A HANDBOOK OF MECHANICAL DEMINING

JULY 2009

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REFERENCE DOCUMENTS

The CD with this handbook contains the following Reference Documents:

1. International Mine Action Standards | IMAS 09.50 Mechanical Demining
2. International Mine Action Standards | IMAS 04.10 Glossary (Ed. 2) Amendments 1, 2 & 3
3. CEN Workshop Agreement | CWA 15044:2004, Test and Evaluation | Demining Machines
4. CEN Workshop Agreement | CWA 15833:2008, Quality management: quality assurance (QA) and quality control (QC) for mechanical demining
5. CEN Workshop Agreement | CWA 15832:2008, Follow-on processes after the use of demining machines
6. The GICHD Mechanical Demining Equipment Catalogue 2008
7. The GICHD 2008 Guide to Road Clearance
8. GICHD 2004: A Study of Mechanical Application in Mine Clearance
9. Common types of erosion: consequences and control measures
10. A selection model for demining machines
11. Sample forms
12. Sample forms (Word format)
13. A Handbook of Mechanical Demining, GICHD (Word format)

FOREWORD

Demining machines are used today in most mine action programmes world-wide, but with varying degrees of success. Mechanical clearance can greatly accelerate demining operations and technical survey, especially when used in combination with other demining assets. However, if not used correctly, demining machines can also haemorrhage funds from a mine action programme, or project, like no other assets. If used correctly demining machines offer new approaches and possibilities to increased cost effectiveness and productivity.

There is now a wealth of different demining machines, each for specific and different purposes and with different capacities. In previous publications, the GICHD has shown the variety of machines available and also studied mechanical application in demining and, in particular, during road clearance. The GICHD recognised the need for a handbook covering further aspects of mechanical demining. This publication covers a broad range of topics including local construction of demining machines, deployment, operational use, contracting and environmental aspects of mechanical demining. The handbook also includes a selection model to assist the process of purchasing demining machines.

We trust you will find the handbook useful and informative.

Ambassador Stephan Husy
Director
Geneva International Centre for Humanitarian Demining

THE AIM OF THE HANDBOOK

The aim of this handbook is to explain, in understandable and easy terms, the simple principles of mechanical demining, to challenge some prevailing attitudes to their use and to encourage dynamic mechanical planning. Our overall aim is to globally increase the amount of mined land that is cleared and released each year through more effective use of demining machines. The handbook provides guidance and advice to mechanical demining operators in the field. The handbook should be used together with the GICHD *Mechanical Demining Equipment Catalogue*, the GICHD *Guide to Road Clearance*, and the GICHD *Study of Mechanical Application in Mine Clearance*. The handbook also refers to other publications published by the GICHD and other organisations. On the CD that accompanies this book there are a number of Reference Documents relevant to mechanical demining.

The handbook is divided into seven chapters and 10 annexes. Each chapter may be read individually but the reader will gain greater benefit from working sequentially through the whole handbook, chapter by chapter. The handbook also contains 13 Reference Documents on the CD-ROM enclosed. The Annexes and Reference Documents are also available on the GICHD website, www.gichd.org. Annex D contains various checklists that can be used for guidance at the various stages of purchasing, deploying and using demining machines. For convenience, the main document is provided in a Word version so that the user can easily extract information for the production of National Mine Action Standards (NMAS), guidelines, Technical and Safety Guidelines and Standard Operating Procedures (SOPs). Readers are welcome to extract wording from the handbook for use in preparing SOPs and other documents. We request that the GICHD is credited or acknowledged on all such documents.

CHAPTER 1

DEMINING MACHINES

DEMINING MACHINES

CATEGORISATION OF DEMINING MACHINES

IMAS 09.50 divides demining machines into three categories: mine clearance machines, ground preparation machines and mine protected vehicles.

The category is decided by the intended main use of the machine. If the main task is to destroy mines and the working tool is suitable for such a task (e.g. flails, tillers, sifters, rollers or a combination of these tools) the machine falls under the mine clearance machine category. If the intended purpose is to remove vegetation, or other obstacles, to prepare for a subsequent clearance activity the machine belongs to the ground preparation category. When the machine is to be used as a platform for a detection system in a Suspect Hazardous Area (SHA) it is normally categorised as a mine protected vehicle. For a non-exhaustive list of mechanical demining equipment available and examples of various machines, see the GICHD *Mechanical Demining Equipment Catalogue 2008* [1] — and the table in Annex A provides a general summary of the tasks normally associated with the machine categories. There is some task crossover between the three categories of demining machines.

Demining machines are generally used in four roles:

- Destroy mines
- Prepare ground[2] (and destroy mines but not in all cases)
- Confirm the presence of mines
- Act as a platform for another tool or application.

Some demining machines can serve several purposes at the same time. For example, if a ground engaging tool is used like a flail during demining operations it may destroy mines, remove vegetation and loosen soil. And if its prime mover was fitted with a magnet it could also remove metal debris and collect information on the mine and ERW contamination.[3]

Machines can be further sub-categorised into:

- Weight classification (light, medium or heavy)
- Intrusive (designed to work inside a SHA)
- Non-intrusive (designed to work from a safe ground "reaching into" the SHA)
- Remotely operated (designed to be remotely controlled from safe ground by an operator, either intrusive or non-intrusive)
- On-board operated (designed to be controlled by a driver/operator from a protected cabin, either intrusive or non-intrusive).

MINE CLEARANCE MACHINES (light, medium, heavy systems)

Mine clearance machines are those machines whose stated purpose is the detonation, destruction or removal of landmines.[4] For example, a front-end loader, armoured and adapted to excavate mined ground, can be defined as a mine clearance machine because the definition includes the removal of mines.

The main mine clearance machine designs are:

- Flails
- Tillers
- Machines with a combination of tools
- Civil or military plant machinery that has been adapted for mine clearance or removal.

Three machines capable of using a combination of tools | The Armtrac 400, the Bozena 5 and the MV-10

GROUND PREPARATION MACHINES (light, medium, heavy systems)

Ground preparation machines are primarily designed to improve the efficiency of demining operations. Ground preparation may or may not involve the detonation, destruction or removal of landmines. Ground preparation machine tasks include:

- Vegetation cutting and clearing
- Removal of tripwires
- Loosening the soil
- Removal of metal contamination
- Removal of building debris, boulders, rubble, defensive wire obstacles
- Sifting soil and debris.

The MSB front-end loader in operation in south Lebanon

MINE-PROTECTED VEHICLES

Mine-protected vehicles (MPV) are vehicles specifically designed to protect the occupants and equipment from the effects of a mine detonation. In mine action, the designation MPV is associated with vehicles that may have been originally designed as armoured military personnel carriers.

MPV are commonly used during survey and detection operations (often on roads), where they may carry equipment such as detector arrays or vapour sampling devices, or push or pull a roller. MPV equipped with steel wheels can be used for hazard reduction, technical survey and area reduction.

A mine-protected vehicle | The RG31 Mk6

PURCHASE OF DEMINING MACHINES

Purchase of a demining machine includes a significant initial capital investment, which needs to be properly assessed. The cost for the running and continuous maintenance of the machine also needs to be taken into account before purchasing a machine. Considerations prior to investing in a machine are listed in Checklist 1 in Annex D.

COMMISSIONING

When commissioning a demining machine, an organisation may consider using standards from other comparable industries when negotiating with manufacturers. Tendering for offers most often benefits the procurer of the goods in terms of best value for money. Not only can the purchase price be reduced but items such as spare parts, mobile workshop, shipping costs, training packages, warranty duration and documentation sets can be negotiated to favourable terms.

When signing a contract with a manufacturer it is common practice for the contract sum to be paid in several instalments. Typically, this could be a sign-on instalment (or initial instalment), one instalment when the machine has passed testing on factory premises, an instalment when the machine has arrived at the agreed destination and a final instalment when the machine has passed the final acceptance test. In some cases bank guarantees may be used[5]. If the contract is for a machine to be built locally, payments can be one initial instalment followed by monthly payments during the construction and with a final payment upon delivery and acceptance of the machine.

The size and the number of the instalments may vary and some organisations will prefer to negotiate a penalty fee with the manufacturer if the machine is delivered later than agreed. This is often the case for commercial demining contracts where a delay in machine delivery could be an expensive exercise for the purchasing agency.

