

A STUDY OF MANUAL MINE CLEARANCE

3. Operational Systems in Manual Mine Clearance: case studies and experimental trials



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The **Geneva International Centre for Humanitarian Demining (GICHD)** supports the efforts of the international community in reducing the impact of mines and unexploded ordnance (UXO). The Centre provides operational assistance, is active in research and supports the implementation of the Anti-Personnel Mine Ban Convention.

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Contents

Summary	1
Introduction	3
Case study 1	
Sri Lanka: Norwegian People's Aid and Danish Demining Group	5
Local demining organisations and controls	5
Demining procedure: The Rake Excavation and Detection System (REDS)	6
Quality assurance and quality control of the REDS system	8
DDG variations to the NPA REDS	9
Use of water	9
Conclusions from the Sri Lanka case study	10
Case study 2	
Iraq: Mines Advisory Group	11
MAG's expansion	12
Manual mine clearance procedures	13
Post-clearance area reduction	15
Deminers and battle area clearance	17
Conclusions from the Iraq case study	18
Case study 3	
Cambodia: Cambodian Mine Action Centre	19
Manual mine clearance procedures	20
Mechanical assistance	22
Post-clearance area reduction	23
Quality assurance and quality control	23
Efficiency plans and trials	23
Conclusions from the Cambodia case study	24

Case study 4	
Sudan: Norwegian People's Aid	25
Local demining administration	25
Quality assurance and quality control	26
Conclusions from the Sudan case study	26
Trial 1	
Comparing alternative manual drills in Sudan	27
Objectives of the trial	27
Drills	28
Data recording and sampling	29
Results	30
Discussion	34
Trial 2	
Comparing manual clearance systems	37
Introduction	37
Methods	39
Data recorded	40
Rate of progress	41
Safety	42
General patterns in the results	42
Prodding	43
Discussion	44
Conclusions and recommendations	45
Annexes	
1. Interpreting statistical analyses	49
2. Hybrid and Crab drills trialled in south Sudan	53
Bibliography	61
Glossary of acronyms	61

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Cover: British Army mine clearance of a road in 1945, "Soldiers using their rifles and bayonets to detect mines. This is called the 'prodding' method and the ground is prodded with the bayonets to clear a lane the width of six or seven men. White tapes are used to mark the boundary as it is cleared"; photograph courtesy of the Imperial War Museum, London ©Crown Copyright, negative number H 29725. All other photos ©"AVS consultants Limited".

Summary

This Section reports on the results of a study of operational systems in manual mine clearance. As part of the study, descriptive field studies of manual mine clearance methods were conducted in 2004 in Iraq (July/August), Sri Lanka (September), Cambodia (September) and in 2005 in Sudan (April and June). Management of operations was studied and the work of individual deminers was observed in detail.

The study found that many mine clearance programmes have developed innovative changes in techniques, some of which are adopted only informally. Thus, several of the procedures observed during the four case studies conducted for this study fell outside the perceived or stated requirements of national and international standards: this led a number of operators to call for a revision of the standards to incorporate the flexibility required by an evolving discipline.

Few groups provided all the safety equipment or worked strictly to the safety regimes required by the International Mine Action Standards (IMAS) or in many cases, the National Mine Action Standards (NMAS). Furthermore, no mine clearance group studied was working in complete compliance with their own written standing operating procedures (SOPs) and several were working in a manner that conflicted directly with them. Reasons given included a lack of time and/or relevant writing skills to introduce the changes, internal decisions to accept the changes and implement them immediately, and delays in getting SOP amendments approved by national mine action authorities.

A series of comparative trials of manual mine clearance systems was undertaken in southern Mozambique and South Sudan. All systems tested, except prodding from the surface of the ground, were effective at locating mines, although some deeply buried mines were missed. In a heavily fragmented area, the most efficient method of clearance involved the use of small powerful magnets as part of the system.

When a metal detector was not used, the method of clearance that optimised productivity, quality and safety involved an ordinary garden spade used as a horizontal “excavator” combined with conventional investigation tools. The “REDS” system (a

garden rake combined with excavation tools) was excellent for confidence and quality assurance/quality control requirements but was very slow.

When working a lane alongside a safe lane, the deminer had more flexibility of movement, and a number of efficiency improvements were obtained relative to the standard manual demining lane. This allows for the development of new and more efficient drills.

During the trials of different manual clearance systems, the rates achieved by the deminers varied from 1.6 square metres to 17.4 square metres in four working hours.

Prodding was most likely to involve an accident to the deminer. Prodding at 30 degrees to the ground achieved an average clearance depth of less than four centimetres, and all the mine surrogates that were located during the trial had been damaged by prodding on to their pressure plate, raising concerns about safety. After prodding, the method most likely to involve a deminer accident was area excavation using an *enxada* (a mattock), a finding that coincides with an analysis of available accident records in the Database of Demining Accidents (DDAS).¹

Six broad conclusions are drawn from the study, which are presented in summary form at the end of the Section.

1. UNMAS/GICHD Database of Demining Accidents, DDAS, 2005.

Introduction

There is considerable scope for improving productivity and efficiency within most mine clearance programmes. For example, drills could be streamlined in order to minimise time wasting within the drill and/or new types of equipment could be used. Many drills appear to be used because of historical commitment from earlier experiences, and little or no attempt is made to adapt the drill to local conditions in new deployment situations.

The reasons are sensible. Demining is a potentially hazardous occupation and caution dictates that deminers will prefer to continue using a drill that has been used safely in the past. Implementation of a new drill or item of equipment may require trials and retraining, both of which have implications for productivity in the short term. Finally, field managers of demining programmes may have neither the skills to run convincing trials, nor the authority to make changes even if a new concept proves satisfactory.

Despite this, innovative procedures *are* being used by demining organisations. Unfortunately, even if these procedures were the subject of careful trials during the implementation phase, they tend to be poorly reported. Thus they remain unknown to the wider community.

This section examines manual demining techniques with three general objectives in mind:

- to provide descriptions of a range of demining drills;
- to describe innovative procedures being used by organisations; and
- to assess and compare the efficiency of different drills under identical conditions.

In general, the assessments are made with reference to productivity, efficiency and safety. It is well known that manual demining drills are strongly affected by local conditions of vegetation, soil type and environmental conditions (especially rain). Manual demining in soft ground progresses faster and more safely than in hard ground. Vegetation clearance can take up a major proportion of the time of a manual deminer. Clearance of vegetation using machines introduces both costs and benefits that depend on the design of the machine and local clearance requirements.

Risk assessment can lead to actions in one place that would be inappropriate in another place. The SOP can be either obstructive or supportive of safety and productivity, and updating the SOP can be a difficult and challenging process. Thus any assessment of demining drills must be placed into context if the drills are to be properly understood, and some constraints cannot be identified or described during a short visit by an external agency.

It is a challenge for any demining organisation to allow the type of research done for this study. Some comments and descriptions in this study could be interpreted as critical by some, or might be used in a biased way by others. This is not the intent of the GICHD and is inappropriate in any context. The broad objective of this study is to inform field personnel of the ideas and procedures being used elsewhere in the demining community, with some assessment of relative costs and benefits. The methodology used is objective, and could and should be widely used. These studies provide a blueprint for similar studies conducted by others, either as an internal exercise, or as part of cross-fertilisation between agencies. The GICHD encourages and supports such activities.

The study was conducted as:

- a series of four case studies of demining drills and concepts; and
- a series of trials of different drills, some of which included innovative equipment.

In each case study, demining procedures are broken into their component parts in order to provide a fine-scale analysis of the anatomy of the drill. The case studies are primarily qualitative, in that systems are described in context. The trials, on the other hand, are primarily quantitative, in that different drills have been tested under identical conditions. Some of the procedures seen in the case studies have been applied in the trials, and some of the trial procedures were entirely new.

Case study 1

Sri Lanka: Norwegian People's Aid and Danish Demining Group

Sri Lanka is divided between government-controlled areas and areas controlled by the Liberation Tigers of Tamil Eelam (LTTE). After some 20 years of conflict, the fighting appears to have reached a stalemate, with both sides consolidating control in their areas and controlling the passage between them with frequent sandbagged “checkpoints”.

The most common anti-personnel blast mines found in Sri Lanka are the P4 Mk1 & 2, Rangan (Jony) 99, Chinese Type 72A, VS-50, and Jony 95. Anti-tank mines are relatively rare, but when found are usually M15 or Amman 2000 blast mines. Improvised concrete-cased anti-tank mines have also been discovered. Three of the most common mines are classed as “minimum metal” mines and can be very hard to locate with a metal detector.

Generally, mines were only destroyed *in situ* if damaged and their condition gave rise to concern. The two clearance organisations observed dealt with the discovered mines in different ways. The Danish Demining Group (DDG) moved mines without disarming them, transporting them in specially made boxes for later mass destruction. The Tamil Relief Organisation's (TRO) Humanitarian Demining Unit (HDU) working with the assistance of Norwegian People's Aid (NPA) routinely removed the detonator/booster from mines and stored them in the minefield for later mass destruction.

Sri Lanka was visited for the purposes of this study for one week in September 2004.

Local demining organisations and controls

The National Steering Committee for Mine Action (NSCMA) is a national coordination mechanism advised and supported financially by the United Nations Development Programme (UNDP), to which all groups report (including those operating in LTTE areas). The strategy for mine action in Sri Lanka is focused on resettlement and reconstruction.

The Sri Lankan army under the US commercial company RONCO's guidance now uses metal detectors in a disciplined drill designed to comply with the IMAS, and is

complemented by the use of dogs and small flails. When DDG deployed into Sri Lanka at the beginning of 2003, they purchased metal detectors, but had not used them in general demining tasks at the time of the case study research (and have since decided to dispose of them). They, and others, adapted the HDU/NPA raking method (described briefly below) and were using it exclusively.

Demining in Sri Lanka began as an activity implemented by both the Sri Lankan Army and the LTTE. They had very limited funds and extensive human resources, and therefore developed the “raking technique”. In LTTE areas the method originally involved no marking, safety distance constraints or personal protective equipment (PPE). Government forces wore PPE, but otherwise similarly paid little attention to safety distances and marking. A number of disabling accidents and a lack of quality assurance (QA) left concern about the thoroughness of the clearance conducted.

In LTTE-controlled areas, the LTTE have established the HDU, which is supported by various foreign donors and gets both donor support and technical assistance from NPA, Mines Advisory Group (MAG), the Swiss Foundation for Mine Action (FSD) and Danish Demining Group (DDG). The HDU, with the guidance of NPA, developed the raking system described in this report as the REDS system.

Demining procedure: The Rake Excavation and Detection System (REDS)

The Rake Excavation and Detection System (REDS) relies on the use of a “heavy” and a “light” rake. While the terms “heavy” and “light” describe their weight, they do not describe their function. The heavy (Harrow) rake is used to break up the ground and the light (Brush) rake is used to move the loosened spoil back as the excavation advances. While in some cases the soil structure is loose and a harrow-rake may not be needed, the Brush-rake is always required to move loose soil back from the front of the excavation. It can also be used to maintain a channel at the sides of a lane to facilitate QA depth inspections.

When a mine is encountered with the Harrow-rake, the design of the tines and the method of use can lift the mine to the surface, but the intention is to subsequently use other tools (garden shovel, paint brush, bare hands) to carefully lift the mine. Occasionally, in loose sandy terrain, a deminer may lift the mine in the process of using the harrow rake.

When a mine is encountered with the Brush-rake, it is intended to be exposed without applying enough pressure to make it function. The flexible rake tines bend out of the way selectively when encountering a hard object and do not transfer the brushing force to the object. In a demonstration, the Brush-rake was used to expose a Type-72 anti-personnel blast mine with the main charge removed, and then the rake operator attempted unsuccessfully to initiate the pyrotechnic still in the mine casing and at the start of the firing train to demonstrate the small likelihood of initiation. Similar “tests” have been used by NPA as a demonstration of the inherent safety of the Brush-rake.

The REDS system starts by using the rakes to create a “Base-trench” in a safe area at the start of a lane. The Base-trench is similar to a “base-stick”, advancing as the excavation progresses, and replaces some of the functions of the base-stick. It is a trench across the start of the lane that is as deep as the required clearance depth and

30–50 centimetres wide. It has a vertical face on the uncleared side and a sloping face on the safe side.

Harrow-rakes

Harrow-rakes have two tines that are curved back towards the user. The length of the tines varied as a result of wear and of manufacturing variations. The curve was at least enough to lift the small mines encountered in Sri Lanka out of the ground as the Harrow-rake was pulled forward.

The rake is placed on the ground in front of the base-trench (not pushed into the ground in any way) and then dragged towards the user (see Figure 1). The tines should dig in automatically and create a pair of furrows in the ground. When the tines encounter light root systems, the user breaks them by pulling. When heavier root systems are encountered, “pruners” are used to cut the roots. Large roots may be cut with a saw.

Stones are raked around, and may be “flipped” out of the ground with the Harrow’s tines. Deminers were very skilled at this and could flip quite large stones (up to 15 centimetres in diameter) as far as 50 centimetres to behind their own feet.

Deminers frequently increased the speed of the process by applying enough downward pressure on the Harrow-rake to make its wooden handle bend perceptibly. Some also became impatient with roots and tugged sharply on the rake handle to try to break them. Unless properly managed, this could well lead to frustration and potentially dangerous practices.



Figure 1. Harrow-rake in use showing the long tines. Metal Brush-rake in foreground.

Brush-rakes

Brush-rakes are made either of sprung-steel or flexible plastic. Designed to brush leaves from a lawn without damaging the grass, their only adaptation before use is the addition of a socket that allows them to be firmly attached to an unusually long (1.6 to 2 metres) and thick wooden handle.

With tines spread in a fan design, the downward pressure applied by the user is spread over a wide area (see Figure 2). The easy flexibility of each tine prevents pressure being concentrated in any one place. A slight downward bend towards the end of each tine helps to collect loose spoil and sweep it back towards the deminer.

The Brush-rake is first used to remove any loose vegetation and “leaf litter” from the area in front of the base-trench. If the ground is soft enough, the Brush-rake may then be used to brush the soil towards the base-trench. After the Brush-rake, the Harrow-rake is used in overlapping sweeps leaving small furrows across the area being worked — to a distance of 30 to 50 centimetres in front of the base-trench.

