Handheld Standoff Mine Detection System (HSTAMIDS) Field Evaluation in Thailand

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ABSTRACT

The Humanitarian Demining Research and Development Program of Night Vision and Electronic Sensors Directorate (NVESD), under the direction of the Office of Assistant Secretary of Defense for Special Operations and Low-Intensity Conflict (OASD/SOLIC) and with participation from the International Test and Evaluation Project (ITEP) for Humanitarian Demining, conducted an in-country field evaluation of HSTAMIDS in the region of Humanitarian Demining Unit #1 (HMAU1) in Thailand. Participants included the US Humanitarian Demining Team of NVESD, ITEP personnel, Thailand Mine Action Center (TMAC), HALO Trust organization from Cambodia, and CyTerra Corporation. The primary objectives were to demonstrate the performance of the U.S. Army's latest handheld multisensor mine detector, the AN/PSS-14, in a demining environment in comparison to the performance of the metal detector being used by the local deminers and also to assess the performance of the trained deminers after limited experience and training with the HSTAMIDS.

Keywords: Landmine detection, HSTAMIDS, AN/PSS-14, Multisensor, Humanitarian Demining

1. INTRODUCTION

The AN/PSS-14, or HSTAMIDS, is the U.S. Army's new dual sensor, handheld mine detector that combines an electromagnetic induction sensor, ground penetrating radar (GPR), and sophisticated algorithms to detect landmines while rejecting most clutter. The HSTAMIDS GPR algorithms give it the discrimination capabilities that metal detectors alone do not have. The Humanitarian Demining Research and Development Program of Night Vision and Electronic Sensors Directorate (NVESD), under the direction of the Office of Assistant Secretary of Defense for Special Operations and Low-Intensity Conflict (OASD/SOLIC) and with participation from the International Test and Evaluation Project (ITEP) for Humanitarian Demining, conducted an in-country field evaluation of HSTAMIDS in the region of Humanitarian Demining Unit #1 (HMAU1) in Thailand.

The first objective of this field evaluation was to demonstrate the performance of the HSTAMIDS in a demining scenario. This was accomplished by executing a comparative evaluation between the HSTAMIDS and a metal detector used by the participating demining organization. Both systems were operated by experienced operators. The second objective was to train the demining organization's deminers in the proper use and operation of the HSTAMIDS. The third objective was to assess the performance of the trained deminers after limited experience and training with the HSTAMIDS. Participants in the field evaluation included the US Humanitarian Demining Team of NVESD, ITEP personnel, Thailand Mine Action Center (TMAC), HALO Trust organization from Cambodia, and CyTerra Corporation.

This paper describes the site environment, site plan and setup, training and test procedures, and a compilation of test results along with brief analysis from the HSTAMIDS field evaluation in Thailand, Sep- Dec 2004.

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2. SITE DESCRIPTION

2.1 Location

This evaluation was conducted near the minefields at the Thailand Mine Action Center's (TMAC) Humanitarian Demining Action Unit (HMAU) #1 in Nongyakaeo, Thailand. Nongyakaeo is in the Sra Kaeo Province of Thailand located approximately 260 km east of Bangkok, 40 km north of Aranyaprathet, and 35 km north of Paoy Pet, Cambodia. Active demining continues in the surrounding areas of HMAU #1 and along the Thai-Cambodian border.

2.2 Environment

Thailand has a very humid, tropical climate with the rainy season from June to October and drier weather from November to April. Heavy rains fell on the evaluation area during and immediately after the September/October site setup. This helped the targets to weather-in, but also may have moved or uncovered more metallic clutter. Only one day was delayed because of rain during the November/December evaluation.

2.3 Soil properties

The location of the evaluation site, which was separated into a test and training area, was not chosen based on any particular soil type or characteristic, but rather for its proximity to actual minefields. The western half of the test area appeared to be clay or clay loam[1] with a short layer of weed like vegetation. The eastern half had a high concentration of medium pebbles[1] that made the soil akin to concrete and difficult to dig. The training area was separated from the test area by about 50m. Its soil was similar, but appeared to have a higher percentage of sand and silt because it was in the drainage area of the field.

