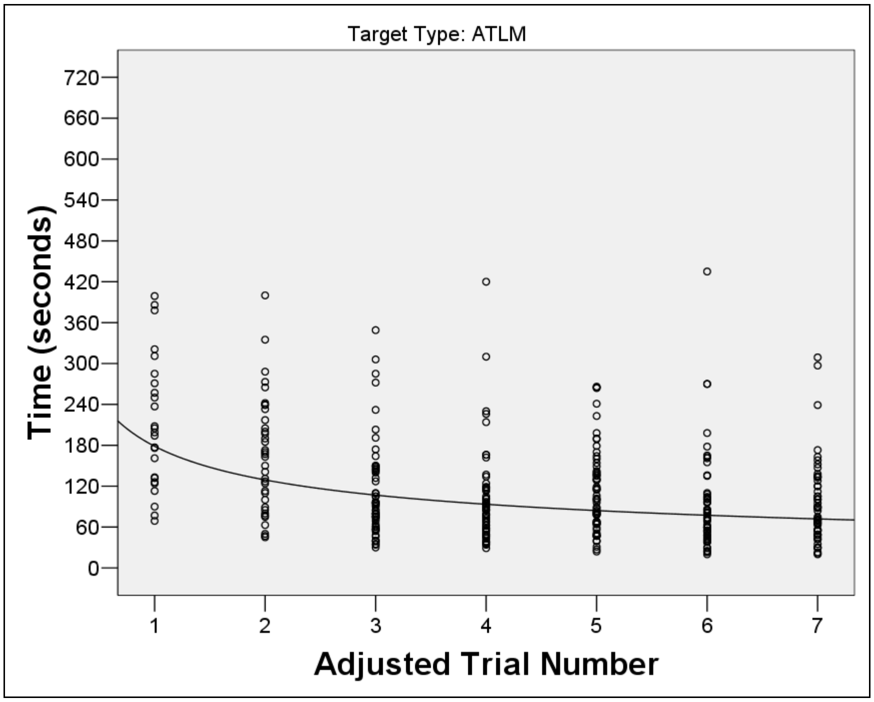


Figure D-6. Total investigation time versus adjusted trial number for ATLM type mines.

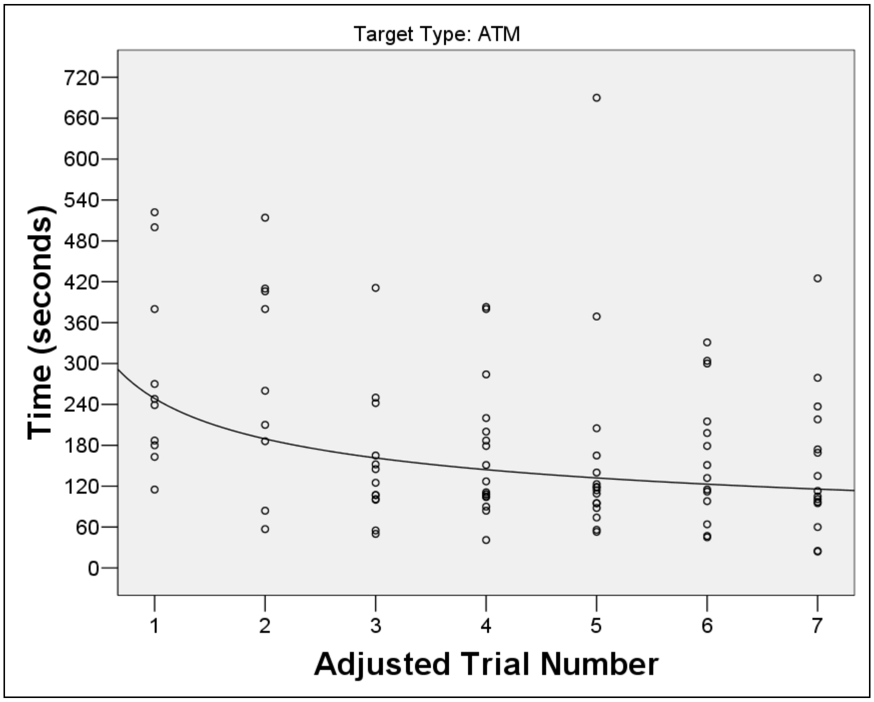


Figure D-7. Total investigation time versus adjusted trial number for ATM type mines.