After the Harrow-rake has been used to break up the new ground, the deminer sweeps the loose earth back into the base-trench. The Harrow-rake is then used again and the process repeated until the depth of excavation is achieved and the base-trench extended forward by 30–50 centimetres. The spoil has been moved to the back of the base-trench, which has also moved forward by 30–50 centimetres.

Deminers swept with the Brush-rake very close to their feet when they were packing loosened spoil at the back of the base-trench. That spoil had already been inspected.



Figure 2. Plastic Brush-rake in use.

Quality assurance and quality control of the REDS system

As with most manual excavation clearance methods, the excavated spoil is moved back inside the originally suspect area. It may contain high levels of metal contamination or be comprised of soil with a high Ground Reference Height (GRH) (electromagnetic signature). The work cannot be subjected to post-clearance sampling and quality control (QC)/QA using a metal detector. Post-clearance sampling requires using the REDS system. On land recently raked and root free, QC using REDS should be comparatively fast and effortless, so may sometimes be appropriate. Ground that had not been raked would be readily apparent and the working depth could be reliably verified with random sampling.

NPA used a side-of-lane ditch system to allow post and tape marking to remain in place during raking and to facilitate internal QA checks of the required excavation depth. Side-of-lane ditches were only “lost” when cleared areas were raked over after QA. The process was an effective method of allowing realistic internal QA by Section Leaders, giving confidence in the maintenance of the clearance depth (Figure 3).

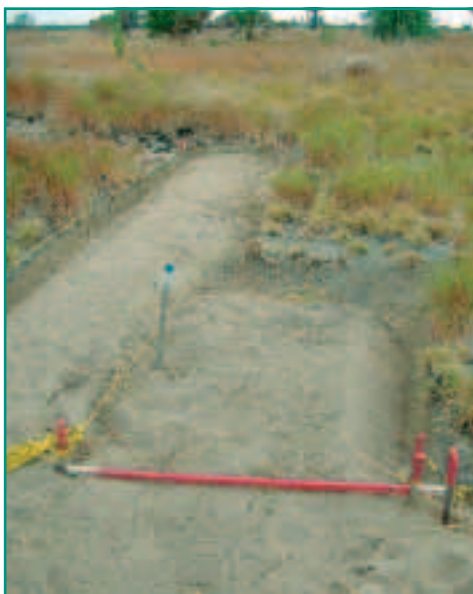


Figure 3. NPA marking and side-ditches supporting effective internal QA checks.

External QA is provided by UNDP teams reporting to the local authorities. QA and QC are conducted during the work rather than sampling after completion and use the same methods as the clearance operations.

DDG adopted the NPA REDS system one year before the study. Internal QA procedures are undertaken by the section leader and team leader while demining is in process.

The overall work is overseen by a field operations officer and an international technical adviser, and is subject to external QA.

DDG variations to the NPA REDS

DDG adopted the NPA REDS system one year before the study. Internal QA procedures are undertaken by the section leader and team leader while demining is in process. The overall work is overseen by a field operations officer and an international technical adviser, and is subject to QA.

DDG has developed a four-tine rake (to speed up the process), which has been used in limited areas where the ground is suitable (*Figure 4*). Looking like a reinforced garden rake, its tines are short and would not lift a mine to the surface as the curved two-tine NPA rake did.



Figure 4. A four-tine adaptation of the Harrow-rake developed by DDG.

Use of water

NPA did not use water to soften the ground during the study, although use of water was covered in the SOPs. Use of small quantities of water (by bucket) was seen on one DDG site. At a second DDG site, water was available in large quantities from hose systems and pumps attached to several 2,000-litre water tanks positioned outside the mined area. (In the Sudan case study, water was used regularly to soften hard ground and appeared to improve the conditions for using excavation tools. See Sudan case study, page 27.)

At the DDG site, 6,000 litres a day was applied over an area in which there were 19 deminers working. After water began to be delivered, they cleared an average of 110 square metres a day, so presumably the water was applied to less than 150 square metres in a ratio of around 40 litres to the square metre. The site was steep, so water run-off would have limited the time for soil absorbance.

The advantage of using water on hard ground may justify the investment in water tanks, water supply and water pumping methods, but it was not possible to gather data on clearance rates in the presence and absence of water to make a full assessment. An internal report provided by DDG for the donor of the water and pumping equipment claimed that, in an unusually hard area, speed of clearance had been increased from 0.35 to 0.65 square metres an hour by the application of water.

Conclusions from the Sri Lanka case study

The sites visited included a site with dense-vegetation, extensive root systems, hard ground and many large rocks. While slow, the rakes were used effectively under these different conditions (and any other excavation method would also have been slow). The rakes used in this system are simple and reliably achieve clearance to a set depth when integrated with conventional manual mined-area drills (area marking, safety distances, internal QA, etc.).

The two-tine Harrow-rake performed well at scarifying the ground and raising mines out of loose ground. The fan-tine Brush-rake performed well at moving loosened spoil back in the base-trench and so advancing the excavation. No accidental initiations had occurred while using the brush-rake, which is believed to be inherently “safer” than designs which concentrate weight and force in the small area at the point of a few tines. Accidental initiations had occurred while using the Harrow-rake, but the length of the handle prevented severe injury when PPE was being used properly.

The REDS system gives high confidence that the ground has been cleared of all explosive remnants of war to the required depth. The safety of the cleared area for end-users relies (as with all other methods) on a correct assessment of the threat depth. With that limitation, the method is at least as safe as any other in terms of the safety of the end-users of the land.

Case study 2

Iraq: Mines Advisory Group

Mines Advisory Group (MAG) has operated in northern Iraq for 12 years, maintaining a demining presence through periods when Kurdish areas of Iraq were difficult to access, very difficult to supply and politically volatile.

Prior to the US-led invasion of Iraq, security was an issue and the use of armed guards on demining sites was common. MAG had sought to develop an indigenous capacity and its international staff numbers were few, falling to zero during and immediately after the conflict.

Following the US-led intervention into Iraq, the number of high-priority tasks requiring attention multiplied dramatically. Military positions along the notional “green line” between the North and South had been attacked, abandoned and looted. The Iraqi border minefields now served no military purpose and the land was being rapidly reclaimed. In addition to minefields, bomb and cluster bomb strike areas also needed to be cleared, along with vast areas around military forts and stores where munitions in unstable condition were spread. Because the minefields had been used to defend military sites, mixed contamination including mines and ordnance was common.

Characteristics of the context include:

1. MAG had responsibility for all levels of survey and clearance, including QC/QA (no external QC/QA was taking place) and had prioritised their own tasks.
2. In all the areas visited, the mines had been laid by military forces in predictable positions and patterns to protect assets. This is the norm in this particular operation.
3. Most mines had been laid in a disciplined manner in rows, and the rows were usually marked with barbed wire, in coils or single stands.
4. No mines were reinforced, booby-trapped or fitted with anti-handling devices.
5. The hillsides were rocky and hard to dig, and the minefields did not have to be concealed. Many anti-personnel blast mines were placed on or flush with the surface of the ground and were visible after the light undergrowth was burned off.
6. The ground was frequently contaminated with metal fragments and short lengths of barbed wire.

7. The fragmentation mines used were POMZ-2M and VALMARA-69 (V-69). No POMZ-2M remaining on a stake was seen. The V-69 anti-personnel mines were laid with up to 10 centimetres of the main body above ground, giving a tripwire height of between 10 and 20 centimetres. They were almost always visible after the undergrowth had been burned. Intact tripwires were very rare. Samples of tripwire collected were of soft mild steel that had originally been painted.
8. The anti-personnel blast mines used were VS-50, TS-50, PMN and Chinese Type 72A. PMN mines were not mixed with other mine types. Chinese Type 72A mines were also laid in discrete rows. VS-50 and TS-50 mines were sometimes mixed, and the difference between their metal content meant that a VS-50 row was always treated as a minimum-metal threat because of the risk of some TS-50s having been used.
9. In many cases tripwire-initiated illumination flares were used among the mines (and were counted among the mines during clearance). The flares were used because the mined areas were intended to always have “covering fire”, so a tripped flare would provide early warning to alert the defenders.
10. Following the conflict, some wire defences had been removed, and paths through the mine-belts had been made by members of the public moving mines aside. The moved mines were usually left in an obvious position on the surface and often marked with a pile of stones. Frequently, they had been disarmed. In a few areas entire rows of obvious mines (usually V-69s) had been removed and partially destroyed (left in a damaged and presumed sensitive condition).
11. As economic activity increased, the national pastime of taking Friday picnics in the hills was practised by increasing numbers of civilians. Picnicking amid the old hilltop defensive positions surrounded by minefields had become increasingly common.
12. Erosion had moved some mines, although disruption of the array structure ensured that the displacement was easily identified.

Iraq was visited for the purposes of this sub-study from 14 July to 6 August 2004.

MAG's expansion

Despite considerable security problems, MAG was rapidly expanding its programme to meet the increasing needs. Seven expatriate Technical Field Managers, a Technical Operations Manager, a Programme Manager and other mine risk education (MRE) staff were in place. Two ARMTRAK 100 flails had been ordered (only one was in country at the time of the visit) and one was being tested while its operators were being trained. Large two-man Ebinger UPEX 740M locators had been imported for deep submunition searches and the first operators were being trained.

A subcontracted dog team (two Bosnian handlers and four dogs) became operational during the visit and were being used in advance of squads of deminers in Post-clearance Area Reduction (PAR) activities, described below. A training course for new deminers was under way and 54 deminers passed the course just before the study ended.

Manual mine clearance procedures

Breaches were cut through the suspect areas to locate the mine rows. In the areas observed, no one-metre-wide clearance lane extended for more than 10 metres before it was widened to 2 metres by cutting an adjacent lane. When mine rows were located, the breach continued to the opposite perimeter.

When the breaches were completed, the clearance plan was refined to make allowance for the known mine rows, which were cleared with a 5–10 metre-wide “security” swathe on each side. Cross breaches were made to join up the original breaches in a grid designed to locate any partial mine-belts that may have been missed. The grid of breaches left areas that were either 10 or 20 metres wide (the required width of these areas was under review). Any areas where mines could have been moved by environmental conditions, such as snow-melt and rainwater run-off, were included in the manual search when mines anticipated in the patterned rows were absent.

Breaches were extended to reach all surface mines that were moved from the belts by people using the area. Areas between breaches were finally “reduced” using the PAR methods.

Manual mine clearance was usually carried out using metal-detector drills. When the level of scrap metal made that impossible (six detector readings in a square metre in one particular example), full manual excavation was carried out. Undergrowth was either burnt off or cut with hand tools as work progressed. At all sites visited, the undergrowth was limited to dry grass and very small thorn bush easily cut with secateurs (pruners).



Figure 5. An excavation lane with spoil placed behind the deminer.

Figure 5 shows an excavation lane where the spoil was placed behind the deminer in the cutting. Any metal contamination remained in the spoil, limiting the capacity for later QA beyond checking that the depth of excavation had been achieved.

The old Schiebel AN/PSS-12s detector in use required that the search-head was close to the ground without touching it. To ensure that the required proximity was achieved consistently, the deminer used small rubber ties (cut from tyre inner-tube) trailing from the search head (*Figure 6*).



Figure 6. Head of Schiebel detector with guiding ties.

Ceia Mil D1 detectors were used when breaches were being cut where the mine-type had not been identified, and were used to clear mine-belts believed to contain low metal VS/TS-50 mines and Chinese Type 72A mines.

When a metal-detector signalled, the deminer scanned the ground for surface fragments and removed any that were visible. When no surface fragment was the cause, the deminer pinpointed the reading and placed a single wooden cube (painted red) on the centre of the indication.

When the marker for an indication was in place, the deminer put the detector in a safe area (which was in a cleared area alongside or behind him in his lane) and brought forward a small plastic bucket, a prodder and a trowel. He started to prod 20 centimetres back from the marker. Loosened spoil was removed with the trowel before prodding again.



Figure 7. A deminer investigating a metal-detector reading. Yellow stakes show where mines were located.

In *Figure 7*, the deminer is on his knees prodding. The “berm” on the left is the spoil from excavated detector readings. Berms were made in “safe-lanes” (at least two metres wide) that had already been subjected to internal QA.

The deminers tended to use a one-handed stabbing motion that rarely penetrated more than two centimetres into the ground. The prodder used was thick (12 millimetres) and made from a mild steel. Trowels and prods were locally made. Some toolkits included short secateurs rather than the grass-cutting “hook” seen in *Figure 8*.

After jabbing at the ground repeatedly, the deminer used the trowel to dig away the spoil and scrape across the face of the area, advancing towards the detector reading. Water was sometimes used during excavation. In the examples seen, insufficient time was left for the water to soften the ground and the main advantage was to prevent dust rather than increase the rate of progress.

Excavations towards detector readings were 12 centimetres deep or less when examined.

Post-clearance area reduction

The concept of post-clearance area reduction (PAR) was developed and implemented in South Lebanon and is also used in Iraq. It involves reducing the originally suspect area as work progresses and the placement of mines becomes clear. Some of the originally suspect area may not be cleared, but will instead be classified as “No Known Risk” and released to the community after fully informed area-reduction. Area reduction was only fully informed after the suspected mine-belts had been located (and where mine-belts were the anticipated threat).



Figure 8. Hand tools used by a MAG manual deminer.

PAR formalises practices that other groups routinely carry out in a less structured manner. MAG staff believe that PAR makes more sense than extensive area-reduction because the suspect area is covered more thoroughly.

The three methods of “post-clearance area reduction” (full-visual, dogs and the flail) are all intended to give an extra level of confidence *after* the clearance of identified mine-rows.

Machines and PAR

MAG had recently purchased ARMTRAK 100 flails (Figure 9), intended to allow reduction of the manual-clearance margins outside the mine-rows from 5–10 metres down to two metres. The area around the belt would be traversed by the flail or the dogs, before being subjected to a “full-visual” search.



Figure 9. The ARMTRAK 100 flail in action in Iraq.

Use of the machine had been accredited by the regional MAC after a trial devised by MAG. The flails may also be used in wider area coverage as part of PAR, although some concern about the environmental impact of the flails had been raised.

It was accepted that the flail alone could not “clear” any ground and Figure 10 shows a picture of a V69 that has been crushed into the tracks of a flail.