Soil electrical conductivity and magnetic susceptibility were measured as a means of qualitative comparison between this evaluation and other test events even though sensor performance versus environment and soil properties was not one of the test metrics. Measurements were taken using the Geonics EM38 soil conductivity meter and the Bartington MS-2 magnetic susceptibility meter.[2] Conductivity was measured with the EM38 in both vertical and horizontal orientations. Table 1 contains a summary of the soil electromagnetic properties.

Table 1. Summary of soil electrical conductivity and magnetic susceptibility measured at Thailand test site

	Range of values	Average over site
Conductivity:		
(Vertical)	0 – 128mS/m	65mS/m
(Horizontal)	7 – 129mS/m	58mS/m
Susceptibility	31 – 196 X 10^{-5} SI	65 X 10^{-5} SI

3. RESOURCES

3.1 Training targets

The training target set used in the Thailand evaluation was the same as that used by the US Army for all AN/PSS-14 training. This training set is composed almost entirely of Simulant Mines (SIMs) that simulate characteristics found in many landmines, but that do not represent any specific mine. SIMs are standard test targets that were developed by the US Army Project Manager for Mines, Countermine and Demolitions (now known as PM Close Combat Systems) as part of a four nation (FR, GE, UK, US) test and evaluation working group establishing International Test Operation Procedures (ITOP) for Countermine and Humanitarian Demining equipment.[3]

3.2 Test targets

The test target set was composed of mines that are found in the area of HMAU #1 and mines that are typically used for US Army testing. Each mine was characterized in one of the following four categories based on its metal content: Anti-Tank, Metallic (AT-M); Anti-Tank, Low-Metal (AT-LM); Anti-Personnel, Metallic (AP-M); and Anti-Personnel, Low-Metal (AP-LM). All mines, detonators, and fuses were free from explosive. The main charges were replaced with RTV Silicone Rubber 3110. RTV 3110 closely approximates the dielectric constant and loss tangent of explosives and is the fill used in SIMs.[3] The metal components and characteristics of the mines remained intact. Finally, each mine was inspected for accuracy by a US demolition expert and a well-known mine expert, Colin King, from the UK.

Within the four categories of mines, there were several specific types of mines. To get statistically significant results, the test was designed so that most mine types were encountered 36 times. Sometimes this was not possible because of a limited number of available test targets in the resource base. In the case of mines with very high metal content, it was assumed that all detector operators would find these mines so they were not included in the same quantities as other mines. Table 2 contains the list of test targets and quantities present in the blind test lanes.

Table 2. Test targets and quantities

Mine Category	# of Mine Types	Quantity of Mines	Percentage
AT-M	2	8	7%
AT-LM	4	34	31%
AP-M	5	38	35%
AP-LM	4	30	27%
(TOTAL)	**15**	**110**	

4. SITE PREPARATION AND SETUP

4.1 General site preparations

After the site was chosen, extensive preparations were completed prior to site setup and the evaluation. Brush and vegetation were removed, and the ground was leveled to facilitate water drainage. A vehicle-borne magnet was used to remove significant amounts of surface metallic clutter. Finally, a three-rung, wooden fence was put around the entire area to keep cattle out, and danger signs were posted to discourage people from entering the field.

4.2 Training area setup

The training lanes were setup using the same grid design that is used in US Army AN/PSS-14 training. There were eleven, 1.5m by 15m lanes with one containing a subset of the test targets (lane K). This was used as a practice lane for the trainees to traverse prior to being evaluated in the test area. The other ten lanes contained training targets (lanes A - J). The training lane layout is depicted in Figure 1.