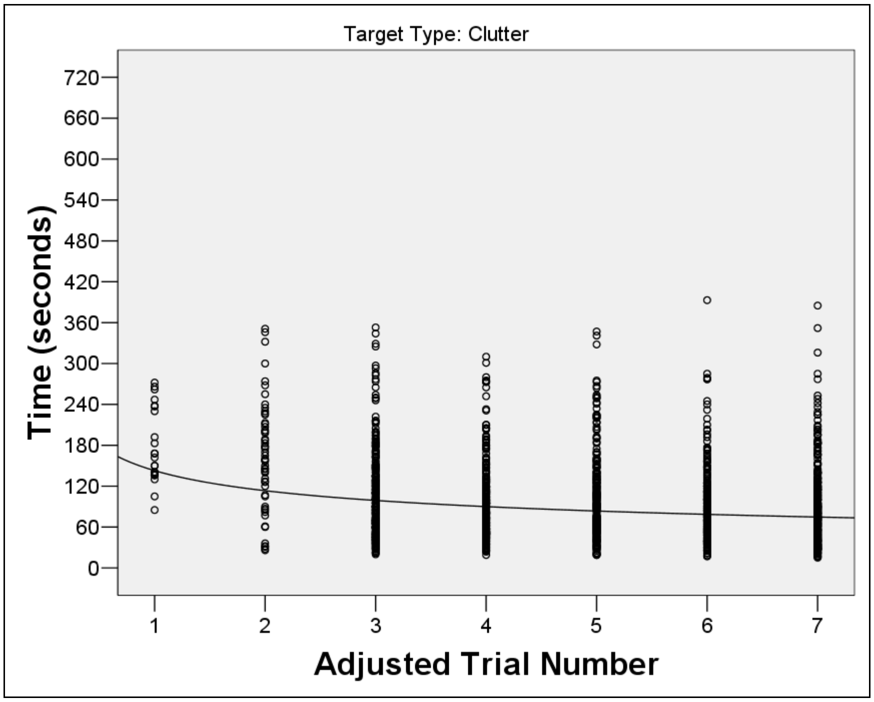


Figure D-8. Total Investigation Time versus Adjusted Trial Number for Clutter Targets.

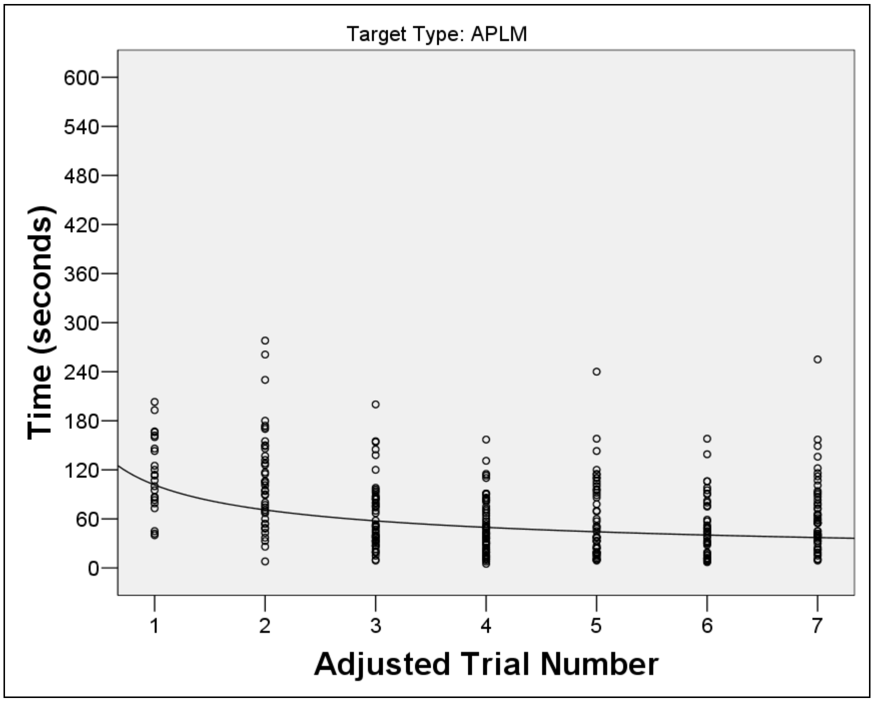


Figure D-9. MD Time per Investigation versus Adjusted Trial Number for APLM Type Mines.