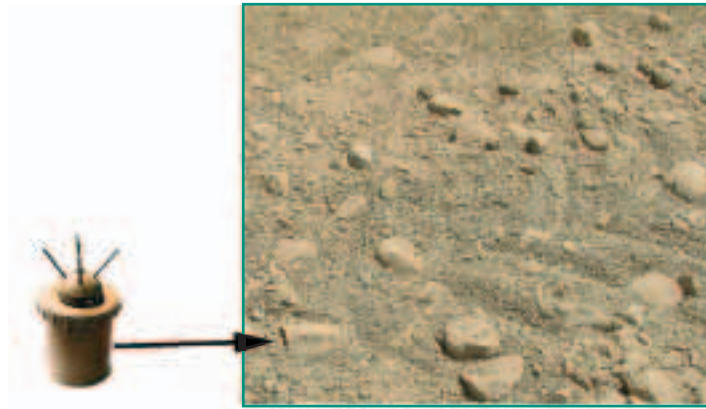


Figure 10. The body of an unexploded V69 is crushed into the tracks of a flail.

Dogs and PAR

Two dog sets (two handlers, four dogs) were being deployed as part of PAR during the case study research (Figure 11). The sets deployed at first light and stopped work before 08:30 due to high temperatures. They were working in 20-metre-wide “boxes” between two-metre-wide breaches, and were entering the boxes from both sides in order to ensure full coverage. Two dogs were run over an area before it was considered clear.



Figure 11. Long-lead MDD at work in Iraq.

“Full-visual” search

Post-clearance reduction of areas that were no longer suspected of being mined, but were within the original suspect area, was carried out using “Full-visual” search. The manual deminers formed a rank (hand to shoulder spacing) and walked across the area between breaches examining the ground (Figure 12). Mines on the surface (moved by local people) were found, along with surface ordnance and battlefield debris. Each deminer carried a sack in which the debris was collected. Visors were raised during the visual scan but as soon as one man spotted something to pick up, the rank stopped and all visors were lowered. The Team Leader walked behind the rank, and side marking stakes were driven in at 25-metre intervals to ensure search overlap as they returned on their next pass.

A “full-visual” search was only conducted in a suspect area when the site managers were confident that all mine belts had already been located and cleared. Their confidence was based on survey and local guide information as well as clearance results. The site threat assessment was constantly updated and the area to be searched with metal detectors or manual excavation was changed when appropriate.



Figure 12. "Full-visual" search.

If a mine or mines were located or suspected, the "full-visual" search would be suspended and manual clearance using metal-detectors or full-excavation would take place.

Deminers and battle area clearance

MAG Northern Iraq did not have dedicated battle area clearance (BAC) teams. Instead demining teams were assigned BAC tasks when appropriate. The number of BAC tasks was high, with battle UXO compounded by tens of square kilometres of land contaminated with ordnance from arms dumps (either scattered by combat strikes or by looting after the conflict).

BAC tasks usually involved a "full-visual" search and could also include metal-detector search in areas where it was suspected that munitions have become concealed. Submunition strike areas were a priority because of the sensitivity of the BLU-97 and KB-1 submunitions used.

Up to the time of the case study, MAG had cleared CBU strike areas with patient excavation. The deepest BLU-97 they had uncovered at that time was at a depth of one metre, but that was very unusual.



Figure 13. The Ebinger UPEX 740M in use.

The national mine action centre (MAC) had introduced a clearance depth of 50 centimetres for BLU-97 strike areas, and MAG had responded by introducing a two-man large-loop detector (Ebinger UPEX 740M) to help them achieve this depth with confidence (Figure 13).

The Ebinger UPEX 740M is not designed to locate anti-personnel mines or any device that presents a threat to those walking on the ground. Its first use in Iraq was to provide a second “deep-search” pass on submunition strike areas.

Conclusions from the Iraq case study

MAG was purchasing replacements for their older metal-detectors, PPE and tools during the study. Meantime, their use of the old Schiebel detector in areas where no minimum-metal mine threats were anticipated allowed rapid clearance of mine-belts while leaving small metal indications behind. In the context, that appeared both practical and safe. They had developed a technique for tuning the Schiebels to ensure that each deminer worked to the same standard, and which allowed internal QA. The adjustment was so successful that they had asked the manufacturer of the detector replacements to devise a similar “tuning-down” adjustment for their new detectors.

When conducting metal-detector search inside known mine-rows, the vast majority of detector signals were on metal fragments, many of which were on or close to the surface. Magnets were not used to reduce the signal investigations that followed, but could have improved productivity as these signals took up the majority of each deminer’s working time.

Mechanical assets and dogs were both being introduced during the study period and their deployment to assist PAR was under investigation. The PAR concept had very significantly reduced the clearance of areas where there was no threat and so had increased efficiency dramatically. To date, PAR had relied on boxing areas and using deminers to make a “full-visual” search as they traversed a formerly suspect area. It was reported by MAG that there had been no accidents while doing this search, which they presented as evidence of the quality of the approach.

Case study 3

Cambodia: Cambodian Mine Action Centre

CMAC has been operating in Cambodia since the end of the United Nations Transitional Authority in Cambodia (UNTAC) in 1992, and currently employs the largest number of deminers in the country. CMAC is divided into six Demining Units (DU1 – DU6). The work of DU3 in Pailin District (near the Thai Border) was studied. Pailin District was one of the last areas controlled by the Khmer Rouge and so one of the last in the country in which demining could start. The border with Thailand is particularly heavily mined, along with roads, road-verges and some villages.

The donor supporting DU3's work at the time of the trial also supported an independent QA capacity via the commercial company QAsia.

Anti-personnel mines found in the area were Type 72A, POMZ-2M and Type 69 mines (without tripwires and in a corroded condition). PMN and PMN-2 mines were also expected. TM-46 anti-tank mines had also been found, along with UXO (mostly 60 and 82 millimetre mortar bombs).

Although survey could be used to predict the presence of a threat, mines tended not to be laid in patterned minefields, or in predictable arrays. When combined with the relatively abundant UXO, the problem is very different to northern Iraq, where patterned minefields were typical.

Cambodia was visited for the purposes of this study on 16–26 September 2004. The rainy season was under way and some rain fell during the study.

Operational background

CMAC's methods have evolved over 13 years and it has operated with very limited technical assistance from the UN over the last four years. At the time of the study, the CMAC management had made significant changes to old working methods and were planning several trials of new drills/techniques intended to increase operational efficiency.

To save money, CMAC had stopped deploying ambulances to each site. Instead each site has a medic and trauma kit. Emergency evacuation is by air ambulance (helicopter) and each site had a helicopter landing grid marked out for that purpose. Driving conditions in Cambodia are difficult and most roads are poorly maintained, thus rapid evacuation by road would not normally be possible.

In all the areas visited, the threat assessment included the condition of the mines encountered. As a result, safety distances were reduced from those recommended in the IMAS because fragmentation mines were not in a functional condition and so their accidental initiation was assessed as a very low risk. Required safety distances between demining pairs were also “flexible”, with the team leader having authority to reduce distances if safety was not compromised.

Manual mine clearance procedures

CMAC operated a one-person drill in two-person teams, primarily because of a shortage of metal-detectors and PPE. Electromagnetic ground disturbance is common in Cambodia, requiring sophisticated metal detectors which were in short supply.

The second deminer waited in a rest area from which they were supposed to monitor their working partner. Effective monitoring was often impossible because direct line of sight could not be maintained and, even when it could, the second deminer was often only able to see the partner’s back.

All CMAC clearance lanes were about 1.5 metres wide (as opposed to the international norm of one metre). The preferred stance of all deminers was to squat, although some placed a knee on the ground at times (*Figure 14*).



Figure 14. A CMAC deminer squatting to cut undergrowth.

Undergrowth was usually cut with secateurs (long handled and short) and conventional garden shears.

CMAC deminers usually cut all the undergrowth to a height of 8–10 centimetres, then removed those cuttings by hand or by “hooking” the cuttings away with secateurs or shears. They then cut again to ground level in order to get the metal detector search-head close to the ground to maximise the search depth. The second phase (and the removal of the cuttings and leaf-litter) took significantly longer than the first phase of vegetation cutting.

Loppers and shears were commonly used to rake undergrowth cuttings and leaf-litter back towards the base-stick.

Although tripwire-initiated mines were present, threat assessments determined that tripwires were no longer intact and functional, and tripwire feeler drills were not conducted on any of the sites studied.

Area excavation

Clearance was being conducted with a mixture of area excavation (*Figure 15*) and metal-detector work. When metal fragmentation was high or expected to be high (as was the case at the sides of roads) area excavation (solely) was carried out. The excavations observed were to a shallow depth (less than 10 centimetres). Neither the deminers nor their supervisors had any means of measuring the depth to ensure that it was adequate or constant.



Figure 15. A CMAC deminer conducting area excavation.

Normally, the use of a long-handled tool for excavation can increase safety by keeping the users hands away from an initiation, and outside the inverted cone of environmental fragmentation that accompanies anti-personnel blast mine detonations. In *Figure 15*, one hand is dangerously close and both are inside the fragmentation cone. Vertical digging like this was common.

Metal-detector search

The detectors in use by CMAC were Minelab F1A4 models purchased in 1999/2000. They had seen heavy use and their signals were erratic. During the study, detectors “drifting” and requiring recalibration was common and sometimes held up progress significantly.

Metal-detector signal investigation

Before using tools to loosen and remove soil following a signal, the CMAC deminers used a magnet (or piece of magnet) by rubbing it over the signal area. The magnet was moved around in the surface soil or leaf-litter to attract ferrous material.

The magnets used were speaker magnet rings (many were broken parts of rings). Fragments located were largely bullet casings and unidentified fragments of rust (*Figure 16*).

If fragments were located, the deminer used the detector again to check whether the source of the detector indication was still present. When no obvious metal was attracted, deminers often attached the magnet to their CMAC trowel and used the tool to lightly scrape the ground where the metal-detector had signalled. Spoil was then tipped off the trowel and over the magnet to try to catch any ferrous fragments that had been just below the surface. Ferrous fragments were frequently located successfully without the need to investigate the detector signal any further.

When the metal detector continued to indicate the presence of metal after the use of the magnets, the deminers began a signal investigation drill.

CMAC's signal investigation drill involved digging an excavation trench a safe distance (20 centimetres) from the reading with a sloping back (towards the deminer) and a vertical face (Figure 17).

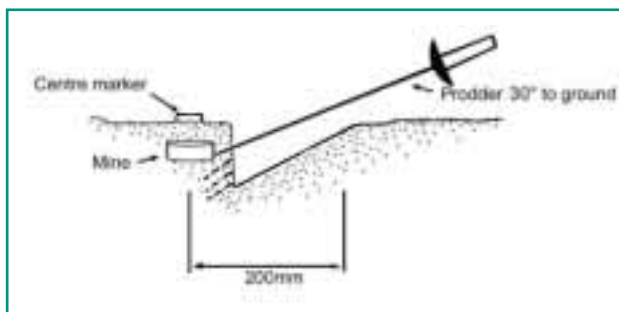


Figure 17. Signal investigation.



Figure 16. A CMAC deminer's signal-investigation tools. Both the prod and the CMAC trowel were locally made and details varied. A "doughnut" speaker magnet is in the centre of the picture.

The face was prodded from the bottom up before slicing away the prodded ground and advancing towards the reading. While prodding, the deminer gripped the prod shaft to record the depth of insertions. The deminer then laid the prod on the surface, pointing ahead of the excavation face by the extent of the prodding depth. A line was scratched at the prod tip allowing the face to be dug away up to that mark using the trowel.

The magnet was also used (sometimes attached to the trowel) to try to find the signal source in the loosened spoil as an investigation progressed.

Mechanical assistance

In one area studied the suspect area had been prepared by a large Hitachi BM307-SG16 machine which cut undergrowth. The machine had left a mess of cuttings and churned, wet ground. Although the machine provided rapid clearance of vegetation, its wheels had churned the ground and some mines may have been driven deeply into the mud. Piles of vegetation half as high as a deminer were left in the working area.

At another site, a petrol driven (2-stroke) manually operated "Weed-whacker" vegetation cutter was being introduced. It was used to cut undergrowth from the area adjacent to a cleared lane (Figure 18).



Fig. 18. Weed-whacker in use.

One operator moved around the site cutting vegetation in front of all the deminers. The cutting width out from the safe lane was 1.5 metres, but the reach of the machine made this width difficult to achieve.

Post-clearance area reduction

A CMAC document entitled *Proposed Concept Area Reduction By Manual Deminers*, in which ideas for “post-clearance area reduction” were proposed, was made available to the case study team. The aim was to provide field deminers with rules allowing areas to be reduced while they worked and so to avoid clearing more land than was necessary. The proposed method was necessarily generic and somewhat inflexible, because it attempted to set rules that could be applied anywhere in Cambodia.

Quality assurance and quality control

Internal QA on areas cleared using a metal detector involved supervisors checking 20 per cent of all cleared areas a second time with the detector. External QA was provided by the commercial company QAsia during the study period.

As with all the case studies reported here, there was some variation between what was described in the SOPs¹ and what was done in the field. The differences caused the external QA company problems, because they were tasked to report all violations of the approved SOPs. These breaches of SOPs were not necessarily dangerous, careless or unplanned. Most were clearly planned and the SOPs were simply out of date.

Efficiency plans and trials

A new manual demining drill being trialled had both deminers in the lane at the same time, with one deminer using the detector and the other investigating any readings. Both deminers would remain in the lane, and the person investigating the reading would watch the detector to confirm the position of a detector indication. The detector user would remain present to reconfirm indications and accelerate the investigation by being ready to check moved spoil.

1. CMAC SOPs for Manual Demining, revised on 28 January 2003.

The new drill was projected to save time in changeovers, in the routines of detector recalibration involved at each change-over, in time taken to exchange tools and in the investigation of readings. The main time cost was that both deminers would rest together at regular intervals. The planned trial would determine whether the gains and losses resulted in an overall gain in the speed of clearance over a given area.

It was argued that CMAC lanes were already 1.5 metres wide, allowing two deminers to work side by side, and that the requirement for both deminers to wear PPE would assure safety.

Conclusions from the Cambodia case study

CMAC had an impressive array of assets including Explosive Detection Dogs, deep-level search locators, brush-cutting machines and manual deminers. An integrated use of these assets was still in development.