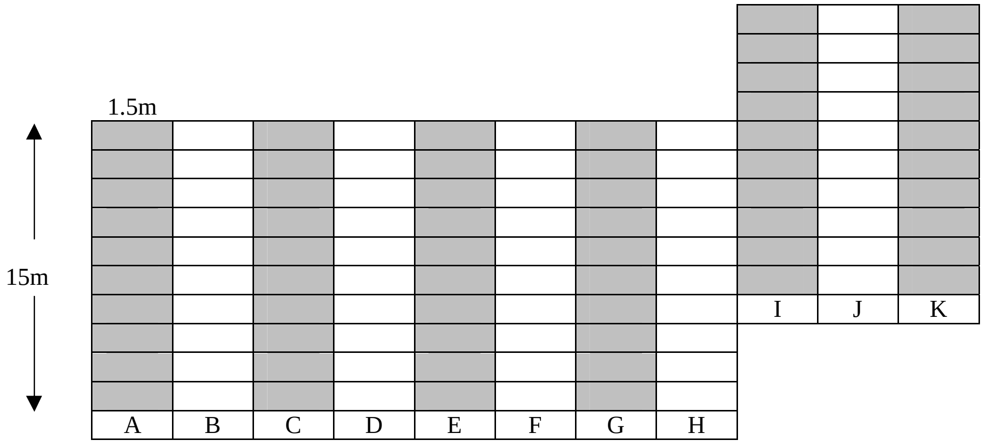

Figure 1. Training lanes A – J and practice lane K. (Not to scale.)

Each lane consisted of ten, 1.5m by 1.5m squares marked out with plastic pegs. A 1.5m by 1.5m grid template was used to locate the position of the targets within each square. The grid template was made of PVC pipe with string equally dividing it into a 10 by 10 matrix. Its horizontal axis was denoted with letters (A to J), and the vertical axis was labeled with numbers (1 to 10). One target was buried per square in the lane. The grid template was laid over the plastic pegs and the target coordinates were noted.

Prior to burial, the immediate area around each target was inspected with a metal detector to insure that it was free from metallic clutter. All targets in the ten training lanes were buried to the depths specified by the training manual. The test targets in the practice lane were buried at the same depths as those found in the test area.

4.3 Test site setup

The test area consisted of ten, 1m by 25m blind lanes and one, 1m by 30m calibration lane. The test field layout is shown in Figure 2. Each of the blind lanes was 5m away from any other lane. The corners of each were marked with non-metallic pegs and had string running between them along the edge of the lane. There were two wooden stakes, one for each end of the lane. Each stake had both the lane number and directional designation for the end of the lane closest to it (Lane 1 East, Lane 1 West, etc).

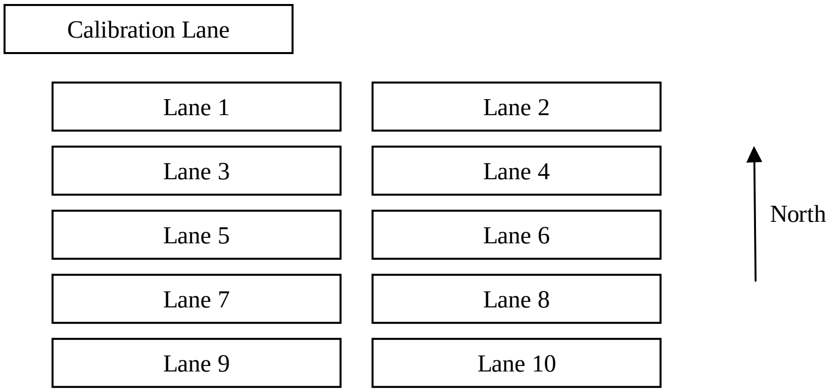

Figure 2. Test field made up of ten blind lanes and one calibration lane. (Not to scale.)

After the lane corners were laid out, metal detectors were used to locate all indigenous metallic clutter in the lanes. The test targets were then arranged throughout the lane so that they had sufficient separation between them and the clutter. This was done to insure that low metal mines especially were not placed in proximity to clutter signals that would give the false impression of detection. No indigenous clutter was removed from the lanes after being located by the metal detectors.

Varying the burial depth of the mines was discussed during test planning, and it was decided with the ITEP members that depth should be held constant to limit variables and increase the statistical significance of the test. The mine depths were agreed upon and established. All antipersonnel mines were buried 5cm deep, and all antitank mines were buried 10cm deep (measured from the top of the mine).