OTHER OPTIONS FOR COMMISSIONING MACHINES

Machines can also be commissioned through a lease agreement, sometimes with an option to buy the machine after a certain time or at the end of the lease.

A third option is where the machine is deployed as a part of a clearance contract that includes other demining components. Under such a contract the machine is normally rented to the contracting agency but managed and operated by the contractor and the machine will normally be removed on completion of the contract.

DEMINING MACHINES

Funding and/or supervising agencies generally prefer demining contractors to own their machines rather than renting them from sub-contractors. This obviously comes with a higher risk and cost. One problem with sub-contracting machines is their availability or — if they are being bought new — the lead time for delivery. This can be a big concern as commercial tenders are often issued with short response periods for contractors.

In addition to the demining machine itself, most machine manufacturers offer a range of services including delivery, customs clearance and preparation of the end-user certificate, spare parts packages, training of operators and mechanics, after-delivery service and more. Some manufacturers also have country offices to assist the customer.

LOCAL CONSTRUCTION OF DEMINING MACHINES

Demining machines have been developed and constructed locally in various countries. These include mine clearance machines, ground preparation machines and mine protected vehicles, both intrusive and non-intrusive. Local construction has been done for various reasons such as difficulties of importing machines, cost and suitability. Countries where local construction has been successful are Angola, Bosnia and Herzegovina, Croatia, Iran, Iraq and Lebanon. Construction is often done directly by individual organisations or through contractual arrangements with a local manufacturer, which constructs and delivers the machines to predetermined specifications.

A locally constructed flail in the Kurdistan Region

DEMINING MACHINES

Local construction can mean that the machines are completely constructed in the country, or that already existing plant machinery, readily available on the local market, such as front-end loaders or excavators are armoured and fitted with tools such as buckets, flails, rollers or sifters. A frequent limitation is access to armoured steel and armoured glass which sometimes have to be imported at high cost, and with complicated procurement procedures and long delivery periods.

BEFORE | A front-end loader in Kurdistan being converted to a demining machine
AFTER | The same machine as an armoured front-end loader with sifter

Local construction requires that detailed specifications for the machines are developed. Such specifications need to be sufficient to meet the hazards expected to be encountered. Checklist 2 in Annex D can be used when planning indigenous construction of demining machines.

Further reading on the subject of armouring can be found in the GICHD 2004 study, *A Study of Mechanical Application in Mine Clearance*, Chapter 5: The protection of vehicles and plant equipment against mines and UXO.

TEST AND EVALUATION OF DEMINING MACHINES

The key aim of test and evaluation of demining machines is to ensure that technologies meet the needs of the end user. All approaches and technologies must be tested in realistic field conditions in an environment similar to that which is to be cleared. A performance test should be carried out on applied equipment, operators and processes as a key part of accreditation to ensure that the equipment and methods are fit for the purpose. When carrying out tests, information should also be collected on previous performance of demining machines from other countries and projects where the machines have been used. For guidance on tests and evaluations, IMAS[6] and CEN Workshop Agreements can be used[7]. A number of machines have been tested by the International Test and Evaluation Programme (ITEP) in recent years. A complete list of all demining machines tested by ITEP can be found on the ITEP and GICHD websites.[8]

MACHINE SHARING AND POOLING

Pooling or sharing demining machines offers a potentially cost-effective solution if several organisations are involved in a country's mine action programme. A single organisation owning and operating a machine might not maximise cost-effectiveness. It is often not possible to use a machine every day as it can be faster than the follow-on productivity rate of manual deminers and mine detection dogs (MDD).

Effective pooling requires that one organisation is entirely responsible for the operation and maintenance of the machines. If several organisations are in charge of the pooled resource, machinery is unlikely to last long.

Machine pooling can start with two organisations renting a machine on a cost and time sharing basis.

A good example of effective pooling was the European Landmine Solutions (ELS) commercial programme in Bosnia and Herzegovina. ELS provided mechanical support for other NGO and commercial demining organisations on a commercial contract basis. The management of the machines, with all the administration and logistics, was the responsibility of ELS, not of their contractors. This meant that programme managers with large clearance programmes were able to use machines when needed but were not troubled by the challenges of managing the mechanical assets themselves.

The major constraints to machine sharing are the logistics and costs associated with moving machines between task sites and organisations, often in countries with poor roads and infrastructure. Machine pooling requires more and long-term operational planning as well as clear divisions of responsibilities.

ENDNOTES

1 GICHD publications are available free of charge via the GICHD website www.gichd.org.

2 Preparing ground includes vegetation cutting.

3 IMAS 04.10. Glossary of mine action terms, definitions and abbreviations. Explosive Remnants of War - Unexploded Ordnance (UXO) and Abandoned Explosive Ordnance (AXO) (CCW protocol V).

4 IMAS 09.50 First Edition, September 2007.

5 A guarantee from a lending institution ensuring that the liabilities of a debtor will be met. In other words, if the debtor fails to settle a debt, the bank will cover it. A bank guarantee enables the customer (debtor) to acquire goods, buy equipment, or draw down loans, and thereby expand business activity.

6 CEN Workshop Agreement, Test and Evaluation of Demining Machines (CWA 15044: 2004).

7 IMAS 03.40 Test and Evaluation (Ed. 1) Amendments 1, 2 & 3.

8 www.itep.ws and www.gichd.org

CHAPTER 2

DEPLOYMENT OF DEMINING MACHINES

DEPLOYMENT OF DEMINING MACHINES

INTRODUCTION

The conventional basis of mine clearance is the manual deminer wearing personal protective equipment, creating or working in a designated lane or box, equipped with a metal detector and a set of excavation tools. The deminer will respond to detector signals in accordance with a developed set of standard operating procedures (SOPs). Control of the process on a hazardous site is rather straightforward as the activity is conducted at a relatively slow and measured pace.

Although mine detection dogs can be useful, they can also be limited, slowed or stopped by unfavourable climatic, vegetative or topographic conditions. However, in general terms, if conditions are favourable, MDDs can move the systematic clearance process forward at increased speed. Coordination and control of MDDs integrated with manual demining can be challenging.

Demining machines can dramatically speed up a clearance programme. Unfortunately, the opportunity to capitalise on the potential of faster clearance is often wasted because of poor operational planning.

The optimal use of machine assets is when manual deminers and MDDs are working in support of one or several demining machines, and the machine(s) is put to maximal use according to its capacity. Machines can also be used in support of manual and MDD operations. Typical tasks would be removal of vegetation, rubble or other features slowing operations.

The main purpose of technical survey is to collect information about the presence and location of hazards in a suspected area. This information is then assessed and used to make decisions about whether to release land, conduct further technical survey, or conduct clearance. Demining machines are a very important asset for technical survey: depending on the level of threat, under certain conditions it can be appropriate to use the machine without subsequent follow-on of a second asset.

Properly managed demining machines can change the face of a demining site quickly. The capacity of a demining machine can typically be between 3,000 and 15,000 square metres per working day [1].

It must also be remembered that:

- An intrusive mine clearance machine, when facing visual or audible detonations, will in most cases have to be followed-on with a secondary method of clearance
- An intrusive mine clearance machine, when no visual or audible detonations have occurred, will in most cases, not have to be followed-on with a secondary method of clearance
- An intrusive ground preparation machine does not always destroy all mines, and thus missed or broken mines must still be cleared using a second asset
- A non-intrusive demining machine must be safely manoeuvred around, and/or in, a mined area on cleared lanes wide enough for the machine
- An MPV platform with a detector array in the survey role used along a road will produce indications that must be investigated by manual deminers, MDDs or other means of mechanical clearance, such as an excavator.

ASSESSING THE POTENTIAL OF DEMINING MACHINES

The deployment of a demining machine should be preceded by a structural review to examine its implications for long-term funding requirements and budgeting, training, logistics, survey processes, clearance methods, quality assurance and quality control (QA/QC).

The first question is: Will the proposed machine be used in support of deminers – or will deminers be working in support of the machine? The same question also applies to the use of MDDs.

If the potential of the machine and conditions favour the machine over the deminers in terms of product and productivity, the machine should be recognised as the primary asset meaning that the bias of operational support shifts towards the machine in order to maximise the output of the machine. Unavoidably, recognising that the machine has the potential to transform operations means that elements of the programme will have to be adjusted accordingly. Failure to make the necessary adjustments will lead to ineffective machine use.