The use of a magnet to help reduce the ferrous fragmentation during metal-detector clearance was successful and improved deminer efficiency.

Apart from the magnets, which have been in use for some time, CMAC is being innovative in other areas. In particular the attempt to introduce PAR is a valuable efficiency exercise. As with most of the case studies, SOPs lagged behind innovations at a field level.

Case study 4

Sudan: Norwegian People's Aid

A long war between the Government of Sudan and the Sudan People's Liberation Movement/Army (SPLM/A) has killed an estimated two million people and displaced four million others. Both parties appear to have recognised the need to find a lasting peace and there is a genuine belief that the peace agreement recently signed will be effective. The peace agreement allows the South of Sudan (New Sudan) to choose to become a self-governing State six years after the implementation of the peace process, signed at the end of 2004.

Norwegian People's Aid has been working with the SPLM/A for more than 20 years to provide humanitarian assistance to the people of South Sudan, and in the last 18 months has begun a programme of mine clearance that is currently based in Yei village, South Sudan.

The impending peacekeeping operation (PKO) in South Sudan will inevitably create an influx of returning refugees. Many will return to areas where there is a risk of mines and UXO, and there is a strong drive to open the roads up before the influx begins in earnest.

Two visits were made to NPA Sudan: 4–8 April 2005, during which general procedures were observed, and 6–16 June, during which structured trials of two experimental demining drills were conducted. April was towards the end of the long dry season (about nine months), and June was early in the rainy season. Considerable rain fell during the trials in June.

Local demining administration

NPA has recently set up a mine clearance organisation currently based in Yei village, South Sudan.

NPA is currently planning for a considerable expansion but at the time of the visit, the demining team consisted of 40 deminers plus management staff. There are four sections of ten deminers who have a section commander to oversee the operations of the section.

Each section operates five lanes, which means that half the deminers are resting at any given time. Work starts at 8am. The first two shifts are for two hours each, after which the deminers change every hour until work ceases at 4pm. Each deminer therefore works a total of four hours a day (excluding short scheduled breaks).

Demining procedure

NPA uses SOPs developed from another NPA programme, and operates using basic drills that have proved effective in many situations. They aim to work in accordance with IMAS. The drills are essentially one-man one-lane, with the deminer clearing vegetation, detecting, investigating signals, watering and clearing signals.

During the nine-month dry season in South Sudan the ground is extremely hard. Prodding and excavation are therefore almost impossible without pouring water on the soil to soften it. Normal procedures require the deminer to move down a standard one-metre-wide lane, cutting vegetation, detecting forward of the base stick, following up investigations and, once the area has been sterilised of metal fragments, the base-stick is moved forward 30 centimetres to begin the process again.

If the ground being investigated is too hard to prod or excavate, water is applied to soften it. There is then a soak period of 5-10 minutes, during which the deminer waits. In areas with significant numbers of indications, considerable time was spent waiting for the ground to soften.

Quality assurance and quality control

The SOPs for the programme state that “*random testing of all demining procedures*” shall be carried out to ensure the quality of the produced land. In reality this means that the section commander checks over the deminers work several times a day. At handover, the incoming deminer “takes over” the land that his partner has cleared and checks the ground again.

Conclusions from the Sudan case study

The drill observed in Sudan was a standard manual demining drill, as used by most programmes worldwide. It appeared that significant delays were introduced during the dry season due to the requirement to water ground and wait for the water to soak before excavation. The trials conducted in June were designed to test alternative procedures in order to address that problem (*see below*).

Trial 1

Comparing alternative manual drills in Sudan

During observations of the NPA manual drills in Sudan made during the dry season on 4–8 April 2005, preliminary tests were conducted of two experimental drills designed to minimise time lost to watering of indications. Full trials of these drills were undertaken on 6–9 and 13–16 June 2005.

Sixteen NPA deminers were used for the trials. All deminers spent one morning in training and practice on the new drills. The deminers then spent 150 minutes (five 30-minute sessions) working each drill in lanes that were placed at least 15 metres apart. Data were obtained for each individual deminer using each drill under essentially identical conditions.

Objectives of the trial

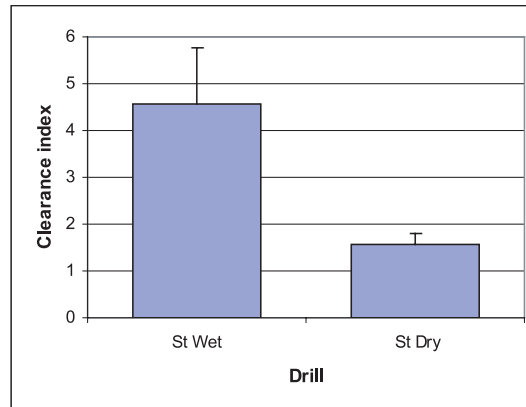
Preliminary results during dry conditions in April 2005 suggested that considerable time was saved using the experimental drills (relative to the standard drill), but too little time was available for a full study. The preliminary clearance data for Standard drill from April, when 4 samples were obtained, are compared in Figure 21 with the clearance data obtained from the more detailed study in June. Clearly, there was more land cleared (275 per cent) in June, when the ground was soft, than in April, when the ground was dry and hard.

The primary objective in June was to explore the use of each drill in greater detail than was achieved in April. Aspects of each drill other than watering and soak time also potentially introduced delays or efficiencies, and two objectives were defined for the study:

- to explore all aspects of the dynamics of the drills; and
- to investigate the effects of watering on clearance rates for each drill.

The study in June was conducted after rain, when the ground had softened, and was therefore conducted under conditions of no delays due to watering. The situation allowed a direct comparison of the three drills under essentially equivalent conditions, without any effect on the data from the known delays caused by watering.

Figure 21. Amount of land cleared (indexed to make the data directly comparable) using Standard drill (St) when ground conditions were wet and dry (normal drill)



Drills

For standard manual mine clearance drills performed on hard ground in a lane, the only option when watering hard ground is for the deminer to wait for the water to penetrate. Moving past the indication site is impossible within safety requirements. Especially for areas with larger numbers of indications, significant delays are the consequence. However, if the deminer can somehow bypass the indication site safely, then detection work could continue while the water is penetrating.

The Crab and Hybrid drills were developed to address the problem of delays during watering. Both require a safe lane along the side of the demining lane, allowing the deminer to bypass an indication. However, as a working lane can be placed next to a previously cleared lane, there is normally no difficulty obtaining such safe access.

Both of the experimental drills commence with the marking of a 50 cm wide strip parallel to a cleared lane. Up until the point of divergence between the drills noted below, the deminer works laterally from the safe lane in 1 m blocks.

- The 50 cm wide strip is cleared of tripwires and vegetation in one run.
- Then the deminer works laterally with a metal detector. Surface signal points are removed immediately by hand. Buried signal points are marked (and watered if the ground is hard) and the deminer moves on to check the entire lane.
- It is at the point where clearance of buried signals begins that the two drills diverge in procedure. Annex 2 gives full details of the two drills.

The Crab drill involves the deminer continuing to work laterally. The deminer returns to the marked signal sources and clears each one. Intervening spaces between indications are not checked again. If more watering is required, the site is watered and the deminer moves on laterally to another marker, returning to the watered site after a few minutes. If watering is required, no time is spent waiting for water to penetrate the soil.

The Hybrid drill combines elements of Standard and Crab drills. Instead of working laterally while dealing with indications, the deminer works forwards only, stepping into the lane as they work. In the version of the drill used here, the entire lane was checked again with the metal detector as the deminer worked forwards. In principle,

this additional metal detector search could be eliminated with the deminer moving directly to each indication. The deminer does not step outside the lane, so if more watering of sites is required, some additional delay is likely.

Data recording and sampling

The deminers were required to prepare the land by searching for tripwires, cutting and removing vegetation before using standard detection and clearance techniques and equipment to clear the land. Cutting and removal of vegetation could proceed ahead of mine clearance for the Crab and Standard drills (because of the adjacent safe lane), and in some cases slightly more land was prepared than was cleared using these drills.

Records were made of the total amount of land prepared, cleared and subjected to QC checks, and of the number of indications found during clearance.

Table 1. Codes and descriptions for sampling the behaviour of deminers using three different demining drills

Recording Code	Description of Action	Analysis Code	Lumping
TS	Tripwire Search	TS	TS
MEV	Measuring Vegetation to be cut		VEG
CV	Cutting Vegetation	VEG	VEG
RV	Removing Vegetation from lane		VEG
MEC	Measuring Clearance	MCL	MCL
CT	Change Tool	CT	CT
MDT	Mine Detector (turn-on)		MD
MD	Mine Detector	MD	MD
MD+	Mine Detector (positive)	MD+	MD+
GW	Getting Water	WAT	WAT
PW	Pouring Water		WAT
ISP	Investigate Signal (Prodder)	ISP	ISP
ISX	Investigate Signal (Excavation)	ISX	ISX
ISD	Investigate Signal (Detector)	ISD	ISD
PPE	Adjust PPE	PPE	PPE
WQA	Waiting for Quality Assurance		QA
QA	Quality Assurance	QA	QA
MKG	Marking	MKG	MKG
DPI	Detector Problem (Interference)		DP
DPC	Detector Problem (Calibration)	DP	DP
DPB	Detector Problem (Batteries)		DP
RE	Resting	RST	RST

The activities of the deminers sampled were as follows:

- 22 actions were identified and coded (Table 1);
- an observer sat at a position from which four deminers could be continuously observed;
- the observer used a repeating countdown timer to mark time intervals of one minute;

- each minute, the observer scanned the four deminers, recording the action being used at the first moment that the deminer was encountered during the scan;
- each deminer was observed using each drill for 150 minutes (providing 150 scan samples /deminer/drill, and 450 samples in total for each individual);
- some lumping of sampled actions occurred before analysis, reducing the sampled actions to 15 broader activities (Table 1);
- the data were used to calculate the proportion of time spent in each activity during the 150 minutes of work on each drill (reported as a percentage); and
- the calculated proportions for each action were used to compare statistically across drills, using the sample size of 16 deminers.

Results

The data provide a quantitative description of how the deminers distributed their work time during each drill. Despite the identical working conditions, many differences were found between the drills (outlined below). Because of heavy rains during the period of the study, the ground was already soft when the deminers were working and essentially no watering of indication sites occurred (proportion of time watering is in Table 2).

All tests reported below used repeated-measures statistical analyses because all three drills were worked by each deminer. A description of how to interpret the results of statistical tests is in Annex 1 to this Section.

Area cleared and number of fragments

The total amount of land cleared of mines by each deminer using each drill was measured in the field. For the two experimental drills, some small amounts of land on which vegetation was cut but not cleared of mines were subtracted from the total area of land reported as cleared.

Less land was cleared using Standard drill than using the two experimental drills (*Figure 22*). Statistical comparison of each pair of bars indicated that significantly more land was cleared using Crab than Standard drill.¹ Hybrid drill was intermediate and was not statistically different from either of the other two drills.

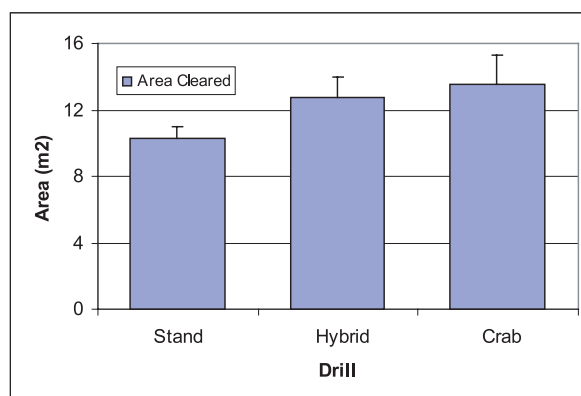
The number of indications is likely to influence the amount of land cleared, because it takes time to deal with each indication. All else being equal, larger numbers of indications should result in smaller amounts of land cleared, and it is possible that differing numbers of indications between drills influenced the result in *Figure 22*.

The pattern in *Figure 22* therefore predicts smaller numbers of indications for the two experimental drills. However, the opposite occurred: the number of indications was higher for the two experimental drills,² but these differences were not statistically different from each other.

1. Duncan's test, $P=0.027$.

2. Mean ($\pm$ standard error) of indications was: Standard = 4.5 ± 1.1 ; Hybrid = 5.1 ± 1.9 ; Crab = 6.1 ± 1.5

Figure 22. Amount of land cleared of mines using each drill.
Bars are mean + standard error.

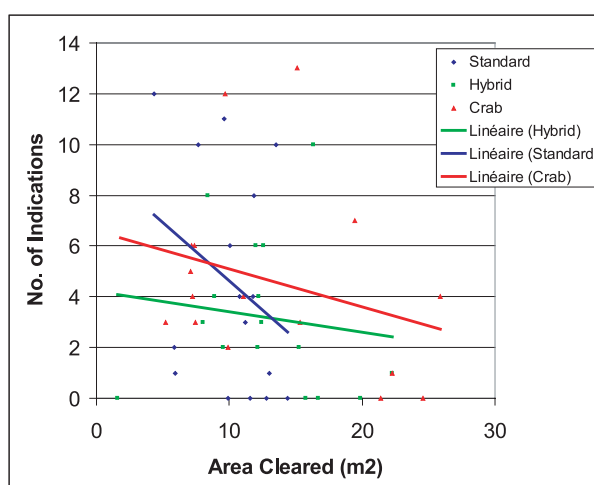


The relationship between area cleared and number of fragments was reviewed in two ways:

- By plotting the relationship between area cleared and number of indications, and inspecting the slope of the curve for each drill (visually, and using regression analysis, which reports a value for R^2 and is most easily understood as a correlation);
- By dividing the area cleared by the number of indications in order to standardise the data, and comparing across drills using analysis of variance.

The relationship between indications and area cleared was explored by plotting number of indications against land cleared for each drill (shown as the trend lines in Figure 23).³ The predicted negative relationship was strong for Standard drill and weak for Hybrid and Crab drills. In effect, higher numbers of indications reduced clearance rates using Hybrid drill, had little effect on the amount of land cleared using Standard drill, and had no effect for Crab drill.

Figure 23. Relationship between number of indications and amount of land cleared for three drills



We conclude here that the two experimental drills resulted in land being cleared at slightly faster rates than for Standard drill in wet soil. The more important result is that numbers of indications had a strong negative influence on clearance rates using Standard drill and less influence on Hybrid and Crab drills. Clearance using the two experimental drills was therefore influenced less by the number of indications and should give more clearance under conditions where high numbers of indications are obtained.