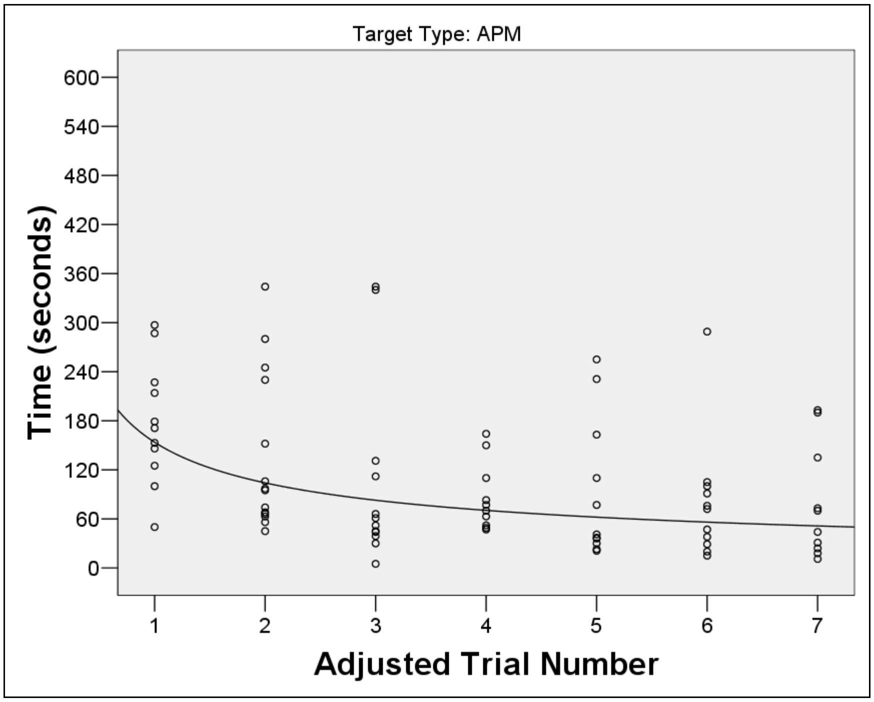


Figure D-10. MD Time per Investigation versus Adjusted Trial Number for APM Type Mines.

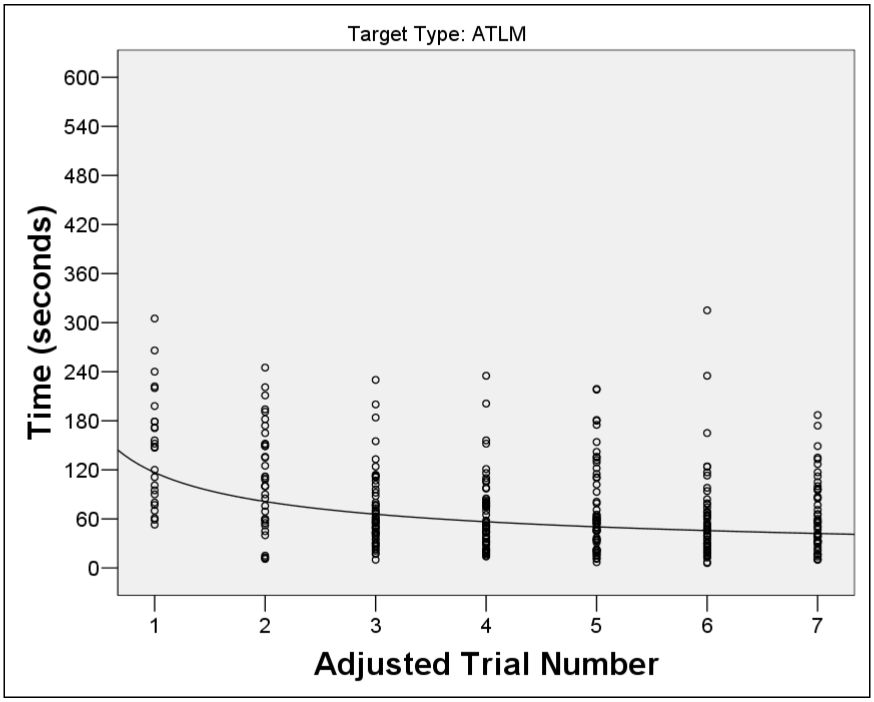


Figure D-11. MD Time per Investigation versus Adjusted Trial Number for ATLM Type Mines.