For example, there is little point in using a flail to clear vegetation and prepare ground at the rate of 5,000 square metres per day if the capacity that follows-on is insufficient to keep up. Little is achieved if vegetation re-grows or soil becomes hard packed and baked because there are insufficient manual assets in the right place at the right time to make use of the advantage brought by the machine.

Modern flails and tillers have the potential to transform mine clearance operations – in particular when deployed onto hard-to-define, low-density mined areas.

Conditions between countries and mined areas vary, therefore it is important that different options are explored. If demining machines are in current use or have been used in the proposed area or country of operations before, it makes sense to critically evaluate their past effectiveness to make use of the lessons learned.

Test reports on various machines exist and can be found on the International Test and Evaluation Programme (ITEP), and GICHD websites.[2] The GICHD has recently developed an online mechanical demining reference library where most publications and documents related to mechanical demining can be found and downloaded.

UNDERSTANDING THE HAZARDS

Mine clearance machines, ground preparation machines and mine-protected vehicles, whether intrusive or non-intrusive are all susceptible to hazards. The following points should be considered when deploying demining machines.

Hazards posed by anti-personnel mines, anti-vehicle mines and ERW

Demining machines can be damaged, even destroyed, by AVM and large items of ERW (although the detonation of most ERW by mechanical action is rare). It is essential to identify the type of ordnance to be encountered in clearance operations. For a non-exhaustive list of samples of mines that are considered "hazardous" to machines see Annex C.

Artillery shells encountered during flailing

Machines are most effective at destroying AP blast mines. They are often less successful at destroying above-surface AP fragmentation mines, although they are likely to remove or destroy the tripwire and fuze on such mines. Machines are generally ineffective against most ERW.

Hazards are posed by fragmentation devices and shaped charges, such as an Explosive Formed Penetrator (EFP). Several varieties of cluster bomblets are also designed to penetrate armoured steel. They can kill or seriously injure machine operators, and damage or destroy machines.

DEPLOYMENT OF DEMINING MACHINES

Some rocket-propelled grenades can puncture armour plating. Fragmentation mines, such as the PROM-1, can cause serious damage to machines, particularly to the operator's cabin, hydraulic units, air filters, radiators, tyres and other vulnerable components. Artillery shells and aircraft bombs can destroy demining machines completely.

A BLU-97 cluster bomb | A demining machine destroyed by an AV mine

MACHINE DEPLOYMENT

Initial deployment and arrival of machines in country

During the initial deployment of machines it is important to have the proper logistic arrangements in place to minimise the deployment time and related costs of the machines. Such arrangements include the necessary permissions to bring/import the machine to the country, customs clearance, end-user certificate and ground transportation capacity. In some countries the machine might have to be moved by air from the port of entry to the area of operation. In such cases this needs to be carefully planned and the necessary permissions obtained well in advance. Deployment needs to be planned for the most appropriate season when it is actually possible to move the machine from port of entry to the area of operations.

Loading a Mini MineWolf into a sea container | A Mini MineWolf loaded onto an aircraft

Transportation infrastructure

Infrastructure to support machine deployment must be thoroughly assessed before a machine is brought into country. Such information can normally be obtained from the governmental agency dealing with roads and transportation. Maps with road and bridge classifications (width, load-bearing classification etc.) should be obtained for planning purposes. Bear in mind that the given classification might depend on seasonal variations in weather. Roads and bridges must be wide and strong enough to allow machines to be transported, preferably without having to be off loaded to pass certain sections of road. If infrastructure is inadequate, find a solution quickly. If the problems cannot be overcome do not bring in the machine! Meeting points for traffic and turning points for the carrier during transportation need to be identified. The transportation vehicle also needs to be suitable for the prevailing road conditions. For instance, a low loader with very little ground clearance might not be suitable for transporting a big and heavy demining machine. Road reconnaissance prior to transportation of demining machines is always recommended. In particular, security constraints on the transportation route need to be clarified prior to departure.

A bridge being bypassed during transportation of a Scanjack in Sudan

Road conditions during the Scanjack's journey

And the Scanjack got through | A Bozena 5 loaded for transportation in Azerbaijan

DEPLOYMENT OF DEMINING MACHINES

A Scanjack aboard a ferry in Sudan

An MV-4 being lifted by helicopter

DEPLOYMENT OF DEMINING MACHINES

Tests

National authorities may require that machines pass an acceptance test prior to operational deployment. This needs to be considered when planning the deployment and transportation of the machine. Transportation to the test site needs to be planned and the time and cost required for the tests taken into account.

For guidance in preparing and carrying out tests and evaluations of mechanical demining equipment *IMAS 03.40 Test and Evaluation of Mine Action Equipment, IMAS 09.50 Mechanical Demining* and *CWA 15044:2004 Test and Evaluation of Demining Machines* should be used. If there is documentation from previous tests, under similar conditions, carried out by a national authority or ITEP, the need for an acceptance test can be discussed.

Testing a demining machine at SWEDEC

THE OPERATING ENVIRONMENT

Common sense dictates that the operational environment is understood. The following factors should be considered as a minimum.

Ground conditions

Demining machines have been designed on a variety of platforms and with different types of tools. Therefore their performance will vary depending on the ground conditions prevailing. Relevant information about the performance of particular machines can be obtained from test reports, independent assessments and previous user feedback. Such documents can be found on the ITEP and GICHD websites.

In extremely dry and arid climates, where soil is brittle and desiccated, a heavy flail will cause large quantities of soil to form powder dust. If this effect is coupled with wind, productive topsoil levels can be dramatically reduced so that the area will be useless for agriculture after clearance.

It is also often overlooked that dust has a seriously detrimental effect on an engine's life. Understanding the air induction and filtering systems of the machine is critical, as is testing how heat affects the running of the machine. Demining machines – particularly flails and tillers – should have several stages of filter systems for the air induction. It is important that the air intake is outside or nearly outside the dust plume enveloping the working machine. Ideally the first stage should comprise of a cyclone type dust separator, backed up by two or more oil-bath or fibre air filters. Engine lifespan is totally dependent on how well dust is separated from the engine's air intake.

According to CWA 15044:2004, soil is classified as in the table below. The type of soil at the clearance site will also affect the degree of dust created during the mechanical clearance operation.

Figure 1 | Soil description

Class	Soil description
Class I	> Humus, loam, compact sand, hard and semi-hard soil covered in vegetation **Machine use is easy**
Class II	> Soil mixed with stone, soil is prevailing, rare vegetation **Limestone, soft, easily crushed by demining tool**
Class III	> Stony terrain, stone plates with soil in between, low vegetation in places. > Semi-hard stone **Machine works in reduced depths (10 – 15 cm)**
Class IV	> Specific conditions where the other classes are not applicable

NB: an area might contain different soil classes

Hard and dry soil conditions in Jordan

Heat

Temperatures on the site where the machine will be used should be considered when planning its deployment. Machine operators need to ensure that the machine has a cooling system that can cope, or can be adapted to cope with, the temperatures encountered without getting overheated. The solution often lies in oversized cooling systems. Normally the hydraulic system is more vulnerable to overheating than the engines of the prime mover or the working tool. This can be mitigated by understanding the working conditions for the machine so that the capacity of the oil tank and oil cooling system can be suitably adapted. When converting plant machinery into demining machines this also needs to be taken into consideration, especially if the machine will be working in a mode for which it was not initially designed.

When adding armour to plant machinery, care must be taken not to completely encapsulate and prevent the flow of cool air through the engine compartment.

Vegetation

Vegetation is one of the main obstacles to demining operations. Mechanical demining machines are often the most effective means of speeding up demining operations where vegetation is present. Some machines are purpose built for this task, while others of different design have also proved able to deal with dense vegetation without reduction in performance. Machines need to be able to remove vegetation without losing the ability to penetrate the ground at the same time.

Density and type of vegetation should be considered against the capability of the proposed machine. If a non-intrusive machine with a vegetation cutter is to be used, it would be wise to conduct a time and motion study to compare machine use against another method[3](for example, a team of deminers with handheld forestry brush cutters may be more efficient than a non-intrusive tractor with a boom-mounted cutter).

When deploying a demining machine in support of manual deminers or MDD for vegetation removal (and tripwires), it is important to ensure that the mine clearance capacity is deployed straight after the machine. This is to allow the mine clearance capacity to keep up with the machine and to prevent vegetation from returning. This is a classical operational management challenge when deploying machines in combination with other mine clearance activities such as survey, community liaison, manual demining, MDD teams, marking and fencing, and QA/QC teams. Soak time for MDDs must also be allowed in accordance with NMAS.