Behaviour of deminers

The 22 sampled actions were lumped into 15 broader activity categories (*Table 1*).

Significant differences were found among the drills for many of the activities (*Table 2*). Of particular interest were:

- Vegetation (more time was spent dealing with vegetation in Standard, (*Figure 24*);
- Change Tool (used twice as much in Standard relative to the other drills, *Figure 25*);
- Use of Metal Detector (used more in Hybrid, *Figure 26*); and
- Marking (done more in Hybrid, *Figure 27*).

Pair-wise comparison of each activity for each pairing of drills indicated that changing tools required significantly less time in Crab than in Hybrid drill, in addition to both being significantly more efficient than Standard drill.

Figure 24. Time spent cutting and moving vegetation in relation to different drills
(Bars are mean + standard error)

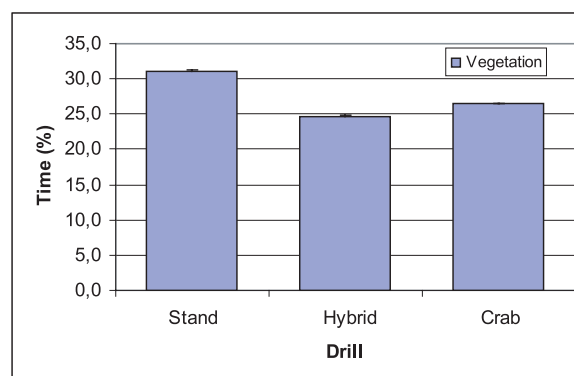


Figure 25. Time spent changing tools, in relation to different drills
(Bars are mean + standard error)

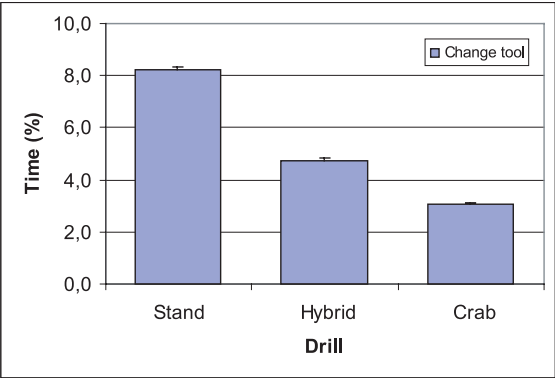


Figure 26. Time spent in standard search with a metal detector, in relation to different drills
(Bars are mean + standard error)

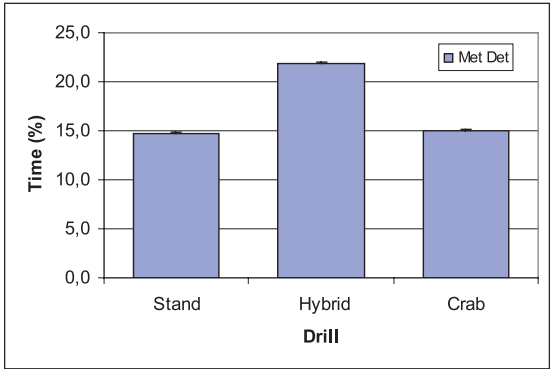
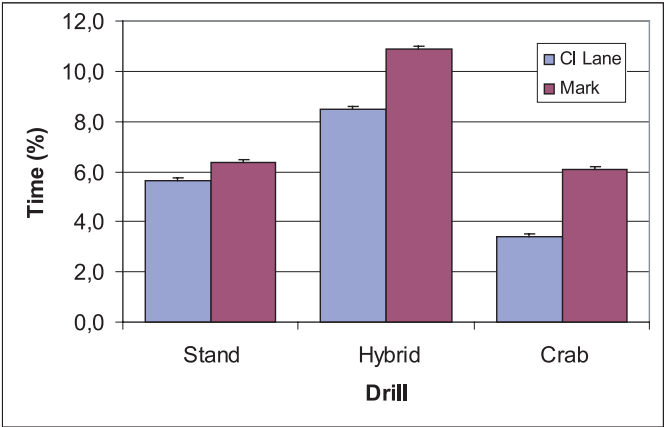


Figure 27. Time spent marking in relation to different drills
(CI Lane = marking a cleared lane; Mark = marking while working a drill.
Bars are mean + standard error)



Most of the differences found between drills in terms of time spent in each activity have implications for deminer efficiency, and we conclude that differences among these drills offer considerable potential for improving the productivity of manual demining.

Table 2. Proportion (%) of time spent in different activities by deminers using three different drills. Activities and codes defined in Table 1. Values are means (on left) and standard errors (on right).

Activity	Standard	Hybrid	Crab	SE Stand	SE Hybrid	SE Crab	Significance
TS	10.7	6.7	10.8	0.12	0.10	0.11	$F_2=8.8$, $P=0.001$
VEG	31.2	24.7	26.4	0.17	0.18	0.16	$F_2=5.3$, $P=0.01$
MCL	5.6	8.5	3.4	0.11	0.09	0.09	$F_2=17.8$, $P=0.000$
CT	8.2	4.8	3.0	0.10	0.09	0.08	$F_2=34.3$, $P=0.000$
MD	14.7	21.8	15.0	0.15	0.17	0.12	$F_2=10.9$, $P=0.000$
MD+	1.6	0.8	1.3	0.08	0.06	0.09	$F_2=1.7$, NS
WAT	0.1	0.0	0.7	0.03	0.00	0.07	---
ISP	2.1	1.4	3.0	0.08	0.06	0.08	$F_2=10.1$, $P=0.000$
ISX	9.8	7.1	13.0	0.20	0.20	0.17	$F_2=2.75$, $P=0.08$
ISD	5.1	4.5	4.5	0.14	0.18	0.12	$F_2=0.07$, NS
PPE	0.2	0.3	0.5	0.04	0.04	0.05	$F_2=0.9$, NS
QA	3.5	8.4	11.7	0.10	0.13	0.12	$F_2=21.0$, $P=0.000$
MKG	6.4	10.9	6.1	0.11	0.13	0.10	$F_2=12.7$, $P=0.000$
DP	0.7	0.2	0.6	0.07	0.04	0.06	$F_2=1.4$, NS
RST	0.0	0.0	0.0	0.00	0.00	0.03	---

Quality checks

The section commander carried out quality control checks on all cleared ground for each drill. Some of the checks were done during the 150 minutes of work time, indicated by the activity data in Table 2, with more time lost to them in Hybrid and Crab drills than during Standard drill. The checks were done to ensure that the drills were not producing unacceptable miss rates, and did not affect other aspects of the results.

Deminers were required to eliminate the cause of a signal during the drill, thus signals found during QC checks imply that a metal fragment was missed. Signals found during QC were:

- Standard: 4 signals by 2 deminers;
- Hybrid: 1 signal by 1 deminer; and
- Crab: 10 signals by 6 deminers.

The higher miss rate using Crab drill is of concern, and is an issue that would need to be addressed during training and development if this drill was adopted for operational demining. It is possible that the explanation for this lies with the unfamiliarity of the detector drills which differ significantly to their normal drills.

Discussion

Although the deminers worked under identical conditions in all drills, differences among the drills were found which clearly influenced productivity. For Standard

drill, the additional wait time cost expected in dry conditions due to watering of hard ground would further decrease productivity.

Extra time was spent in Standard drill on dealing with vegetation and changing tools. These results are because the deminer completes all activities in very small areas before moving on to the next small area, and must remove vegetation to the cleared areas behind, which can involve walking back down the lane. The deminer is constantly changing tools in order to do all required actions before moving forward another 30 centimetres. With Hybrid and Crab drills, the deminer can move vegetation to the cleared land at the side (hence minimising time spent carrying vegetation), and changes tools less frequently because larger areas are worked before a change of tool is required.

More time was spent in Hybrid drill Marking, and using Metal Detector. The extra time costs were presumably because of the additional full search undertaken in this drill as the deminer worked forwards towards the previously found indication sites.

For all of the above activities, Crab drill was either similar to or more efficient than the better of the other two drills — measured as less time spent changing tools, fewer start lines, less marking and less time using the metal detector. Discussion with the deminers indicated that they preferred Crab drill to Hybrid drill.

Although more signals were found during QC for Crab drill than for the other drills, more indications were dealt with during Crab drill overall. Thus the additional missed signals have no influence on the patterns in the data presented here. The missed signals were possibly because there was no final search with the metal detector during Crab drill, and certainly suggest that more training and experience is required for this drill.

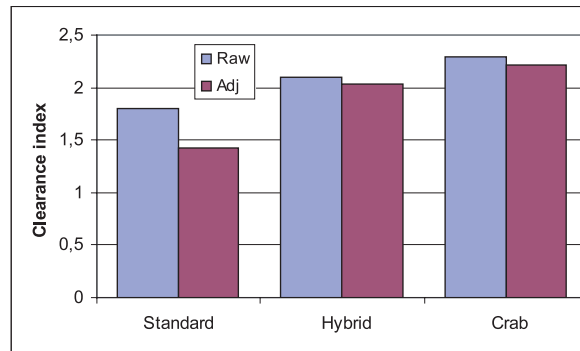
Crab drill appears to offer considerable opportunity for improving efficiency in manual mine clearance. Even when the ground was soft, Crab drill was more efficient than Standard drill on a number of measures. The benefits can be obtained without compromising safety or imposing dramatic changes on the methods used by deminers. It is predicted that the benefits will be even stronger in situations where the ground is hard and watering is required, and once deminers are more familiar and experienced with the new procedure. This prediction is explored next.

Observations made of Standard drill in April 2005 indicated a typical watering/soak time of 10–12 minutes in dry soil, but sometimes was as little as five minutes. For Standard drill, soak time represents a delay. However, for Hybrid and Crab drills soak time is used to carry out other activities, and the delay caused by watering is small. To explore these delays in more detail, the measured clearance values obtained in June 2005 were used to project the time loss under dry conditions, using predicted delays for each indication of five minutes (the minimum expected) for Standard drill, and one minute for Hybrid and Crab drills (*Figure 28*).

Time loss due to watering will depend on the number of indications in the lane; if there are no indications there will be no loss. Thus in *Figure 28*, only lanes in which there were at least three indications in the lanes cleared in June were used to predict time loss. It is the drop between the pairs of bars that portrays the productivity loss due to soak-time delays. The drop is small for Hybrid and Crab drills because only a one-minute loss was predicted. The drop is much bigger for Standard drill because of the five-minute delay. The projected difference represents productivity that can

be obtained **in addition to** the improved productivity arising from differences between the drills already described above. More indications will result in even larger relative gains.

Figure 28. Projected productivity effects of time delays caused by watering in dry conditions



Raw data are from the June 2005 study done in wet conditions. Adjusted (Adj) bars are projected on the basis of a predicted small delay due to watering for the experimental drills, and a predicted larger delay for Standard drill.

It is clear that small changes to drills can have significant effects on productivity, sometimes in unexpected ways. The GICHD encourages demining organisations to test these and other alternatives to standard drills. Other alternatives are explored in the Mozambique trials.

Trial 2

Comparing manual clearance systems

Introduction

Trials of manual mine clearance methods took place in Moamba, Mozambique, in October/November 2004 using a series of drills used by different organisations around the world.

The use of a metal detector and signal-investigation tools was compared with selected other manual mine clearance methods/tools. Each of the eight drills was assessed in a context and under circumstances that were as similar as possible and which closely reflected the realities of mine clearance in Moamba.

The trials allowed a comparative assessment of selected manual mine clearance systems (Table 3). Parameters measured were:

- speed of clearance;
- detection rate of targets within a predefined depth;
- safety of the deminer while conducting each drill;
- deminer comfort; and
- deminer confidence in the technique employed with respect to safety and methodology.

The trials were conducted at a training base in Moamba belonging to the Accelerated Demining Programme (ADP) in rural Mozambique, with assistance from three field mine clearance groups. ADP provided monitoring and evaluation staff, deminers, equipment and a wide variety of other resources.

Deminers were trained or refreshed (as appropriate) to apply each drill in lanes made for the purpose at the site. Training was conducted by experienced trainers from ADP and NPA.

Table 3. Manual mine clearance drills/systems compared in trials in Mozambique

Drill	Description
1. <i>Standard ADP detector system</i>	Minelab GC (ground compensating) detectors and ADP investigation tools were used to clear the trial areas by two ADP deminers under the supervision of a section commander. The ADP long tools were used to ensure that all tools were identical, apart from those deliberate additions under evaluation.
2. <i>Standard ADP detector system plus magnet clip-on tool</i>	Minelab GC detectors and ADP investigation tools were used to clear the trial areas by two ADP deminers under the supervision of a section commander. The ADP long tools were used as in Drill 1. The trowel was adapted to reflect CMAC's tool with a magnet along one edge. When a signal was encountered, the magnet was used without touching the ground to try to lift any scrap that was present. If that failed, the unmagnetised edge of the trowel was used to lightly scrape the ground surface and the spoil was rolled over the magnetic edge and off the trowel. When that failed to locate a source for the signal, standard signal-investigation procedures were followed and the spoil rolled over the trowel as the deminer worked.
3. <i>Standard ADP detector system plus magnetic brush rakes</i>	Minelab GC detectors were used along with a modified magnet Brush-rake (a two-metre long tool) to clear the trial areas by two ADP deminers under the supervision of a section commander. When there was a detector signal, the ground area was swept with the Brush-rake and the attached magnet picked up ferrous fragments. The magnet Brush-rake was used along with other long ADP excavation tools that had no magnets attached.
4. <i>Detector in low-fragment area</i>	The Minelab GC detectors alone were used, and targets were marked without investigation by two ADP deminers working under the supervision of a section leader. The deminers then swapped working areas, the position of markers was recorded and the markers removed. The drill was then repeated including the investigation of signals using a magnetic trowel in addition to standard ADP long tools. This repeated search tested the accuracy and repeatability of detector pinpointing. Fragments were not placed in this area. The second part of this trial was a "detection reliability" test as described in the European Committee for Standardization (CEN) Workshop Agreement CWA 14747:2003. ^{o)} The part of the trial which included full signal investigation was timed and monitored, and treated as one of the comparative trials.
5. <i>The REDS rake system</i>	The Rake Excavation and Detection System was used to clear the trial area by two ADP deminers under the supervision of a section commander. The method was taught by an NPA trainer who came from Sri Lanka for the purpose. REDS is a system of excavation using two types of rake that is ideal on soft ground, but which is also sometimes used on very hard ground (see <i>Sri Lanka Case Study</i>).
6. <i>Standard ADP spade area-excavation</i>	The ADP excavation-only system (no metal detectors) was used to clear the trial area by two ADP deminers under the supervision of an ADP section commander. This excavation method involved the use of prodders and an ordinary garden spade. The spade was used to cut slices of earth away from the face of an excavation that had been started outside the lane.
7. <i>Standard NPA (Mozambique) excavation</i>	The NPA Mozambique excavation system was used to clear the trial areas by two NPA deminers under the supervision of an NPA section commander. NPA Mozambique sent two deminers and a section commander/QA person to take part in the trials, using the complete system (including marking) to which they were accustomed. A key feature of the system is a short, purpose-made trowel, used for excavation.