In addition to mines, characterized clutter was also placed in the lanes to better understand sensor performance. The clutter consisted of mine shrapnel, fragments of miscellaneous detonated mines, and pieces of mine safety clips.

After the indigenous clutter was located and all targets were emplaced, the entire site was surveyed with a laser surveying system to establish the ground truth containing lane corner points, mines, indigenous clutter, and characterized clutter. Fixed concrete reference monuments were placed around the test field for calibration and orientation of the surveying equipment.

At the end of site setup, all lanes were raked so that visual clues were removed. The site then remained untouched for five weeks prior to the evaluation to allow time for everything to weather-in.

5. METHODOLOGY

5.1 Overview

Testing was split into two portions. During the first half of testing, two experienced HSTAMIDS operators from the US and two experienced metal detector operators from TMAC tested on the ten blind lanes. This took place concurrently with the HSTAMIDS training described in the previous section. During the second half of the testing, the newly trained HSTAMIDS operators from TMAC and HALO Trust tested on the same ten blind lanes. Thus, there were three categories of operators: Metal Detector, Experienced HSTAMIDS, and HSTAMIDS Trainees.

The objective of the first half of the test was not to compare the HSTAMIDS to the performance of all metal detectors. Rather, to establish a baseline performance with the local demining technology and a baseline performance of the HSTAMIDS in the hands of experienced operators, both as a means of comparison with the performance of the newly trained HSTAMIDS operators. The TMAC deminers tested with the same metal detector, the Vallon VMH-1, which they use during demining operations at HMAU #1.

5.2 Training

Five deminers—two from TMAC and three from HALO Trust, Cambodia—were trained during this evaluation by the same US contractor that provides AN/PSS-14 training to the US Army and Marine Corps. All training was done through interpreters. This added an additional challenge because the interpreters had no experience in demining practices or technology. Maintenance and troubleshooting techniques were not covered during this training interval to allow for more hands-on training time.

The primary focus of the deminer training was HSTAMIDS proficiency and target detection. As in all HSTAMIDS training, only basic clutter rejection was taught. This is a skill that becomes enhanced with continued experience using the HSTAMIDS.

The trainers had the HSTAMIDS trainees go over the training lanes as if they were actual minefields. The trainees used non-metallic markers (poker chips) to mark all detections. The trainers then used the grid template to score the trainees by comparing the coordinates of the poker chips to the coordinates of the ground truth and noting which targets were found and which were missed. Proper sweep speed, height, and coverage were taught and then carefully observed.

To prepare the trainees for the blind test when they would be encountering inert mines instead of SIMs, the trainers had them go over the practice lane in the training area and the calibration lane in the test area. This preparation was limited to only a few hours at the end of regular training.

5.2 Test procedures

During testing, the operators went down each lane until a detection was encountered. Non-metallic poker chips were then used to mark detections. Both the metal detector operators and HSTAMIDS operators marked every thing they detected. The metal detector operators marked every signal they encountered as a suspected mine according to worldwide standard operating procedures. The HSTAMIDS operators made a determination whether the target was a mine or clutter, and marked each detection with one of two colors of chips. Red chips for mines and white for clutter.

Data collectors assisted the operators in placing a chip on each detection and kept track of how many had been placed. Once a lane was completed, a laser surveying system was used to record the location of all chips. This data formed an alarm file for that particular lane run. Each alarm file was input into Countermine Test Management Software (CTMS) to compare operator detections versus the original ground truth for that lane. CTMS was used to provide near real-time test statistics for each operator and verify surveying results before any chips were removed from the test lanes.

To acquire a statistically significant number of mine encounters, each category of operator had to cover the test lanes a total of four times. The two experienced HSTAMIDS operators and two metal detector operators traversed each lane twice, once in each direction. No operator was to go over a lane more than once in the same day. For the five HSTAMIDS trainees the lanes were divided up so that they covered the site four times as a whole, but no individual deminer went over a test lane more than once.