Mines can be contained in soil and branches and can re-contaminate already cleared ground. This typically happens when vegetation is grabbed and lifted over cleared ground without prior inspection. Care should be taken to ensure that cleared areas remain free of mines: this can be achieved by a thorough control system preventing cross contamination. One way of doing this is to create specific vegetation inspection areas. According to CWA 15044:2004, vegetation is classified as in the table below.

Figure 2 | Vegetation description

Class	Vegetation description
Low vegetation	> Green or dry grass, thin or thick, weeds, few low bushes up to 1 m high
Medium vegetation	> Grass, weeds, individual bushes, medium to high density, 1-2 m high > Few individual trees up to 10 cm in diameter
High vegetation	> Bushes, weeds, grass > High density > Greater than 2 m high > Individual trees with diameter greater than 10 cm
Specific conditions	> Specific conditions where the other classes are not applicable


Low vegetation


Medium vegetation


High vegetation


Vegetation cut by a flail in Bosnia


Dense vegetation cut by a flail in Bosnia

DEPLOYMENT OF DEMINING MACHINES

Work in urban areas

Residential buildings, schools, factories, airports, bridges, roads, fences and other man-made features restrict machine use. It is important to examine and understand how structures will impact on the clearance operation. It is also important to have a plan to deal with obstacles when machines are used in an urban environment. Coordination with local authorities, community leaders and the affected population is key to a successful operation. Additional manual assets will usually be required when working in urbanised areas. These assets will be used to clear close to buildings and other structures where machines cannot reach or will do damage.

There should always be a plan for mitigating the negative effects of mechanical demining when operating in such environments. The generation of dust, for instance, is far less during the rainy season. The tracks of heavy machines can be fitted with rubber shoes to minimise damage on tarmac roads and bridges. Plans should also be made to allow normal traffic to pass with minimum delay during clearance operations.

A MineWolf working close to built-up areas in Aqaba | Jordan

DEPLOYMENT OF DEMINING MACHINES

Topography

Most demining machines have difficulties working on slopes steeper than 30º (as distinct from a machine's ability to drive at steeper elevations *without* operating the main tool). Over 30º, an alternative to mechanical demining should be considered.

It is also important to know that demining machines generally perform better when engaging the working tool moving *down* a steep slope rather than moving uphill. (This is opposite to manual demining operations where, for safety reasons, deminers work uphill). Side slopes steeper than 15º should be avoided during mechanical demining.

A Bozena 5 working on a hillside

An MV-10 working downwards on a hillside

OTHER CONSIDERATIONS

Remote operations

In many countries, field camps will have to be established to support the mechanical demining operation. Demining staff will live and operate from such camps for weeks or even months. This adds another dimension to already-costly mechanical demining operations. Additional considerations include the logistics of transporting water, food and other supplies to the camps. Security of staff needs to be considered and additional support staff might be needed. A rotation plan will be needed for staff to go on breaks. Additional equipment such as tents and camping equipment will have to be purchased. More vehicles will be required together with provision of medical support. A particular requirement of field mechanical demining operations is the need for mobile workshop facilities capable of supporting most maintenance and repair jobs.

A field camp during mechanical demining operations in Sudan

Health of staff

Good hygiene is essential. When working with fuel, oil and lubricants staff must have access to proper washing facilities. Bad hygiene will directly affect the health of staff with implications for operations. This publication's purpose is not to provide medical advice to operators but there are a number of resources where information on travel medicine can be sought, e.g. the Centres for Disease Control and Prevention (CDC) with the Yellow Book[4] and the World Health Organization (WHO) website for international travel and health[5].

Box 1 | An example of mechanical demining methodology in Lebanon

The following is an example of the approach and methodology for mechanical demining from South Lebanon[6] from late 2008.

Concept of operations

The goal was to clear known, recorded military-pattern laid minefields in Lebanon. Mechanical and MDD assets are used to clear access routes to the minefield perimeter (normally a visible minefield fence). Then manual clearance assets are used to clear into the minefield and locate the mine rows. Once the mine rows, mine orientation and pattern are confirmed, then the known mine rows are manually cleared. Confirmation clearance is then carried out using a second asset on a minimum of 10% over the mine rows. Mechanical and MDD assets can then be used to clear the peripheral areas outside the mine rows, and on both sides of the minefield fence.

Mechanical flail or tiller assets are generally not used as a sole clearance tool and will in most cases be followed by manual or MDD clearance. However, in suspected hazardous areas where there is no previous history or evidence of mines or UXO, mechanical demining can be conducted for verification purposes. The Lebanese Mine Action Centre (LMAC) and the Mine Action Coordination Centre South Lebanon (MACC SL) operations department may authorise mechanical demining without a second clearance asset on a site-by-site basis.

Limitations

From previous experience with mechanical assets, particularly the use of underpowered flail systems, the Lebanon Mine Action Centre (LMAC) and the Mine Action Coordination Centre, South Lebanon (MACC SL) now prohibits the use of flails as a primary clearance tool over known mine rows.

DEPLOYMENT OF DEMINING MACHINES

Box 1 contd. | An example of mechanical demining methodology in Lebanon

An excavator fitted with a flail in Lebanon

Mechanical flails and tillers are not permitted for clearance of areas known to contain AP mines fitted with a "cocked-striker" mechanism, such as the No.4 or the GYATA 64. This is due to the increased risk to follow-on clearance assets as mines that have not been detonated or broken up during the mechanical operation may have been made more sensitive to functioning.

Flails and tillers are not used as a primary clearance tool in Lebanon in minefields where a pattern can be determined. Manual clearance is always the preferred method of clearing "pattern minefields" followed by confirmation using flails, tillers or MDD. Manual clearance of pattern minefields allows for the accurate recording of the size, shape, pattern and exact quantities of mines in the area for future reference. Primary mechanical clearance has the potential to destroy useful information about the minefield.

Flails and tillers are normally not used as a sole clearance tool in high-threat hazardous areas and will normally be followed by manual or MDD assets. However, in a low-threat hazardous area or SHA where there is no previous history or evidence of mines or UXO, mechanical flailing is conducted as a verification operation. The LMAC/MACC SL Operations Department may authorise mechanical clearance without follow-on clearance on a site-by-site basis. Normally, however, a second asset should follow mechanical verification or clearance conducted in any low-threat hazardous area with a history or evidence of a hazard.

Box 1 contd. | An example of mechanical demining methodology in Lebanon

Mechanical assets such as excavators or sifters can be used for primary clearance of contaminated earth spoil and rubbish piles as long as sifted spoil/rubbish is rechecked by a second asset. This secondary clearance is completed to check for fuzes or mine parts that may have passed through the sifter. Manual or MDD assets can be employed for this purpose.

LMAC and MACC SL are continually seeking ways to increase productivity and to release land as efficiently and as economically as possible. The premise for this is to employ an appropriate response to the level of threat presented and to ensure that all decisions are adequately documented and recorded. The National Technical and Safety Guidelines (TSG) provides the framework and guidelines for the employment of assets, but it is the collective responsibility of all concerned (national authority, coordinating body, clearance organisation) to determine the appropriate response.

Guiding principles

Parameters for each mechanical system will vary but, in general, each system must:

- Be safe for the operator and be adaptable in order to cater to the specific mine hazard and specific ground conditions
- Have an internal organisational structure which permits full integration with other clearance assets
- Be designed and structured in such a way that it accelerates mine clearance operations in a safe, cost-effective and productive manner.

The development and employment of mechanical assets must take into account the following factors:

- The specific mine/UXO hazard
- The simplicity of design and operation
- The maintainability and sustainability of the equipment in the area of operations
- The ability to deploy itself, or be deployed to the clearance site
- The adaptability of the mechanical assets in different terrain conditions
- The requirement for detailed and accredited SOPs
- The ability to achieve the clearance depth required (20 cm), for Lebanon
- The requirement for the training of national operators to maintain a national capacity if required.

ENDNOTES

1 For further information on clearance rates for various demining machines, see the GICHD Mechanical Demining Equipment Catalogue.