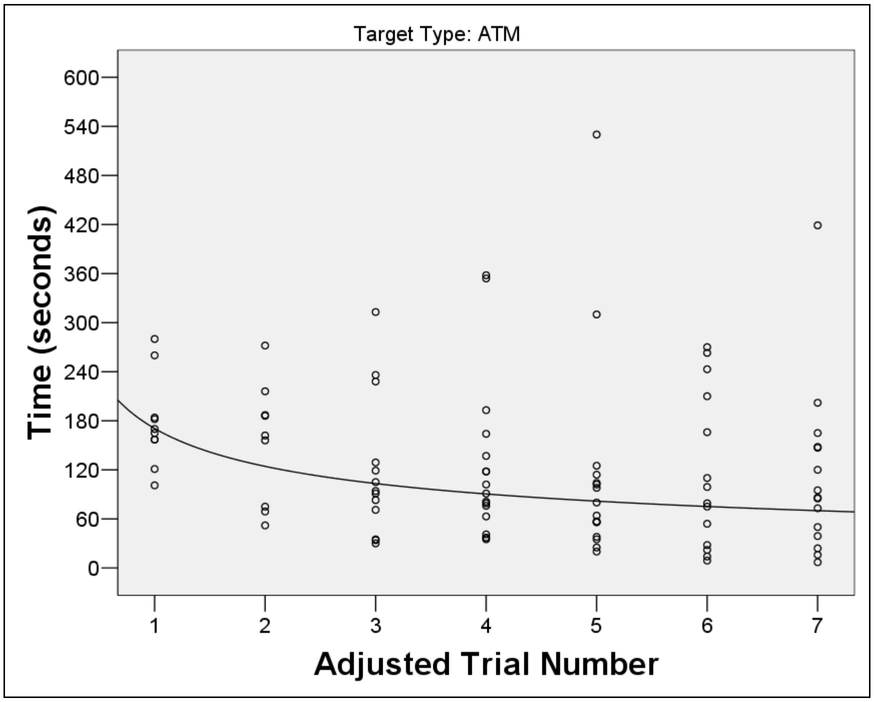


Figure D-12. MD Time per Investigation versus Adjusted Trial Number for ATM Type Mines.

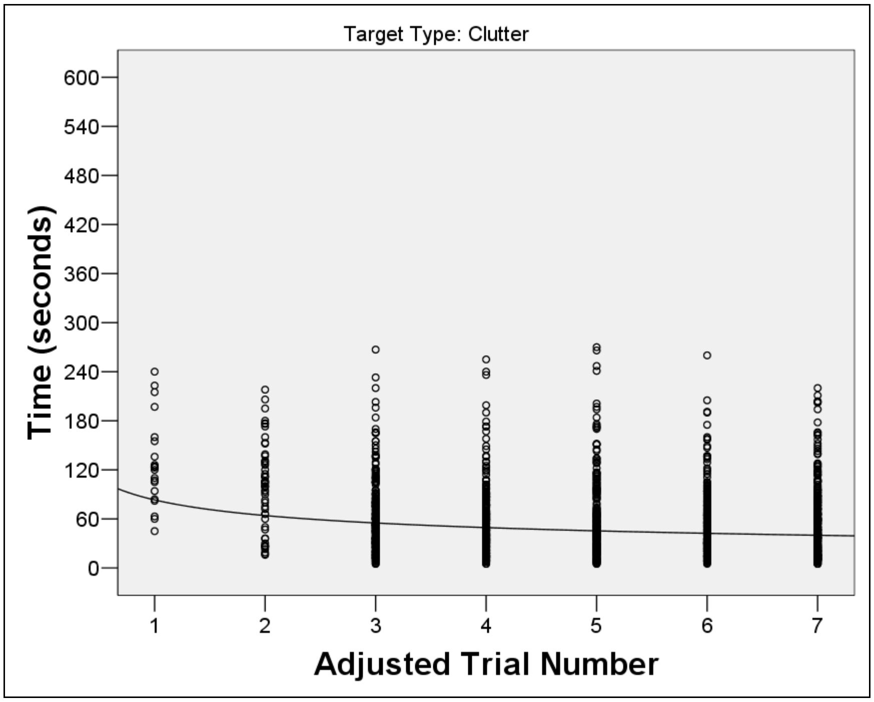


Figure D-13. MD Time per Investigation versus Adjusted Trial Number for Clutter Targets.