Drill	Description
8. <i>Standard mattock excavation</i>	The <i>enxada</i> (mattock) system was used to clear the trial areas by two ADP deminers under the supervision of a section leader. The <i>enxada</i> excavation method involved the use of prodders and an <i>enxada</i> . Mattocks of various sizes were sourced and the size most closely reflecting the type employed in Mozambique was used.
9. <i>Prodding from the surface</i>	ADP prodders were used to determine the depth that could be prodded in the conditions at the trial site. Two deminers worked on separate areas of a single square metre in which targets had been placed at depths straddling the depth to which it was possible to prod in that ground while using two hands and excessive force.

a) European Committee for Standardisation (CEN) Workshop Agreement CWA 14747:2003 (available at: humanitarian-security.jrc.it/mine-clearance/cw07/).

These trials were of complete demining systems, not just the tools involved. The system included full field supervision and internal QA methods, without which the deminers would not have declared an area as “clear”.

Methods

Trial lanes

Lanes laid out for the trials were in pairs, each 5 metres long and 1 metre wide. Vegetation in all lanes was cut prior to placing targets. Eight target mines were positioned in each pair of lanes, at depths of 12 centimetres and 1 centimetre (measured to the top of the mine). Four lanes were worked in each trial (although all four were not always completed). Graded scrap fragments collected from minefields were placed in the 12 lanes used for those trials where metal detectors were used. Throughout the trials, the fragments were placed at a density of 7 per square metre. Other metal items may have been present, thus seven items a square metre was the minimum number in the lane.

Surrogate mines (target mines)

Surrogate mines were made from wood to the exact dimensions and approximate weights of Chinese Type 72A and GYATA-64 anti-personnel mines (*Figure 27*). Metal pieces that gave identical signals to the real mines (to the detectors used and at the depths placed) were inserted. The top of each mine was coated in a latex solution producing a “witness-plate” on the top to preserve the evidence of any top impact during recovery. An “initiation” was assumed if the damage to the wood beneath the rubber was in a position that would have applied pressure to the pressure-plate and of a depth that indicated significant force had been applied.



Figure 27. The damage to the top of this surrogate GYATA-64 was not visible before the witness plate was peeled away.

Trial duration

All trials (except trial 9) used two deminers and a supervisor for up to three days or 10 square metres cleared by each deminer (two lanes), whichever was sooner. Thus, trial duration was constrained by both area and time.

Data recorded



Figure 28. QinetiQ representative observing trial.

Data were recorded for each trial by an independent Trial Monitor using a pre-agreed recording format (*Figure 28*). Independent Trial Monitors were ADP, the German University, the Bundesanstalt für Materialforschung und -Prüfung (BAM), and QinetiQ.

Quantitative records were made of: time; area; ambient conditions; concealed mines located; damage to mines located; fragments located; and unusual sub-surface features that affected speed of advance. The method of internal QA/QC was also recorded. After trials using area excavation methods, random depth-achievement checks were made. No depth checks were made during work or prior to the end of the trial in that area.

Through interviews, qualitative assessments were made of: safety of method, comfort of tools used, user confidence in safety and thoroughness, and confidence in internal QA/QC.

When a target mine was located, its position was recorded by the Trial Monitor who then removed the device, taking care not to touch it on the top surface. The discovered devices were placed at the far end of the lane where they remained until the day's work was over. Apparent tool impacts were recorded by the Trial Monitor and later checked by removing the witness-plate and examining the top of the surrogates (this was done to all surrogates regardless of whether an impact was apparent).

All trials using metal-detectors had one or more buckets in which to place the metal scrap located. The total amount of recovered scrap metal was recorded. In trials where magnets were used, each deminer had a second bucket in which to place metal recovered with the aid of the magnets. The number of fragments found with a magnet was also recorded.

Although these trials involved an assessment of the difference made by using different techniques in the same area, the trials were of complete systems, not just the tools involved. The system included full field supervision and internal QA methods, without which the deminers would not have declared an area as "clear".

Drill 9 (prodding only) was also used to investigate the effects of rain. The depth of prodding was measured before and after heavy rain.

A description of how to interpret the results of statistical analyses is in Annex 1.

Four lanes were cleared for drills 1, 2, 3, 4, 6 and 8. Three lanes were cleared for drill 3. Two lanes were cleared for drill 7.

Rate of progress

The time taken using each drill was measured as a function of rate of forward movement in the lane (in centimetres). Considerable variation was found among drills for rate of clearance, with drills using metal detectors tending to be faster than drills in which no metal detector was used (*Figure 29*).

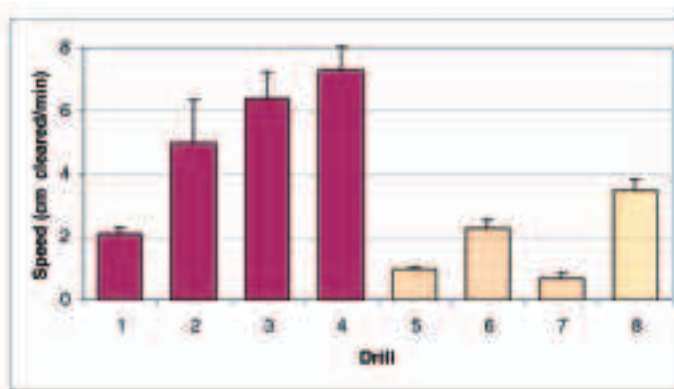
Statistical analysis of the relationships in *Figure 29* showed significant variation (one-way analysis of variance, $F_{1,7} = 17.94$, $P < 0.01$). Post-hoc pairwise tests are used to check for the sources of significant differences in a multiple comparison such as here. Using a post-hoc test, drills 3 and 4 were shown to be similar, and significantly faster than the other drills. The other drills were not significantly different from each other.

The standard ADP drill using a metal detector (drill 1) was similar in speed to the four drills in which no metal detectors were used. The addition of a magnet to the trowel (drill 2) improved performance. Adding a magnet and brush rake (drill 3) improved performance further. The fastest drill (drill 4) was the equivalent of drill 2 applied in an area free of metal fragments.

By using the magnetic brush-rake (drill 3), in terms of clearance rate, a high-fragmentation area (as in drill 1) was effectively reduced to a low-fragmentation area (as in drill 4). These results clearly show that any opportunity to remove metal fragments from a clearance zone should be taken, and demonstrate the value of magnets in high fragmentation areas.

Figure 29. Clearance speed of different manual mine clearance drills (drill types defined in Table 3).

Drills 1-4 used metal detectors; drills 5-8 did not. Bars are mean + standard error.



Although no significant variation was found among the four drills in which no metal detector was used, the data suggest that use of a tool such as a mattock (drill 8) or spade (drill 6) results in clearance rates similar to or slightly better than those achieved with a metal detector and no magnet when many fragments are present. REDS (use of rakes, drill 5) was very slow under the conditions in Mozambique, and was similar to the equally slow Mozambique NPA drill (drill 7).

Safety

With respect to deminer safety, an “initiation” was considered to have occurred when damage to the top of the surrogate mines was extensive enough to make an initiation probable. Drill 4 (standard ADP tools and a magnetic trowel) and drill 8 (mattock) had very poor deminer safety results (Table 4). Deminers believed that the mattock was an inappropriate demining tool and contributed to the poor safety result. However, drill 4 gave a similar result to that found for the mattock, and drills 2 and 4 were identical, with the exception that there were no fragments present for drill 4. These results suggest a much higher accident rate than is normally experienced by the organisations working the drills. The results should be interpreted cautiously as the deminers knew there was no risk during the trials.

Table 4. Safety consequences for deminers and end-users.
Drill types as in Table 3.

Drill	Initiations/10 m	Mines missed/10 m
1	0.5	0
2	0.5	2
3	0	0.5
4	1.5	0
5	0.5	0
6	0.5	0
7	0	4
8	1.5	0

With respect to safety of end-users, mines were missed by drills 2, 3 and 7. No mines were missed by the other drills.

Only deep buried mines (at 12 centimetres) were missed. The mine surrogates were all Chinese Type 72A anti-personnel mines which would not normally be planted at that depth, and it is possible that the NPA deminers and supervisor (drill 7, no metal detectors) assumed that mines would be shallower despite being instructed to work to the national clearance depth of 13 centimetres. Type 72A mines are minimum metal and are difficult to detect using metal detectors when buried deep (drills 2 and 3). At least one mine buried at 12 centimetres depth was missed due to assumed detector irregularity.

General patterns in the results

Drill 1 (Standard ADP detector system): an area containing more than seven metal signals /m² was cleared successfully to 13 centimetres using the Minelab F1A4 metal detector and conventional tools for detector signal investigation.

Drill 2 (Standard ADP detector system plus magnet clip on tool): attaching a magnet to a hand-tool used for detector signal investigation in an area containing more than seven metal signals/m² halved the time required to achieve “metal-free” status, although some deep mines were missed.

Drill 3 (Standard ADP detector system plus magnet brush-rake): addition of a magnetic brush-rake to the equipment used in drill 1 in the presence of more than seven metal signals/m² resulted in a clearance rates three times faster than for drill 1.

Drill 4 (Detector in low-fragment area): showed that, when using conventional detector signal-investigation routines, the accuracy with which the detector signal was pinpointed did not affect whether or not the associated device was found. (The trial did not reliably show the effect that a pinpointing inaccuracy would have had on deminer safety had the mines been real.)

Drill 5 (The REDS rake system): the REDS area-excavation system was used successfully in the trial area, and was the only area-excavation process that allowed for realistic field QA without constant supervision. It was also the method that gave most confidence in total clearance (including small items such as fuses) to a given depth, because of the soil-sifting process involved. However, it was one of the slowest methods.

Drill 6 (Standard ADP spade excavation system): the controlled use of a conventional garden spade was the fastest area excavation method under trial. Deminer safety was the same as for the REDS system, and both were safer than the two other excavation methods.

Drill 7 (Standard NPA Mozambique detection system): using a short, purpose-made trowel for area excavation was very slow, and would have resulted in deep mines being missed if continued over the entire lane.

Drill 8 (Standard mattock excavation): using a mattock for area excavation was fast, but dangerous for the deminer because it resulted in severely damaged targets that would probably have resulted in initiations. Despite its relative speed compared to other area-excavation methods, it was slower than clearance systems using a metal detector and magnetic tools.

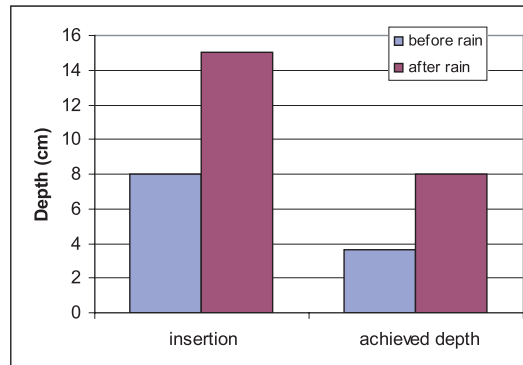
Prodding

Drill 9 was a simple prodder trial, where the depth achieved by prodding in a small area was measured before and after rain. Because prodders are normally required to be used at an angle of about 30°, the apparent depth (length of prodder inserted into the ground) and achieved depth (vertical depth from surface to prodder tip) were measured and calculated. Individual insertions with the prodder were measured, with sample sizes of 16 insertions (before rain) and 18 insertions (after rain) made at two different locations (two of the lanes used in drill 8).

The achieved depths were approximately half the insertion depths (*Figure 30*). The achieved depth after rain was approximately double the achieved depth before rain. The maximum achieved depth after rain was 11 centimetres. These results indicate that prodding in hard soil will result in most mines deeper than about 5 centimetres being missed, whereas prodding in soft soil (after rain) will result in most mines deeper than about 10 centimetres being missed.

The tops of all the target mines that were located during trial 9 (prodding) had been deeply damaged by the prodder.

Figure 30. Insertion depths and achieved insertion depths using a prodder before and after rain.



Discussion

Considerable variation was found in the effectiveness and safety of the different demining techniques studied here. Perhaps most significant in terms of improving productivity in manual demining is the usefulness of a very simple and cheap tool, a small magnet, for dealing with indications from a metal detector.

When no metal detectors are available, the most efficient method in terms of both speed and safety is to use a garden spade to slice thin layers of earth horizontally from the side of a vertical excavation face. This process was a little slower than when a mattock was used, but was considerably safer. The primary advantage of any such excavation system is that the entire ground is turned over, giving very high confidence in the demining product (down to a certain depth).

With respect to QA/QC requirements, REDS was the best system trialled. But under the conditions in Mozambique it was very slow. It is particularly suited to the conditions in Sri Lanka where the soils are sandy and easy to work for most of the year, and there is relatively little ground vegetation. It could have potential for application in some desert and semi-desert situations.

Prodding is an inefficient and dangerous means of locating concealed mines at any depth. It is also essentially impossible to prod deeper than 10 centimetres using standard prodders, and prodding rarely achieves even that depth, especially in hard ground. These conclusions confirm results found previously by Trevelyan (2003).² When linked to excavation using other tools, prodding can be effective at greater depths, but is still slow and dangerous.

1. Trevelyan, J. (2003).

Conclusions and recommendations

Conclusion 1. Manual mine clearance innovations.