2 www.gichd.org and www.itep.ws

3 See GICHD pamphlet: Time and Motion Studies for Demining: Snapshots of Operations.

4 www.cdc.gov/Features/YellowBook/

5 www.who.int/ith/en/

6 The example has been provided by Tekimiti Gilbert, MACCSL Chief of Staff.

CHAPTER 3

THE USE AND LIMITATIONS OF DEMINING MACHINES

THE USE AND LIMITATIONS OF DEMINING MACHINES

MINE CLEARANCE MACHINES

Mine clearance machines are those primarily designed to operate in a hazardous environment where the tasks involve locating and destroying landmines. Such machines can be deployed on a great variety of tasks. If the intent is to clear mines, the machine will fall under the mine clearance machine category: if the deployment is to support assets such as manual deminers and MDD it falls under the category of ground preparation machines.

FLAILS

The most common type of purpose-built mine clearance machine currently on the market is the flail. There are many different models of flails available (see the GICHD *Mechanical Demining Equipment Catalogue*). However, they all operate on the same principle: metal chains and hammers attached to a rotating shaft hit the ground violently when rotated at speed and penetrate the ground thus setting off or destroying mines.

WHY SHOULD FLAILS BE USED?

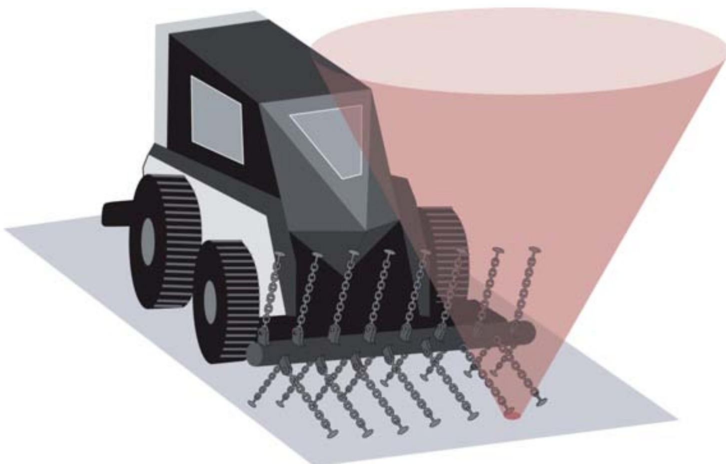
Flails are cost effective and can significantly speed up demining operations when used correctly. Flails are also a proven and well-recognised system within the humanitarian and military demining community. This provides a big knowledge base to support implementation and management of mechanical demining operations.

What has made the flail design so popular since the early 1940s is a “virtual” drum created by centrifugal forces, suspending hammers in a greater diameter than the rotating shaft of fixation. This not only adds greater force to the ground impacting hammers but also improves the tool’s survivability. The flail design is simple and most flails can survive an AVM blast without requiring any major repair since the working tool is outside the sector (cone of destruction) affected by the blast. Normally an AVM blast will only require the change of one or more hammers, which can be done in minutes. The design is also relatively light compared to other ground engaging designs.

THE USE AND LIMITATIONS OF DEMINING MACHINES

It is well known that all mechanical tools have their strengths and weaknesses. The flail has been known to outperform other mechanical systems, such as tillers, in soft sandy soil, muddy conditions and where larger pieces of rubble and debris can be expected. The flail's major advantage, however, is its survivability capacity against multiple AVM blasts. This is why flails still represent the bulk of demining machines on the market.

Figure 3 | The cone of destruction



Flails have many purposes: they can be used as an intrusive machine to remove vegetation, break up the soil, remove tripwires and destroy mines, all at the same time. With hard soil and/or dense vegetation with tripwires, flails can be the only viable option. Flails offer a relatively safe way of doing mine clearance since a minimum of personnel need to enter the hazardous area.

CONSIDERATIONS WHEN USING FLAILS

There are three concerns with flails:

- Possible throw-outs
- Soil expansion (overburden)
- Ridges/skipped zones.

Impediments to flail efficiency can be fixed, at least partially, by adjustments to flail power, the forward speed of the machine, hammer shape, ground depth penetration, flail shaft height in relation to the ground, and flail shaft helix configuration.

Throw-outs

If the mine is thrown in front of the continuing path of the machine, it is unlikely to escape detonation or break-up when encountered a second time. But if mines are thrown in previously cleared or non-suspected areas this is a serious problem. Throw-outs can be addressed and mitigated through modifications to SOPs for mechanical demining.

Under-powered flails when engaging polycarbonate- or bakelite-cased AP mines in loose soils will result in more throw-outs. These are normally visible on the ground. Solutions lie in increased power, caging the flail and hammer design.

Throw-out trials carried out by the GICHD[1] indicate that most mines, when passed by a flail and if not detonated, will stay within two metres of where they were laid — but a small portion will be thrown considerable distances. During trials, one mine was thrown 65 metres. Throwing patterns do not seem to be linked the size of the mine and during trials mines were mostly thrown directly forward. Tests indicate that throw-outs are mainly mines that have been buried deep, hidden behind rocks or have a malfunction.

One example of a machine adapted to cope with the risk of throw-outs — by Mines Advisory Group (MAG) — is the locally built flail in Lebanon. MAG fitted the flail with covering rubber mats, which can be raised/lowered from the cabin allowing the flail to go close to obstacles such as trees and large rocks.

The flail adapted by MAG in Lebanon with rubber mats to reduce dust and throw-outs

Ridges/skipped zones

The pattern created by the points at which chains are attached to the flail shaft is referred to as the helix configuration. A flail helix configuration is usually designed so that, when chains have hammers connected which are of greater circumference than the chain links, all strikes on the ground should be overlapped by adjacent hammers. The intended result is that no section of ground is missed by the flail.[2]

Some flail manufacturers have minimised the danger of skipped zones by improvements to flail helix designs and, through increased rotation speed, have also achieved more strikes to the ground. For certain flails, however, skipped zones remain a challenge. On some flails, such shortcomings are immediately predictable due to the sparse positioning of the chains attached to a shaft.

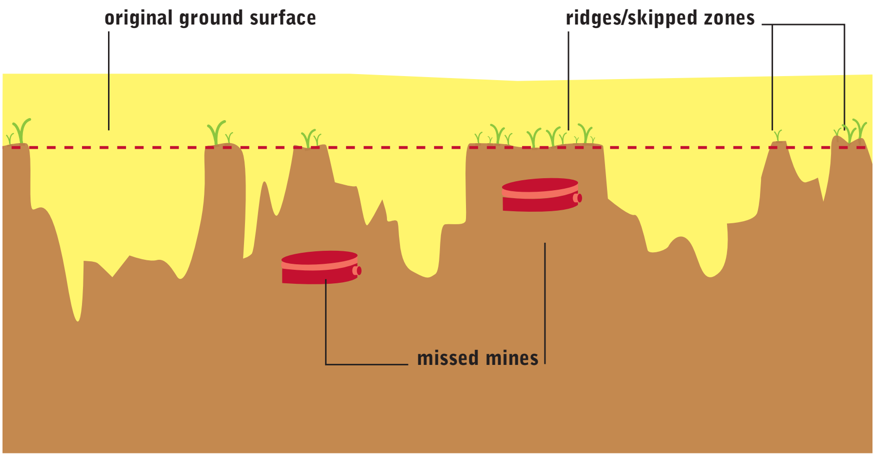
The manner in which a machine is operated will also affect the incidence of skipped zones. The lesser penetration depth appears to minimise the "snaking" effect of the chains as they go through and across the ground. If the demining machine employed is not powerful enough for the working tool the result might be an increase in ridges/skipped zones.

Forward speed of the machine also plays a part. In general, the slower the vehicle is driven while flailing the ground, the lesser the likelihood of ridges/skipped zones. Unfortunately, a slower-moving vehicle also reduces productivity.

Operational flail systems should be evaluated and tested with hammers attached to the chains. If, for cost reasons, a user removes the hammers it follows that the machine is no longer working as designed and may be under-performing.

The solution lies in operating the machine at a slower forward working speed when this phenomenon occurs.