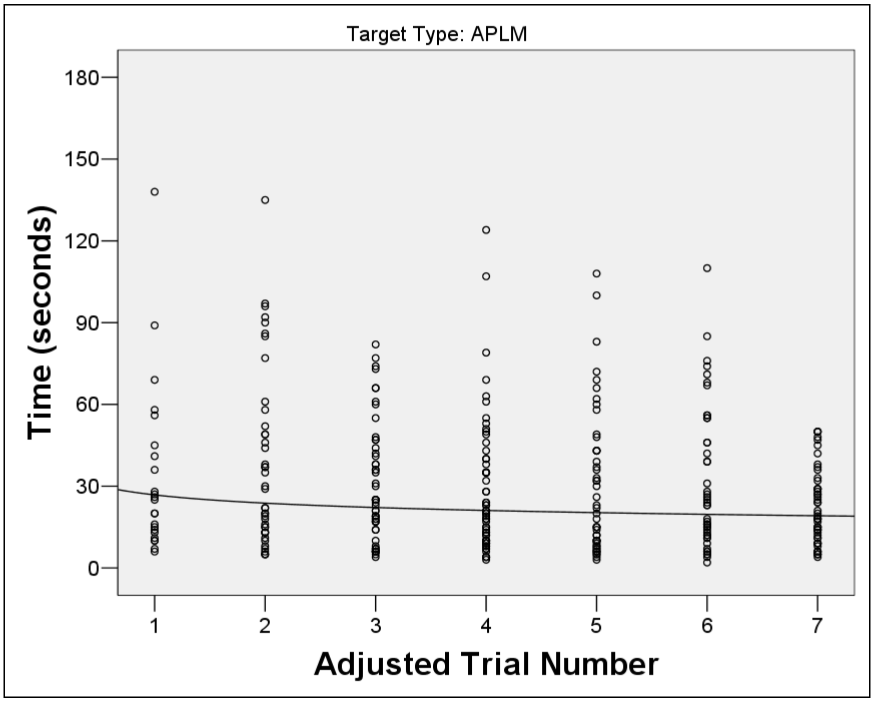


Figure D-14. GPR Time per Investigation versus Adjusted Trial Number for APLM Type Mines.

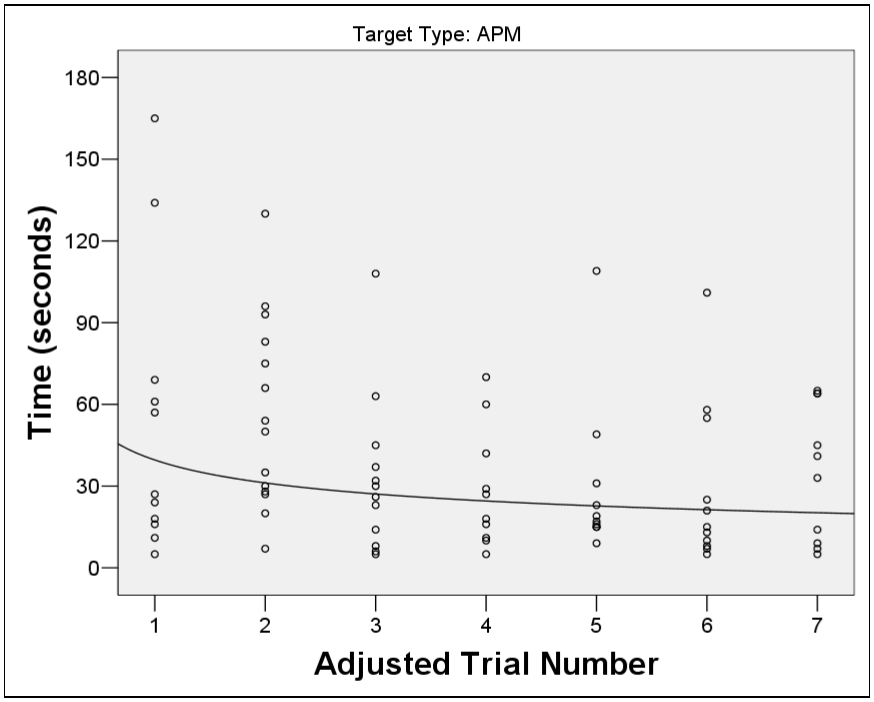


Figure D-15. GPR Time per Investigation versus Adjusted Trial Number for APM Type Mines.