The mine clearance industry demonstrates significant innovation. Such innovations are normally a response to local conditions and constraints. While they may only be effective under similar conditions, they could also represent novel ideas with broader potential application. For example, post-clearance area reduction (PAR) is likely to be most effective where patterned minefields predominate and the Rake Excavation and Detection System (REDS) is most effective under conditions of soft soil and limited vegetation cover. Whereas PAR (developed in Lebanon) transferred easily to Iraq, REDS (developed in Sri Lanka) was very slow in Mozambique relative to other drills.

Findings

Most mine clearance programmes visited over the course of the study included innovative advances, some of which had been adopted informally. Most of these innovations had been adopted in order to increase the speed of clearance. However, careful testing prior to implementation in order to demonstrate the believed advantages and check safety issues had not always been carried out. Procedures for incorporating innovative procedures into SOPs and having them improved by the national mine action authority (NMAA) were not streamlined, and were often ignored.

Key to understanding the nature and application of an innovative procedure is a clear description of the situation in which it is being used. For example, formalising the process of reducing areas originally suspected of being mined after the clearance of *known* mines has proven to be very effective in patterned minefields. The follow-up procedure described in Iraq of having a team visually inspect areas after PAR is likely to be perceived as too hazardous in many situations. However, the procedure is acceptable when an appropriate risk assessment has been undertaken. The question of whether such a procedure could or would be implemented in an operational environment where there was an effective NMAA is worth considering.

Recommendation 1.

- a. Innovation is welcome at any time and is relatively easy to achieve in mine clearance. However, the new techniques and processes must be*

rigorously trialled and documented, and implementation should only follow careful assessment of the results of such trials.

b. Mine clearance agencies do not routinely have personnel with the skills needed to design and undertake carefully controlled trials. Support from organisations such as the International Test and Evaluation Programme (ITEP) and the GICHD can and should be requested as a part of the trial process.

c. The results of trials of innovative techniques are a valuable resource for the demining community, even if the trial turns out as a failure. Results of trials should be made widely available, for example through placing trial reports onto websites and reporting them at workshops and conferences. The GICHD or equivalent organisations can help with this process.

d. There is a need to streamline the approval process for innovative techniques, including developing procedures for having them written into SOPs.

Conclusion 2. Magnets and brush rakes.

The use of magnets and brush rakes as additional tools to the standard manual mine clearance “toolbox” will increase manual mine clearance efficiency in many circumstances.

Findings

Trials undertaken in Mozambique supported operational experience in several countries that simple magnets and brush rakes can increase rates of clearance. Most demining is undertaken using simple tools, and any opportunity to add a new simple (and cheap) tool to the toolbox should be widely encouraged. In Sri Lanka, one demining organisation eventually rejected metal detectors in preference for the REDS procedure using rakes.

Recommendation 2.

a. All programmes should consider the integration of “non-standard” tools in order to improve clearance rates in manual mine clearance programmes.

b. Integration of these tools should be tempered with a full quality management system to ensure safe clearance methodologies.

Conclusion 3. Risk and quality aspects.

The methods most likely to leave mines behind or lead to accidents are:

- Area excavation in which the required clearance depth was not rigorously maintained;
- Use of metal detectors that are only marginally able to do the required task, because of either design or age; and
- Prodding from the surface.

Findings

All mines missed in the Mozambique trials were buried at a depth of 12 centimetres. Two of the procedures using metal detectors missed mines because of a combination of search speed and metal detectors inadequate for the task. Recent trials of metal detectors suggest that they routinely do not achieve stated manufacturers’ specifications. Mines were also missed using an excavation technique that was not

being applied rigorously to the required depth standard. Prodding from the surface could not supply the required detection depth, especially in hard soils.

Recommendation 3.

a. Demining agencies presumably only use metal detectors that are inadequate to a task because they have no other options. Regular replacement of metal detectors should be a part of budget planning. Also, metal detectors that are functional in one deployment location might not be adequate in another. Sponsors need to be made more aware of the limitations of metal detectors and the replacement requirements.

b. Use of prodding as a standard demining procedure should be reviewed, with a view to minimising use of this potentially dangerous and limited tool.

Conclusion 4. Traditional versus new techniques.

Established procedures tend to become self-maintaining as a result of training and experience, building in extra resistance to change. Demining agencies obtain too little information about the procedures used by other agencies, and/or have too little opportunity to compare notes and discuss alternative options. Field managers are in a difficult situation: on one side they are required to adhere rigorously to established procedures (laid down in an approved SOP) yet, on the other side, as a result of experience they can often see options for improving productivity without compromising safety.

Findings

Trials run in south Sudan and Mozambique clearly identified opportunities for improving procedures and equipment. Any agency adopting new procedures or equipment will need to do small trials and training, make adjustments as a result of local conditions, and modify and rewrite SOPs. However, the benefits to be gained in terms of productivity appear to be much more significant than the costs involved in making changes.

Recommendation 4.

a. Current manual mine clearance techniques, although appearing to exist as a result of long experience and trials, can still be challenged to achieve a higher degree of efficiency. Trials in this study suggest a significant potential productivity gain. Field managers should investigate the potential for increased clearance rates by carrying out trials and implementing change if appropriate.

b. Field managers and technical advisors should have the opportunity to meet and exchange ideas in a workshop format on a regular basis.

c. Support for trials and modifications should be made available by the wider community in order to assist implementation.

Conclusion 5. Standing Operating Procedures (SOPs).

Although some lag is expected between innovation and the development of SOPs, the evidence in the case studies was that updating of SOPs was viewed as a difficult and low priority task.

Findings

In all of the case studies, SOPs were found to be out of date or in need of development. There was little motivation to improve them, presumably because this was not seen as a priority at a management level. SOPs are often too rigid and inflexible, which prevents innovations and potentially useful changes. SOP changes often require approval from national authorities which may be a bureaucratic and time-consuming process. SOPs should therefore allow minor changes without the need to consult mine action authorities on every occasion.

Recommendation 5.

- a. Updating SOPs needs to be given a higher priority in order to ensure ongoing compliance with the International Mine Action Standards (IMAS) and National Mine Action Standards (NMAS). Support from external agencies may be required to ensure that such updating proceeds regularly. National agencies should be more proactive on this issue, perhaps through providing an updating support service.*
- b. SOPs should be written in less rigid forms, which will make it easier to change them when necessary.*

Conclusion 6. Standard drill versus Hybrid and Crab drills

The standard manual mine clearance drills appear to be implemented in a similar fashion in most countries. This is in part due to a perception that the technique is too well proven to be challenged. Two experimental drills — the Hybrid and the Crab drill — show, however, that it is possible to significantly increase the speed of manual mine clearance by adapting an innovative approach to the clearance process. The Crab drill is particularly promising and appears to be 30 per cent more effective in wet conditions. In dry soil, the potential gain is significantly higher. This technique, or variations of it based around the principle of minimising the time for tool handling, vegetation cutting and watering/soak time, should be considered by field managers.

Findings

The Hybrid and Crab techniques both proved more efficient than the Standard manual mine clearance drills during the trials in Sudan. In wet soils, the difference between the Crab and Standard drills were significant which suggests that the Crab drill may be used permanently both during wet and dry conditions (provided there is a requirement for vegetation cutting). Dry soil conditions where watering is required amplifies this difference significantly. Programme managers should, though, consider that the Standard drills do provide security and safety measures; reaching this level of safety would require additional levels in Hybrid and Crab drills.

Recommendation 6.

The Hybrid and Crab techniques should be considered as alternatives or substitutes for traditional manual mine clearance techniques as they may offer a significant increase in clearance efficiency in most conditions.

Annex 1

Interpreting statistical analyses

Reports of statistical results use a technical shorthand that is not generally familiar to those reading reports about demining. Thus a short introduction is provided here.

Statistical tests normally compare two or more groups of data. One group of data constitutes a set of measurements of a variable (e.g. proportion of time spent using a metal detector), usually obtained as one measurement per subject. The number of subjects therefore constitutes the sample size (N). The test itself involves applying a mathematical formula to the sets of measurements in order to calculate a **test statistic** — a number which represents the variability found within and between the sets of measurements.

In simple terms, if the test statistic is small, that normally means either or both of:

- the variability within each set of measurements is large, and
- the difference between the means is small.

Most people understand a mean (or average), but have more difficulty understanding the concept of variability (or variance) around the mean. Table 1 gives a simple example using data from the Sudan study. Two sets of measurements are listed, each giving the proportion of time one deminer (the subject) spent using the metal detector in two drills.

Table 1. Two sets of data for seven subjects with means and variances (calculated as standard deviation)

Subject	Use MD, Drill 1	Use MD, Drill 2
A	15.3	21.3
B	17.3	20.7
C	12.7	6.0
D	13.3	10.0
E	8.7	10.0
F	10.0	26.7
G	15.3	21.3
Mean	12.9	15.8
Variance (s.d.)	3.2	8.2

The means are only slightly different between the two sets of measurements, but the variances are quite different. The reason is easily seen by reviewing the data. In drill 1 (low variance), the measurements range from 8.7 to 17.3. In drill 2 (high variance) the measurements range from 6.0 to 26.7. Just from looking at these data, it is easy to predict that the two sets of measurements will not be statistically different from each other, but that prediction is not made using the rather similar means — it is made by looking at the ranges and variances of the sets of measurements.

When reviewing a set of measurements visually, the range is useful. But statistical tests do not normally use the range in the data. In simple terms, what they estimate is the relationship between the means and the variances. For example, it is quite possible for two means with the values 12.9 and 15.8 to be statistically different — all that is required is that the variances be small (considerably smaller than in this example). In that case, the ranges of the data would also be much narrower or, put another way, the data would be clustered more closely around the mean.

There is no need to understand the mathematics underlying statistical tests in order to understand the results of a test. The calculations have been subject to a long history of development and testing and are standardised in many computer software packages. The package used for the analyses in this report is called Statistica®.

The meaning of “significant”

It is essential to understand the concept of a difference that is “**significant**”. This term has specific technical meaning, and the notion of a statistically significant difference is central to any statistical conclusion.

In essence, increasing differences between the means, and decreasing variances around each mean, together imply an increasing likelihood that the two sets of measurements are **significantly different** from each other in statistical terms.

In Table 1, the means of the two sets of measurements were slightly different, but were they different enough to allow a conclusion that the difference was in some sense real? Statistical testing provides an objective mechanism for addressing that question.

The hypothesis being tested here is that drills 1 and 2 are somehow resulting in a different use of metal detectors. In other words, there is something fundamental to drills 1 and 2 that leads to a real (or statistically significant) difference in the way metal detectors are used.

Statistical testing uses a standard rule: if $P < 0.05$, then the conclusion should be drawn that there is a statistically significant difference. P is estimated using the result of the statistical calculation (the test statistic).

P stands for “Probability”, and the shorthand $P < 0.05$ can be written out in words as: **the probability of the measured difference being due to chance is less than 1 in 20 (5%, or 0.05).**

A probability of less than 1 in 20 is regarded as unlikely enough to support a conclusion that something other than chance factors are at work. The difference between the sets of measurements is real, i.e. is an effect of the different conditions.

These days, the computer normally reports an exact probability and that probability is then reported as part of the Result, along with the test statistic. Thus a standard statistical report (in this example for a t-test) will be phrased as:

X was significantly bigger than Y ($t = 10.9$, $P=0.004$, Table Z).

An enormous amount of useful information is bound up in this simple sentence. But in essence, it simply says that the difference between X and Y can be attributed to something other than chance, and it also gives the direction of difference: X is bigger. It is appropriate therefore to appeal to the different conditions under which X and Y were measured as the likely source (or cause) of that difference. A summary of the data used to make the test can be found in Table Z. Table Z might alternatively have been a graph.

A t-test is the simplest form of an analysis of variance, because only two sets of measurements are compared (as in Table 1). If more than two sets of measurements are available (i.e. more than two conditions are being compared), then a more general test is required: the standard test is analysis of variance (ANOVA). In the Sudan trials, three conditions were compared, so an ANOVA was used to test the data. ANOVA returns an “F” statistic, which is reported along with the result:

There was significant variation among the three conditions, with X being largest and Y smallest ($F=7.2$, $P=0.008$).

A P value of 0.008 is lower than the $P<0.05$ rule, so the appropriate conclusion is that differences among the sets of measurements are due to something other than chance, hence the use of the word “significant” in the sentence.

Where three or more conditions are being compared, the analyst may want to know which pairs of conditions are significantly different from each other. Say the F test gives a significant result and the means are A:2.4, B:5.8 and C:6.3. Just by looking at these means, it seems reasonable to expect that A and C are significantly different, with B intermediate. B might be significantly different from A but it is unlikely to be significantly different from C. This is the situation that arose in Figure 21 in the Sudan study. The statistical procedure used to assess these pairwise comparisons is called “post-hoc analysis”. In Figure 21, it turned out that A:C was a significant difference, but A:B and B:C were not significantly different.

Annex 2

Crab and Hybrid Drills

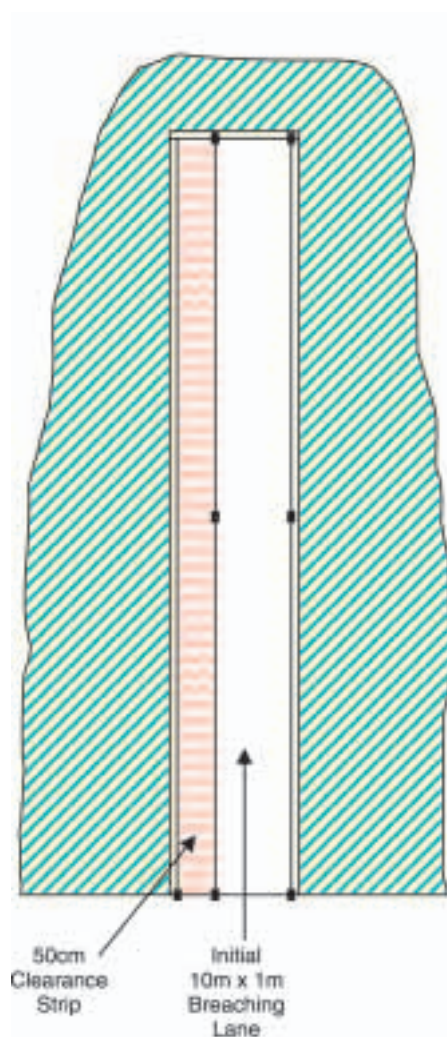


Figure 1. Hybrid and Crab drills.