Figure 4 | Ridges and skipped zones



In isolated instances, it is conceivable that ordnance may lie unaffected by a flail, situated within a skipped zone. In most cases, the overlap of chain strikes on the ground dictated by the flail helix configuration will avoid this

Soil expansion

Soil expansion is sometimes referred to as overburden or bulking, this is the expansion in volume of loosened soil created by the action of the flail. The measure of the bulking factor of soil is its volume after excavation divided by volume before excavation. As the flail moves along its path, a trail of loosened soil is left in its wake. In the event of a mine being missed by the machine, overburden may conceal missed mines, making it more difficult to locate missed mines after a machine has completed its sweep. The amount of overburden created varies between mechanical systems and soil types. It has been discovered that overburden can be significant enough that some current models of metal detectors are unable to detect mines buried as a result of it. The amount of overburden created is increasing with the depth the machine is flailing. A ground penetration depth of 20 centimetres will produce roughly twice the amount of overburden created by flailing to a depth of 10 centimetres. The phenomenon of soil expansion is also equally applicable for tiller systems.

Steep gradients

Flails should not be operated on gradients over 30º. Steep gradients pose one of the most significant limiting factors on the ability of a flail to operate. Most machines can operate up to the 30º - 35º range, but these figures often refer more to “hill-climbing ability”, the ability of the prime mover to drive up a hill without engaging ground with the working tool. Actual performance, however, depends on the power-to-weight ratio as well as the traction and contouring ability of the machine. The solution might be to drive uphill and operate the working tool only in a downhill operation.

Uneven terrain

Uneven or fluctuating terrain can be a major obstacle when operating flail machines. Yet, in terms of mitigating changes in the surface, the flail still has advantages over many other clearance tools. And there are now a number of flail-contouring systems on the market. Some are purely based on skis or rollers riding on the surface, keeping the working tool at a certain level. These designs are simple and robust but have limitations in dealing with greater surface variations. Other contouring systems are more advanced, using hydraulic or electronic sensors. These systems are often less robust but give a better performance in uneven terrain.

Rocky terrain

Rocky terrain is an obstacle to effective deployment of flails. Rocks begin to cause serious challenges for flails when they are 10 centimetres in diameter or bigger. Rocks and stones shield the mines lying beneath or near them, greatly increasing the probability of a missed mine or an ineffectual, glancing strike. Individual chains of the flail cannot connect with cracks and dents in the ground protected by rocks. When flails are operated in rocky ground it should be expected that the demining machine will lose an increased amount of hammers.

Difficult ground versus power

Some flails rely on the same power source for both the forward drive of the vehicle and the flail shaft rotation. When a machine begins to struggle in difficult ground, power is taken away from the flail unit and given to the prime mover so that it may continue along its route. Consequently, the flail slows down and chain impact weakens, as does its sub-surface influence zone. Chains take longer in their dragging, horizontal path along the ground before the next cycle of rotation. The chances of throw-outs, overburden and skipped zones are potentially increased.

As a rule of thumb, a flail should have at least a total of 70 horse power per metre flail to carry out the work to the expected result.

Types of mines in the area of operation

If a flail is put to work in a suspect area where fragmentation mines and ERW are mixed with sub-surface blast mines, it is essential to employ alternative clearance techniques on the understanding that fragmentation mines and ERW are likely to be in the residue. Flails do not consistently destroy thick-cased fragmentation mines and ERW. They are usually taken up by the action of the flail, but will frequently survive inpact – with the increased inconvenience of being removed to a new and sometimes unknown location. On the positive side, tripwires are ripped out and mine fuzes are usually broken off. Annex C has a list of mines considered to be high threat to demining machines.

Dust

Dust generated by a flail can result in a near-blind operation of the machine. The dust can blind an entire work site when wind conditions are unfavourable or when there is no wind. Flails should not be used under excessively dusty soil conditions, when there is no wind present. It is mandatory to plan for a flexible approach to each task site so that the working direction of the machine can be adjusted to the wind direction. Machines should ideally be operated with wind coming diagonally towards the machine to allow the operator to see the overlap from the last run. An operator who cannot see the area to be cleared, see minefield marking and see obstacles such as trees, large rocks or boulders is not able to work in accordance with the clearance plan. Not being able to see clearly also means that the machine could collide with other physical obstacles, fall into ditches, or worse.

The Aardvark MkIII Flail operating in dusty conditions in Iran

One solution is to use a gyro compass or a GPS to control the operation of the machine in combination with adjusting the direction of operation according to the wind direction. Another option, when dust is blocking the line of sight between the operator and a remote controlled machine, is to fit the machine with cameras, as has been done with the machine shown in the picture below. This remote-controlled machine has been fitted with three cameras at the front and one at the rear.

The Mini MineWolf fitted with cameras to operate in dusty conditions

The cameras on the Mini MineWolf

HAMMER AND CHAIN CONFIGURATION

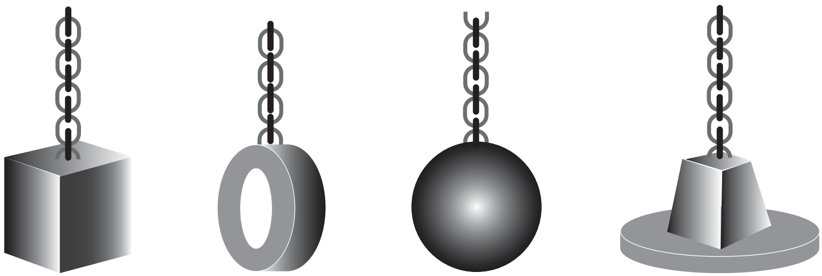
Only a few tests and trials have been done on the design and durability of hammerheads and chains for flails. The Swedish EOD and Demining Centre (SWEDEC) conducted such tests between 2003 and 2005. The main objective was to optimise costs over the machine's lifetime, while maintaining flail performance. The SWEDEC tests showed that the weight distribution and centre of gravity of the hammers are essential for the performance of the tool. It also identified the ideal dimensions and weights for hammers for two specific flail systems.[3]

On weight distribution of the hammer, SWEDEC recommended that most of the material should be concentrated near the wear plate and that the centrifugal forces are concentrated at the far end of the hammer. The test report also recommended that chain quality should be sufficiently high for the chain to outlast more than one hammer set. Wrought iron hammers were found to be less likely to break than cast iron hammers.

Hammers should be selected based on the following considerations:

- A chisel hammer will maximise ground penetration and cut into mines
- A ball hammer will minimise ground penetration but maximise stress distribution onto the ground
- A ring hammer will cut into soil and mines
- A block hammer is effective for ground penetration and imparting energy into the ground.

Figure 5 | Examples of hammers



BLOCK
Effective for ground penetration and imparting energy into ground

RING
Cuts into soil and ordnance

BALL
Minimizes ground penetration while maximizing stress distribution

CHISEL
Maximizes ground penetration and cuts into mines

A chisel hammer (tungsten coated)

Use of a flail with chains alone and no hammers should *only* be done when the purpose is to clear vegetation before other means of clearance are used. The ground penetration with chains alone is minimal. Tests by the Defence Research and Development Canada (DRDC) have proved that the digging performance is poor and unreliable without hammers.

A few flail systems have proved to have insufficient power delivered to the flail shaft when operating in field conditions. This has resulted in operators removing the flail hammers to be able to keep the system moving. By this the working characteristics of the flail strike to the ground and performance is greatly reduced. If the flail has been tested and accredited with hammers the flail must only be operated in this configuration.

Securing the hammers to the chain can cause problems. This is due to the extreme forces working on the connection when working in hard ground for prolonged periods. Roll pin or solid pin connections are good but normal nut and bolt fasteners are not. SWEDEC has proposed that the hammer be secured by a clip that is pounded closed. This is a simple and effective and could probably be cast in a single piece by indigenous metal shops.[4]

A hammer with a fastening device

One other consideration with hammers and chains is the cost of logistics. Transport costs for new chains and hammers can be significant, especially by air. Therefore ordering and transportation must be carefully planned so that the shipping can be done at lowest cost and as efficiently as possible so as not to delay or stop operations.

Box 2 | Flail hammer costs

If hammers are worn out quickly in hard soil conditions and only last for 18 hours, all hammers have to be replaced twice during a normal 40-hour work week. If the flail has 38 hammers and the machine is operating 40 weeks a year, 3,040 hammers will be needed every year. At an average cost of € 20 per hammer the total cost will be € 60,800 per year. This cost only includes the hammers and not the chains, nor transportation, nor installation.

It may be possible to make savings by local sourcing or manufacturing but this may be offset by quality control problems, especially if high-grade chains or special treatment of the hammers are necessary.

As part of preparing this handbook a questionnaire on regarding hammers and chains for flails was sent to manufacturers and operators. The response was very positive and a summary of responses follows.