5.3 Test metrics

The HSTAMIDS Thailand test results were scored according to the following description of detections and false alarms. Operators were credited with a detection if their chip was within a certain distance, R_{halo}, of the edge of a target. Any chip outside of this distance was considered a false alarm. If more than one chip fell within the detection halo, the operator was only credited with a single detection. The value of R_{halo} was 15cm during this evaluation as in all US Army testing of the HSTAMIDS. Figure 3 illustrates the possible outcomes for detection and false alarms.

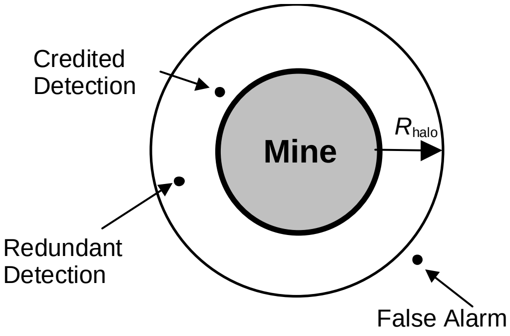

Figure 3. Pictorial definition of detections and false alarms.[4]

The detection probability (P_d) and false alarm rate (FAR) are the two primary measures derived from this type of test. The detection probability is the fraction of the encountered mines that are detected:

$$P_d = \frac{\text{\# of mines detected}}{\text{\# of mines encountered}} \tag{1}$$

The false-alarm rate has been commonly defined in the test community as the number of false alarms per square meter of test lane:

$$FAR = \frac{\text{\# of false alarms}}{\text{total lane area}} . \qquad (2)$$

The probability of false positive (P_{fp}) is another measure that can be obtained. For this test, the probability of false positive is defined as the fraction of characterized clutter that is detected:

$$P_{fp} = \frac{\text{\# of characterized clutter detected}}{\text{\# of characterized clutter encountered}} \qquad (3)$$

6. TEST RESULTS

6.1 General test information

These are the test results for the three categories of operators: metal detector, experienced HSTAMIDS, and TMAC and HALO Trust HSTAMIDS trainees. Table 3 gives some general information for each operator category. It contains the number of lanes that each operator covered, total area covered, number of mines encountered, and number of emplaced, characterized clutter encountered. Table 4 contains the number of mine encounters per mine category. (*During the test, one metal detector operator did an extra lane. This is why the numbers are not identical in Table 3 or in Table 4 for all three operator categories.)

Table 3. General test information for each operator category

	# of Lanes	**Area Covered (m^2)**	**# of Mines Encountered**	**# of Emplaced Clutter Encountered**
Metal Detector*	41	1023	450	488
Experienced HSTAMIDS	40	998	440	472
HSTAMIDS Trainees	40	998	440	472

Table 4. Number of mine encounters per mine category

	AT-M Encounters	**AT-LM Encounters**	**AP-M Encounters**	**AP-LM Encounters**
Metal Detector*	33	141	155	121
Experienced HSTAMIDS	32	136	152	120
HSTAMIDS Trainees	32	136	152	120

6.2 Results for metal detector operators

Table 5 shows the false alarm rate, probability of detection, and probability of false positive for the metal detector operators. The total false alarm rate includes indigenous and characterized clutter.

Table 5. Test results for the Vallon VMH-1 metal detector operators

	FAR **(m^{-2})**	
	avg.	90% CL range
Total	1.023	1.078 - 0.968
Indigenous	0.598	0.641 - 0.555

	P_{fp}	
	avg.	90% CL range
Characterized Clutter	0.82	0.85 - 0.79

	P_d	
	avg.	90% CL range
AT-M	1.00	1 - 0.91
AP-M	0.98	0.99 - 0.95
AT-LM	0.29	0.36 - 0.23
AP-LM	0.96	0.98 - 0.92

The overall detection rate for the metal detector operators was 76%. They did well with the AT-M and both categories of AP mine, but the metal detector sensitivity to low metallic anti-tank mines was poor. The probability of false positives is essentially a detection probability for clutter. The results show that only 82% of the characterized clutter that was added to the lanes was detected by the metal detector operators.