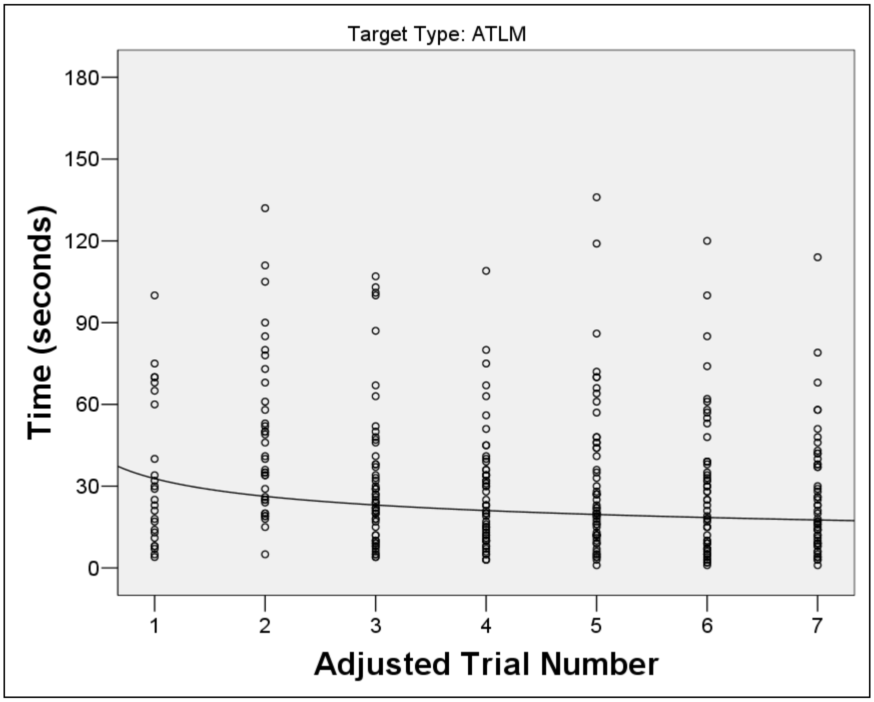


Figure D-16. GPR Time per Investigation versus Adjusted Trial Number for ATLM Type Mines.

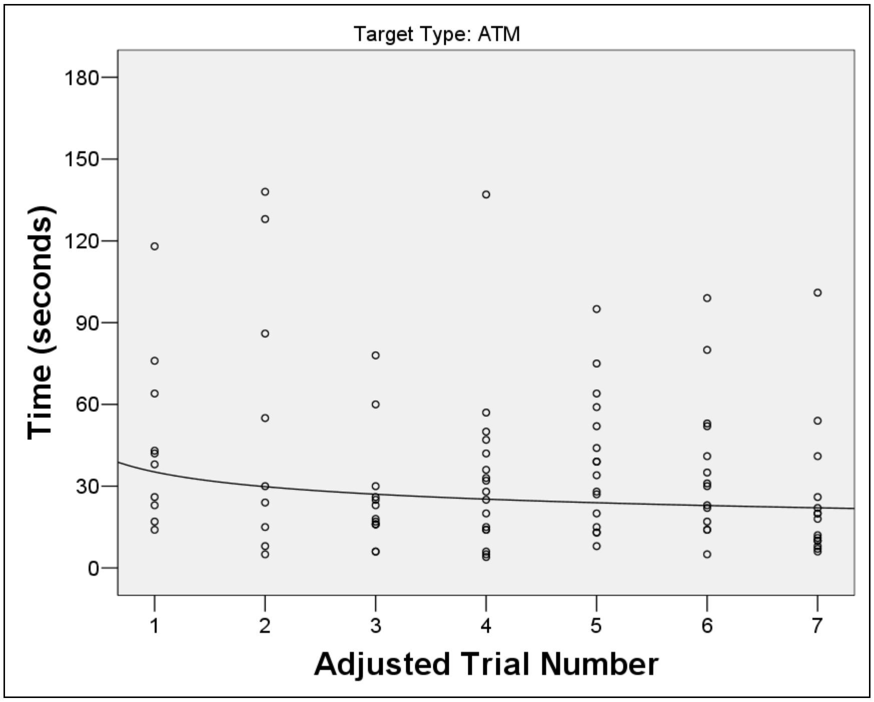


Figure D-17. GPR Time per Investigation versus Adjusted Trial Number for ATM Type Mines.