Box 3 | Tungsten coating of hammers

One manufacturer provided pictures of hammers with and without a coating of tungsten. Pictures 41 and 42 show the results after two hours of flailing with chisel hammers, with and without tungsten coating. The lifespan of the tungsten-coated hammer was increased by four to six times compared to uncoated hammers.

Tungsten coating costs approximately € 12 per hammer. But its benefits saved money when the cost of untreated hammers was more than € 4, as the coating lasted at least four times longer. If the costs of down-time and labour to change the hammers several times are factored in, coating was still probably a good deal for hammers costing only € 2 each.

The same manufacturer had also tried a block-shaped steel hammer made from hardened steel (Ck60 steel) which proved to have an even longer lifespan than the tungsten-coated hammers.

Information courtesy of Digger Foundation.

A tungsten-coated hammer after two hours of flailing
A non-coated hammer after two hours of flailing

Questionnaire responses on the operational life expectancy of chains and hammers indicated a range from six to 80 hours, depending on the material, shape, and ground conditions. In one example the manufacturer said that a block-shaped, non-hardened hammer used in north Sudan could last for a little as six hours. The same, block-shaped but hardened hammer could last as long as 80 hours, however, when working in easier soil conditions in south Sudan. Producers claimed that chains normally lasted longer than hammers, generally between 80 and 100 hours.

Operators claim that the cost of purchasing and replacing hammers and chains has a high impact on project budgets, thus they prefer to produce hammers and source chains locally if possible. Again, this may have implications if high-grade chains or tungsten coating or hardening of the hammers is necessary.[5]

A broken hammer head after use in Sudan

A broken hammer head after use in Afghanistan

THE USE AND LIMITATIONS OF DEMINING MACHINES

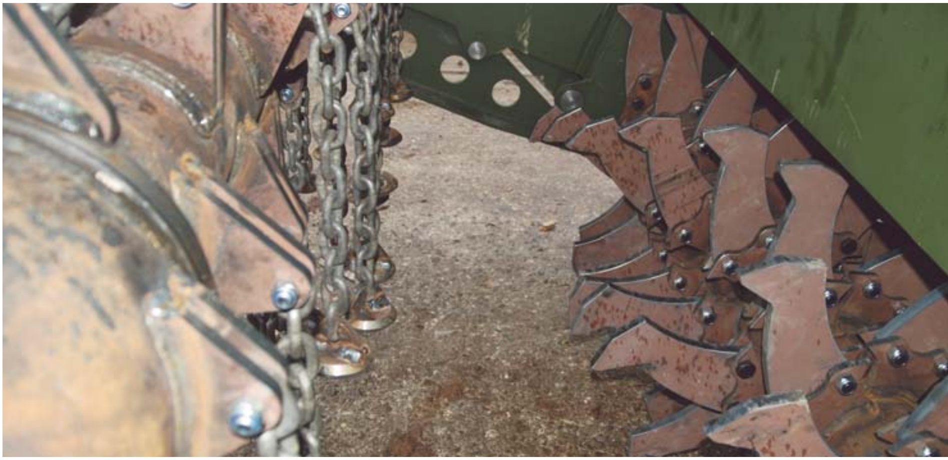
TILLERS

Tillers are the second largest family of purpose-built demining machines. Most tillers are based on plant machinery, forestry machines or tank chassis. Accordingly, tillers are often characterised by their heavy weight and large size, although lighter designs are beginning to be available. In recent years a new generation of tillers has emerged on the market. The designs vary but the major characteristic of the new models is their lighter weight. In general, they utilise industry-standard tungsten bits mounted on a rotating skeleton drum or arms extending from a central shaft. This evolution has allowed for lighter prime movers to be used as platforms for the tiller tool.

The most popular tiller working today consists of a solid or skeleton rotating drum fitted with overlapping rows of steel alloy bits. The bits grind and chew up the ground as the rotating tiller is lowered to a selected depth. AP mines, smaller items of ERW and, for certain models, AVMs are either detonated or broken up as the steel bits strike them.

An open-basket tiller design

A counter-clockwise chisel tiller design



A tiller that has been combined with a flail

A light tiller which can also act as a flail – the MV-4

UNDERSTANDING THE EFFECTIVENESS OF TILLERS

As with flails, tillers are at the mercy of topography and soil, with performance reduced in steep or uneven terrain.

The hill-climbing ability among tiller systems on the market ranges between 25° and 35°. Some tillers are bulky and difficult to manoeuvre over extreme terrain. The type of soil also limits their performance: tillers will not perform well in wet conditions or in rock-strewn soil. Large stones and rocks can protect mines/ERW from the intrusions of an oncoming tiller bit. Where the rock type is hard, damage to tiller bits can be expected.

The Komatsu Bulldozer D85MS-15 tiller system in Afghanistan

The presence of light-to-medium vegetation may enhance tiller performance, by allowing the bits to grip the soil and reducing slipstreaming. Most tillers operate less effectively in medium vegetation. The restrictions on tiller performance presented by soil, terrain and vegetation are similar to those experienced by flails.

Tillers appear to perform better at depths of 10–20 centimetres. Where mines are found deeper than 20 centimetres, performance begins to deteriorate.

Slipstreaming

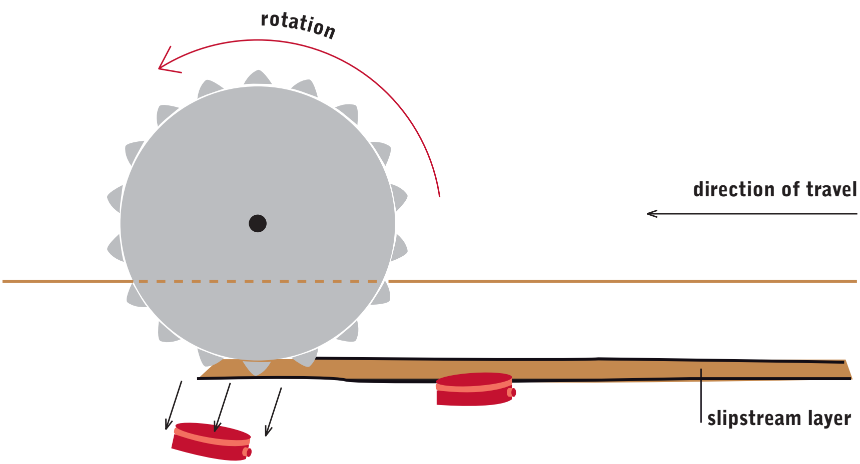
Slipstreaming is a theoretical phenomenon whereby the rotating action of the tiller drum creates a thin layer of free-space between the end surface of the tiller bits and the surface of the ground beneath. Although as yet unproven, it is suggested that this space contains aerated, loosely packed debris such as broken-up soil, small stones and mulched vegetation. On occasion — depending on the design of the bits fixed to the drum, the soil type being engaged and the mine type concerned — ordnance may get into the slipstream and escape destruction. It appears that the occurrence of slipstream beneath a tiller drum is aided by increasing rotation speed. It can resemble the effect of a vehicle tyre spinning on icy ground while remaining static, or the pebbles left behind a retreating glacier.

The slipstream effect is also increased by dry, light soil conditions. Reportedly, where light-to-medium vegetation is present in an area worked by a tiller, slipstreaming is significantly reduced. This appears to be due to the additional “grip” on the soil provided by mulched vegetation matter. When vegetation of above-medium thickness is encountered, the performance of a tiller begins to be degraded as with any other mechanical system. Once an item of ordnance becomes caught in a slipstream, it may remain within the slipstream layer until the tiller drum has passed over it. Should it prove a factor at all, it should be stressed that slipstreaming does not occur under all conditions. It is not known what percentage of ordnance that fails to be destroyed by tillers is due to this effect.

The factors that contribute to slipstreaming are not exactly understood. Where it occurs, its negative effects can range from severe to non-existent, depending on the size of the mine type involved. Smaller mines or fuzes may escape destruction by "hiding" in the slipstream. With existing tiller machines, drum rotation speed varies from approximately 100 to 700rpm.

The use of the open skeleton tiller or a tiller with arms extending from a central shaft will limit slipstreaming since the soil processed by the working tool is allowed to escape through the open tool configuration. This prevents the build-up of pressure, which normally leads to the creation of slipstream. Another alternative for mitigating slipstreaming is to use a different tool, such as a flail in cases where the risk of slipstream is obvious.