6.3 Results for experienced HSTAMIDS operators

The following tables provide the results for the experienced HSTAMIDS operators. The results are split into two categories: Probability of Alert and Probability of Detection with Correct Classification. The probability of alert, shown in Table 6-A, is based on the combination of what the experienced HSTAMIDS operators identified as mines plus what they identified as clutter. These results effectively show the total amount of what was detected before any discrimination. The functionality of the probability of alert for the HSTAMIDS is the same as the probability of detection for the metal detector since the metal detector cannot do any discrimination.

Table 6-A. *Probability of Alert* (mine and clutter declarations) for the experienced HSTAMIDS operators

	FAR **(m^{-2})**	
	avg.	90% CL range
Total	0.884	0.935 - 0.832
Indigenous	0.417	0.453 - 0.381

	P_{fp}	
	avg.	90% CL range
Characterized Clutter	0.99	1 - 0.98

	P_d	
	avg.	90% CL range
AT-M	1.00	1 - 0.91
AP-M	1.00	1 - 0.98
AT-LM	1.00	1 - 0.98
AP-LM	0.99	1 - 0.96

The overall probability of alert was 99.7% for the experienced HSTAMIDS operators. One mine out of 440 encounters was missed. (There was a mine declaration right beside this target, but it was 2cm outside the detection halo and thus counted as a false alarm.) These results are significantly better than the metal detector operators' detection rate of 76%. Nearly all of the characterized clutter was also detected as shown by the P_{fp}.

The probability of detection with correct classification, shown in Table 6-B, is based on what the experienced HSTAMIDS operators identified as mines. These results show the discrimination that can be achieved with the HSTAMIDS especially when comparing the false alarm rate and probability of false positive to the results in Table 6-A.

Table 6-B. *Probability of Detection with Correct Classification* (mine declarations only) for the experienced HSTAMIDS operators

	FAR (m^{-2})	
	avg.	90% CL range
Total	0.201	0.225 - 0.176
Indigenous	0.124	0.144 - 0.104

	P_{fp}	
	avg.	90% CL range
Characterized Clutter	0.19	0.27 - 0.12

	P_d	
	avg.	90% CL range
AT-M	1.00	1 - 0.91
AP-M	0.95	0.98 - 0.92
AT-LM	0.93	0.97 - 0.89
AP-LM	0.93	0.96 - 0.87

The experienced HSTAMIDS operators had a high probability of detection with correct classification (94% overall) while significantly reducing the false alarm rate. They were able to correctly classify 81% of the emplaced clutter as clutter. Looking at the total false alarm rate, which includes all of the indigenous clutter that remained in the lanes, the experienced HSTAMIDS operators achieved 77% overall clutter rejection.

6.4 Results for HSTAMIDS trainees

The following tables provide the results for the TMAC and HALO Trust HSTAMIDS trainees. Table 7-A shows the probability of alert results before discrimination.

Table 7-A. *Probability of Alert* (mine and clutter declarations) for the HSTAMIDS trainees

	FAR (m^{-2})	
	avg.	90% CL range
Total	0.782	0.830 - 0.733
Indigenous	0.354	0.387 - 0.320

	P_{fp}	
	avg.	90% CL range
Characterized Clutter	0.91	0.93 - 0.88

	P_d	
	avg.	90% CL range
AT-M	1.00	1 - 0.91
AP-M	1.00	1 - 0.98
AT-LM	0.97	0.99 - 0.93
AP-LM	0.97	0.99 - 0.93

Just as the experienced operators, the trainees outperformed the metal detector operators at finding mines. The overall probability of alert was 98% for the HSTAMIDS trainees. They also detected most of the characterized clutter.

Table 7-B contains the probability of detection with correct classification after the determination was made whether the target was mine or clutter. This was a unique experience for the trainees since deminers in the field cannot make this decision with the equipment currently available to them.