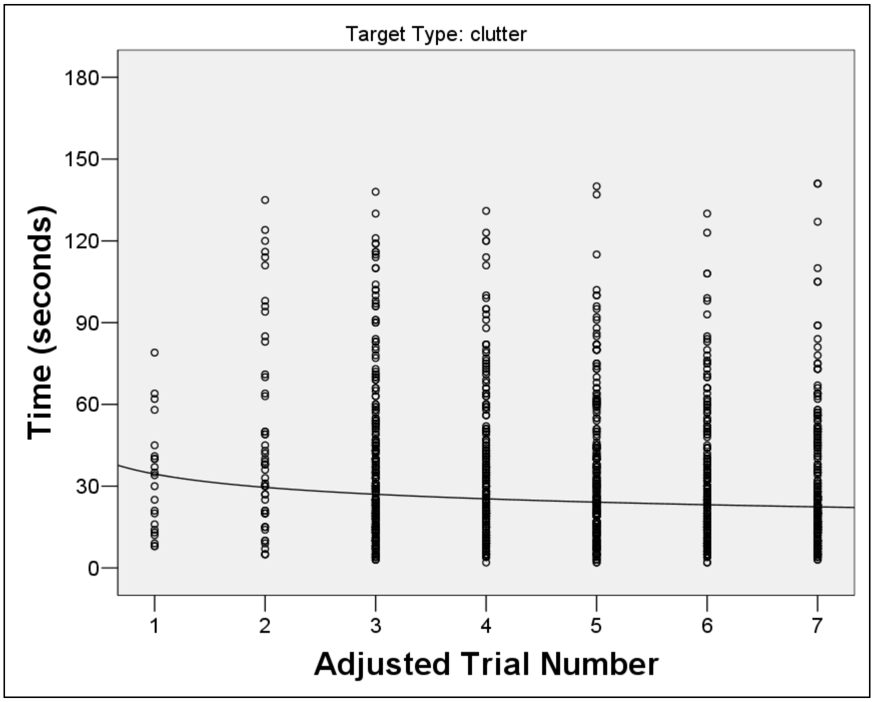


Figure D-18. GPR Time per Investigation versus Adjusted Trial Number for Clutter Targets.

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Appendix E. Rate of Advance

Table E-1. Descriptive statistics: rate of advance by lane.

	Adjusted Trial Number																											
	1				*2*				*3*				*4*				*5*				*6*				*7*			
Lane	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD
A	19	0.28	0.47	0.60	33	0.28	0.32	0.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
B	15	0.30	0.28	0.14	30	0.35	0.46	0.37	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C	9	0.22	0.26	0.17	36	0.49	0.65	0.66	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
D	25	0.44	0.52	0.44	10	0.40	0.55	0.47	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E	23	0.26	0.39	0.27	28	0.31	0.42	0.30	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F	-	-	-	-	-	-	-	-	40	0.30	0.36	0.22	29	0.38	0.54	0.44	20	0.54	0.63	0.42	20	0.50	0.50	0.17	30	0.41	0.38	0.18
G	-	-	-	-	-	-	-	-	8	0.18	0.19	0.06	30	0.48	0.54	0.26	30	0.40	0.45	0.23	20	0.61	0.62	0.37	30	0.29	0.30	0.14
H	-	-	-	-	-	-	-	-	48	0.42	0.54	0.65	30	0.33	0.34	0.16	9	0.12	0.15	0.07	19	0.28	0.32	0.19	-	-	-	-
I	-	-	-	-	-	-	-	-	16	0.19	0.23	0.12	9	0.33	0.27	0.11	10	0.53	0.61	0.36	30	0.41	0.46	0.26	20	0.37	0.43	0.30
J	-	-	-	-	-	-	-	-	10	0.32	0.34	0.12	46	0.47	0.66	0.72	16	0.45	0.47	0.19	20	0.41	0.44	0.19	19	0.21	0.33	0.24
K	-	-	-	-	-	-	-	-	17	0.45	0.75	1.12	20	0.23	0.33	0.28	30	0.27	0.30	0.21	30	0.31	0.41	0.36	30	0.42	0.44	0.22
L	-	-	-	-	-	-	-	-	-	-	-	-	8	0.33	0.44	0.34		-	-	-	-	-	-	-	-	-	-	-
M	-	-	-	-	-	-	-	-	20	0.32	0.41	0.26	-	-	-	-	40	0.40	0.52	0.31	19	0.57	0.68	0.36	-	-	-	-
N	-	-	-	-	-	-	-	-	9	0.52	0.58	0.25	-	-	-	-	13	0.45	0.48	0.23	10	0.53	0.53	0.25	30	0.36	0.45	0.22

Table E-2. Descriptive statistics: rate of advance by participants' test outcome.