Both drills extend the initial, 1m wide, breaching lane by 0.5m (+ 10cm overlap) at a time.

A lane marker is placed at the entry point 0.5m in the direction of clearance to delineate the area to be cleared in one bound, and tripwire search and vegetation clearance is carried out.

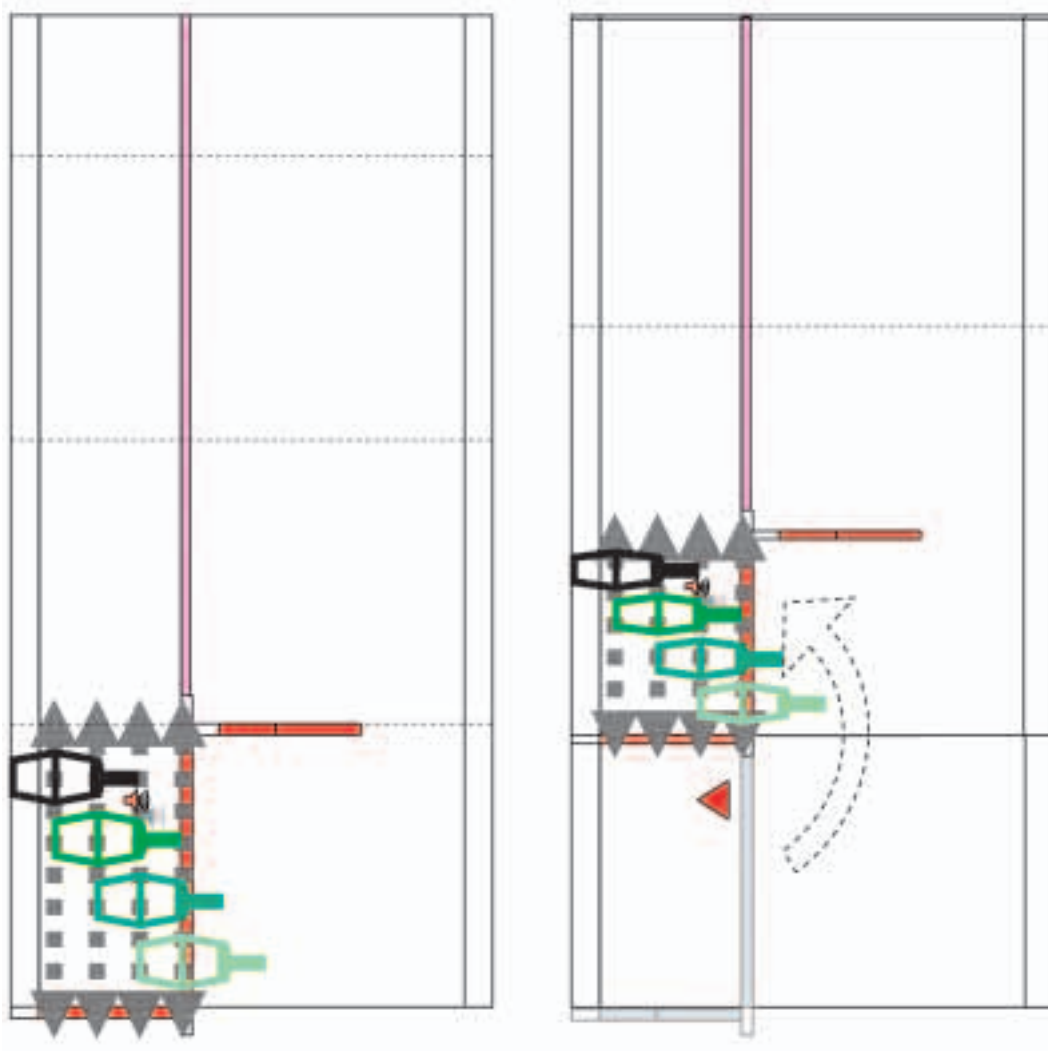


Figure 2. Hybrid and Crab drills

Using a 120cm basestick and two 60cm half-sticks, the 0.5m strip is searched and signals are marked.

A fingertip search is carried out to find and remove surface-laid fragments.

Buried signal points are watered and marked. No excavation takes place at this stage.

Search progresses in 1m intervals

Once the initial search is complete, all signals will have been marked and watered.

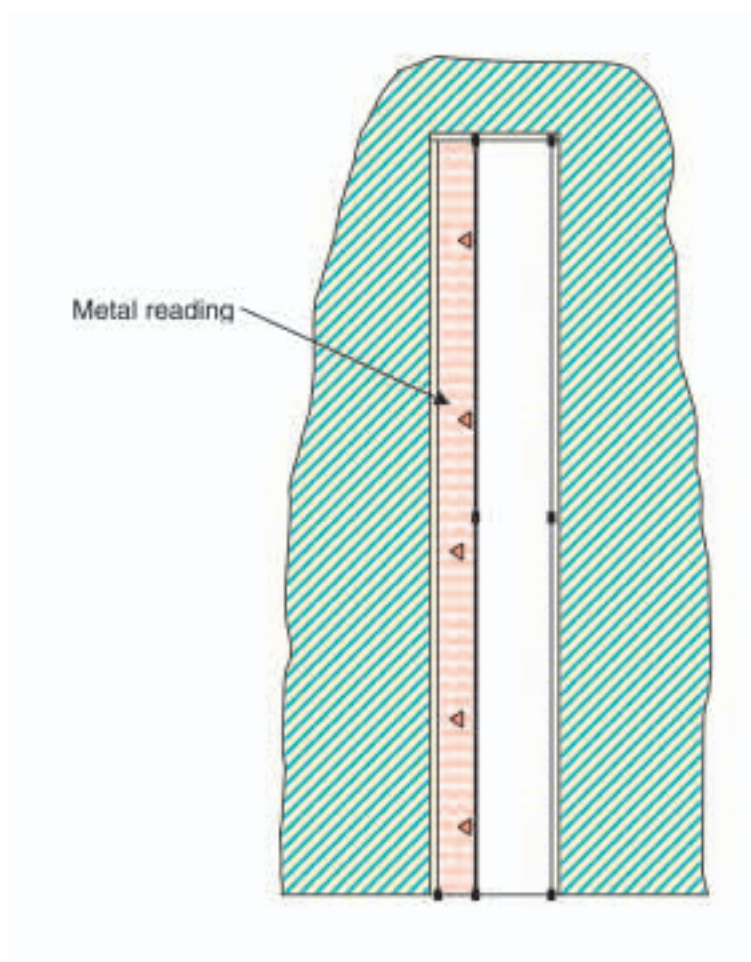


Figure 3. Hybrid and Crab drills

Once the initial search is complete, all signals will have been marked and watered.

Hybrid drill: Search is done relatively quickly because area will be subsequently re-searched.

Crab drill: Search is a full search

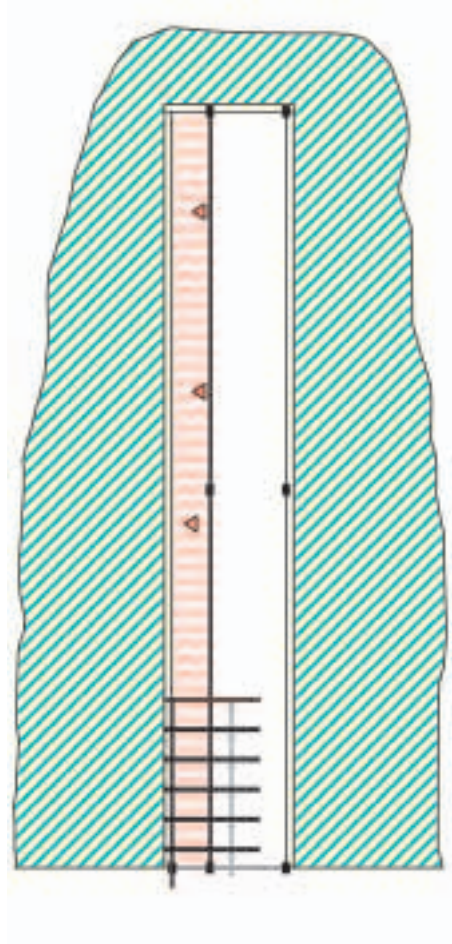


Figure 4. Hybrid drill only

Search progresses along the lane.

Only those signals immediately forward of the basestick are investigated.

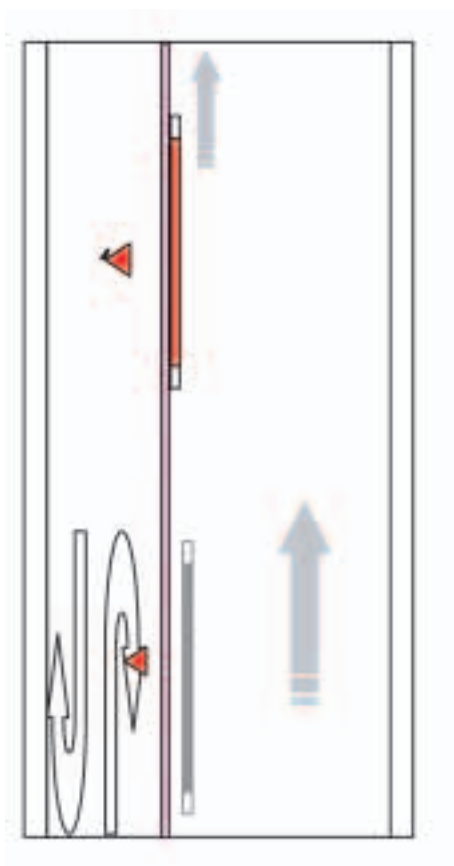


Figure 5. Crab drill only

From behind a 120cm base-stick, placed no further forward than the mine tape boundary, the 0.5m strip is searched.

Individual signal sources are investigated and removed.

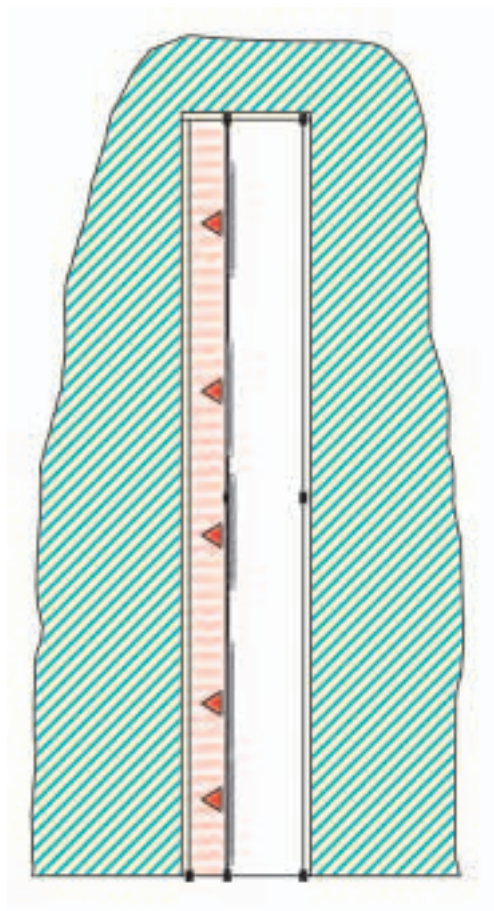


Figure 6. Crab drill only

Only previously marked signal sources are investigated, the intervening spaces are not.

Probing, watering and excavation drills may switch between different signal readings to make maximum use of watering 'soaking in' times.

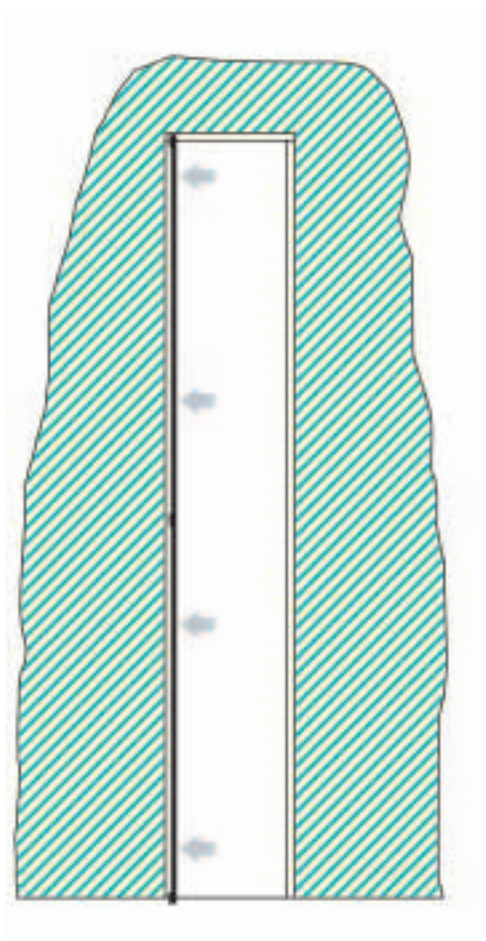


Figure 7. Hybrid and Crab drills

Following investigation and clearance of all signals and a Quality Control check of the lane by the Section Commander, the baseline is moved forward 50cm.

Bibliography

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Glossary of acronyms

ADP	Accelerated Demining Programme
ANOVA	analysis of variance
BAC	battle area clearance
CMAC	Cambodian Mine Action Centre
DDAS	Database of Demining Accidents
DDG	Danish Demining Group
FSD	Swiss Foundation for Mine Action
GHR	Ground Reference Height
HDU	humanitarian demining unit
IMAS	International Mine Action Standards
ITEP	International Test and Evaluation Programme
LTTE	Liberation Tigers of Tamil Eelam
MAG	Mines Advisory Group
MCRA	mine clearance risk assessment
MRE	mine risk education
NGO	non-governmental organisation
NMAA	National Mine Action Authority
NMAS	national mine action standards
NPA	Norwegian People's Aid
NSCMA	National Steering Committee for Mine Action
PAR	post-clearance area reduction
PPE	personal protective equipment
QA	quality assurance
QC	quality control
REDS	Rake Excavation and Detection System
SOP	standard operating procedure
SPLA	Sudan's People Liberation Army
TRO	Tamil Relief Organisation
UNDP	United Nations Development Programme
UNTAC	United Nations Transitional Authority in Cambodia



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