Table 7-B. *Probability of Detection with Correct Classification* (mine declarations only) for the HSTAMIDS trainees

	***FAR* (m^{-2})**	
	avg.	90% CL range
Total	0.254	0.282 - 0.227
Indigenous	0.128	0.149 - 0.108

	P_{fp}	
	avg.	90% CL range
Characterized Clutter	0.30	0.34 - 0.26

	P_d	
	avg.	90% CL range
AT-M	1.00	1 - 0.91
AP-M	0.95	0.98 - 0.91
AT-LM	0.78	0.84 - 0.71
AP-LM	0.80	0.86 - 0.73

The trainees did not do quite as well at correctly identifying the mines as the experienced operators did, but their clutter rejection performance was very good considering their lack of experience. The overall probability of detection with correct classification was 86% for the trainees, and they reduced the total FAR by about 68%. Their clutter rejection results were nearly as good as the experienced operators clutter rejection rate of 77/%.

Language barriers, lack of experience in test scenarios, and limited HSTAMIDS experience were all factors that contributed to the trainees' lower performance when compared to the experienced operators' results. However, they still showed an improvement over the performance of the metal detector operators in overall Pd and FAR, even in the discrimination mode.

6.5 Time comparison

During a one-month period in 2003 at HMAU #1, 7 AP mines and approximately 4,500 metal fragments were removed from the ground in a 11,872 square meter area. TMAC data shows that the average time to determine whether a detected signal is a mine or a metal fragment is 20 to 30 minutes. In Table 8, the lower estimate of 20 minutes is used to show the potential time savings that the HSTAMIDS would bring to TMAC's demining operation.

The time savings was calculated using the difference between metal detector and HSTAMIDS total time. Total time equaled time scanning plus time digging. The scan rate was calculated for each operator category by keeping track of how long it took the operators to finish each lane.

Table 8. Clutter discrimination and potential time savings (Calculated with TMAC records showing 20 minutes to determine mine or clutter)

	# Clutter Detected	**# Clutter Called Mine**	**Time Scanning**	**Time Digging Suspected Mines (hours)**	**Time Savings (hours)**
Metal Detector	956	956	17 hours @ 1.01 min/m^2	319	0
Experienced HSTAMIDS	806	183	21 hours @ 1.25 min/m^2	61	254
HSTAMIDS Trainees	713	232	38 hours @ 2.29 min/m^2	77	221

In the hands of experienced operators, the HSTAMIDS showed a time savings of over 250 man-hours while maintaining an overall probability of detection of 94%.

7. CONCLUSIONS

The objectives of the HSTAMIDS field evaluation in Thailand were successfully accomplished. The performance of the HSTAMIDS was demonstrated, local deminers were trained in its use, and the deminers' initial capabilities with the system were evaluated.

This test was challenging in several respects. The mines were buried at deeper depths than what is typically found in real-world conditions. Clutter density was much greater than most metal detector tests that try to minimize metallic clutter in the lanes. Finally, a test with 15 different mines, many of which are the most challenging in the world to detect, makes it very difficult for operators to determine mine versus clutter with such a wide variety of potential targets.

Despite the challenges, the HSTAMIDS was clearly better than the metal detector in finding the mines. The experienced HSTAMIDS operators found all of the mines but one while the metal detector operators missed over 100 out of 440 mines. When scoring what the experienced HSTAMIDS operators identified as mines, they rejected 77% of the false alarms with an overall detection rate of 94%. Even with limited experience, the trainees did almost as well as the experienced HSTAMIDS operators, rejecting the majority of the clutter as they correctly classified 86% of the mines. When considering only the types of mines that are found at HMAU#1, the HSTAMIDS shows the ability to detect 100% while providing significant clutter rejection and time savings. Thus the HSTAMIDS could provide real benefit to the demining operations in this area of the world.

The Humanitarian Demining R&D team continues to focus on projects to improve the discrimination performance of the HSTAMIDS—projects to help make the operator's decision easier so that he can maintain detections while reducing false alarms. Continuing work on algorithm development and hardware modifications is showing good results and promise of further improvements for the HSTAMIDS.

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