	Adjusted Trial Number																											
	1				*2*				*3*				*4*				*5*				*6*				*7*			
Test Outcome	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD	n	Median	Mean	SD
Pass	34	0.29	0.35	0.21	39	0.32	0.40	0.33	53	0.32	0.47	0.69	55	0.31	0.44	0.36	55	0.34	0.41	0.23	59	0.39	0.43	0.29	60	0.28	0.33	0.20
Fail	57	0.30	0.45	0.47	98	0.35	0.50	0.50	115	0.33	0.44	0.45	117	0.39	0.52	0.51	113	0.40	0.48	0.32	109	0.44	0.51	0.30	99	0.41	0.42	0.23

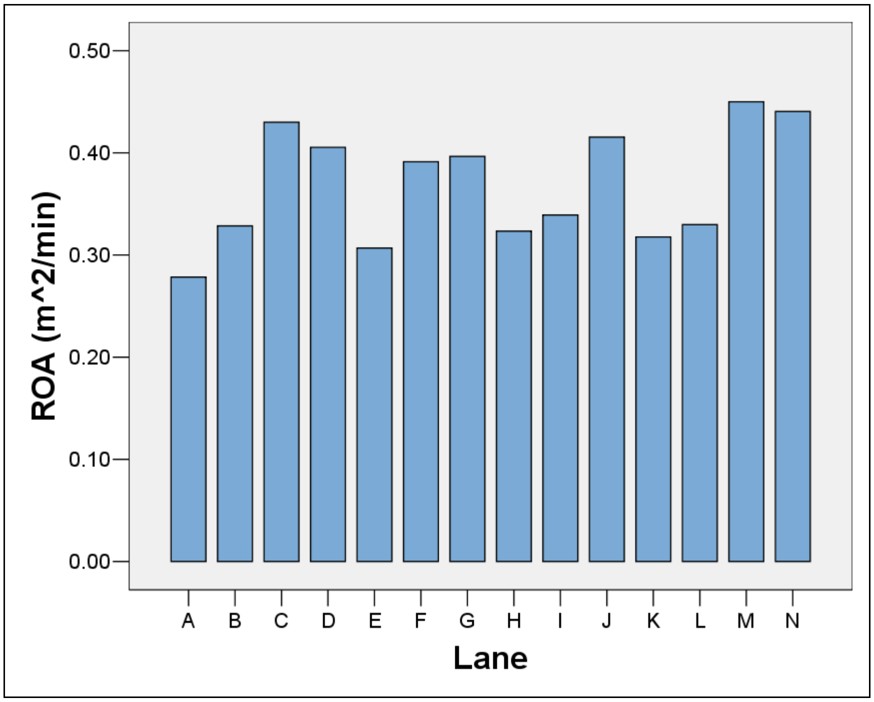

Figure E-1. Median Rate of Advance versus Lane for all Trials.

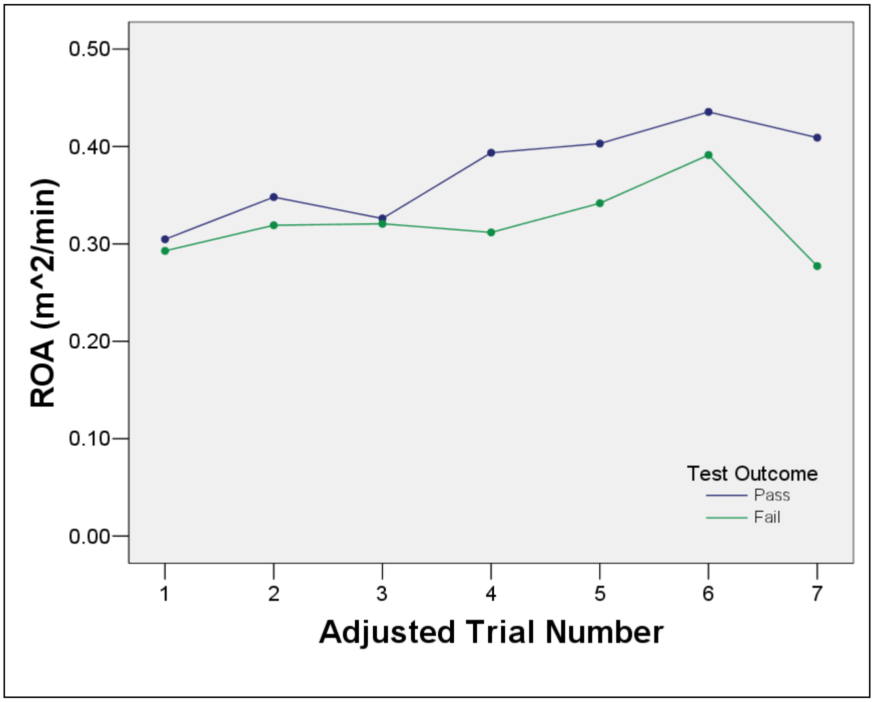

Figure E-2. Median Rate of Advance versus Adjusted Trial Number by Participants' Test Outcome.

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