Figure 6 | Slipstreaming

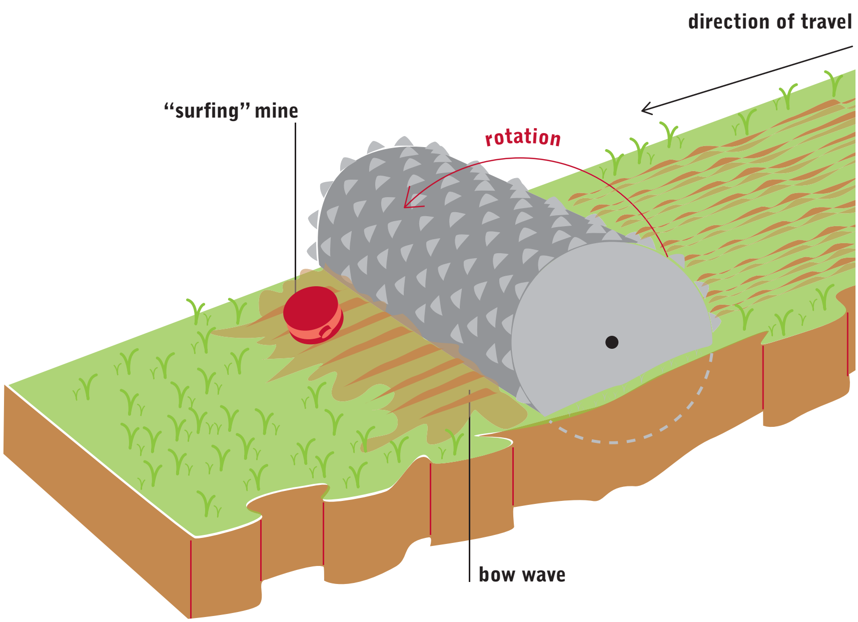


Bow wave

Bow wave has the appearance of water pushed in front of a ship. Ordnance may be found within the bow wave at the front of a tiller drum. On occasion, ordnance caught in this position may roll continually within the bow wave and never end up between the jaws of the tiller bits and the ground surface, thus escaping destruction even though the soil particles that comprise the bow wave are ever changing: the ordnance acts like a surfer, always keeping slightly ahead of the breakpoint. Certain wet soil conditions makes this a more likely occurrence.

Operators should be aware of the bow wave phenomenon and should be trained how to mitigate this effect. Newer and more modern tiller designs, which allow soil to escape through the tiller system, such as the open skeleton model, will reduce the build-up of soil in front of the tool. Other options are to reduce the forward speed of the machine and to periodically reverse and re-engage the accumulated soil from the bow wave to destroy any mines that have escaped through surfing. Another alternative in cases where there is a risk of mines escaping through bow wave is to use a different tool, such as a flail.

Figure 7 | Bow wave



FLAILS AND TILLERS IN A TECHNICAL SURVEY ROLE

When planning technical survey it should be considered that a demining machine can be used for operations that involve either:

> Covering the complete area – i.e. processing all of the ground with a flail or tiller, aiming to identify the boundaries of the hazardous area through audible and visual detonations of mines. Areas with detonations are subject to further clearance and areas where no detonations have occurred are either released or subject to follow-on activities

> Creating breach lanes into the suspect area with the aim of identifying the exact location and orientation of a pattern minefield. Breach lanes can also be used to provide access for other clearance assets, such as manual demining teams and MDD. If no hazards are found, decisions may be made to release land based on sufficiently high confidence gained that there are no hazards in the area.

Technical survey using machines in Azerbaijan. Bozena 4 and 5 machines were used to create the lanes. Follow-on was done by one MDD in areas covered by flails and by two MDD between lanes

An Armtrac 100 in the Skallingen peninsula | Denmark

There are two methods of using a machine in a technical survey role. A machine can be deployed from the outside edge of the SHA and work inwards; it can also be deployed from inside the SHA and work outwards. When the centre of contamination is known the machine is used to clear outwards, normally after the mines have been manually cleared. The process will work less well in low-density, ill-defined mined areas.

CLEARANCE THROUGH MECHANICAL EXCAVATION

Excavation of soil from suspect land is one of the most reliable methods of ensuring that suspect ground is rendered clear to a stated depth. The method involves removing suspect soil for subsequent inspection for mines/ERW and then returning it when cleared, or processing excavated soil in situ with, for example, a bucket-mounted sifting system. For certain demining tasks, excavating rubble and destroyed infrastructure is often the only way of doing clearance.

Most machines employed in the excavation role are adapted commercial plant machinery, upgraded with armour and armoured glass. Machines typically include front-end loaders and excavators. They represent an effective, accessible and relatively cheap alternative to the purpose-designed mechanical systems sold as mine clearance machines. Typically such machines are of a non-intrusive type.

The most commonly used of such machines are the front-end loader fitted with a bucket in the front and the loader excavator with an extendable backhoe and support legs. Such machines can also be fitted with a purpose-built sifter.

Excavators have hydraulic, extendable arms, with which it can reach over obstacles such as walls, ditches and earthworks to excavate in suspect locations where it would be physically impossible or damaging to infrastructure to deploy a full-size bucket.

The general method for mechanical excavation has three main stages:

1. **Excavation of potentially mined soil**. If the excavation method is by front-end loader bucket, the bucket should only be three-quarters full in order to avoid possible spillage of suspect soil when the machine is moving (the load capacity for a typical loader bucket is around 2.5 cubic metres). A bucket sifter system can process and clear soil excavated in situ while moving along a clearance path within the suspect area.

2. **Processing of suspect soil to locate mines/ERW** — using a sifting device or a grill. The distance between bars in the sifting device or grill will allow soil to pass through while larger items, such as mines and stones, will be retained. Processing can also be carried out through spreading the contaminated soil evenly over an inspection area. The soil is then inspected using manual methods with rakes or metal detectors or MDD. Another option is to use plant machinery to feed contaminated soil into an industry standard sifting system, optionally combined with a magnetic separating system. Once ordnance has been located it can be destroyed.

3. **Returning cleared soil to the original suspected area**. When soil is being processed by a sifting tool inside the hazardous area, the cleared soil escapes the sifting tool and falls back to where it came from. When soil is inspected in a separate inspection area it should be returned immediately after the inspection. Care should be taken to bring back fertile topsoil to its original location.

A sifting machine in the Skallingen peninsula | Denmark

Mechanical excavation and sifting operations are slow but effective, and they might be the only viable solution in a built-up area or where deep buried mines are suspected.

Excavation of buildings

Excavation of buildings is a specialised undertaking that essentially follows the same principles as excavation of soil. There is a special need, however, to be aware of the consequences of removing bearing structures in the wrong order. It is also extremely important to create an inspection area prior to the excavation and to take special care of the manual labour involved. Before starting excavation of buildings all structural aspects must be taken into account, such as electricity, water, sewerage, the risk of collapsing features, and even the possibility of exposing human remains. Safety distances also have to be considered. Sentries are of great importance given the difficulties of controlling civilians in urban areas.

A location is needed for the processed debris and advice should be sought from the affected community, remembering that people may well want to make use of the debris.

Rubble removal in Lebanon

Critical issues

The critical issue with large-scale excavation tasks is that the method very quickly develops into a soil management process, sometimes on a vast scale. Site and process control are vital. Before embarking on an excavation task, implementers must ensure that they have studied and fully understood the consequences of their proposed actions. This factor should not be underestimated. The historical record of mechanical mine action is full of examples where the key management function of operational design and testing has not been carried out. In some cases the results have been catastrophic — causing both environmental damage and real hardship to the intended beneficiaries.

Particular attention should be paid to the relationship between capacity (volume) that can be excavated in a working day and the throughput (processing or inspection volume) that can be dealt with at a similar pace.

Caution is also required if the inspection process is dependent on one machine such as an industrial sifter or a rock crusher. The operational plan must include provision to mitigate against breakdowns of the prime processor. Although this seems simple it is also important to take the management decision to stop excavation in a timely manner if the processing method breaks down.

Most sifter systems are sensitive to wet or moist soil. Under such conditions the processing of soil will be dramatically reduced. The two major physical factors contributing to this decrease of productivity are that wet soil is simply heavier than dry and that wet soil tends to clog the sifter systems.

When developing an operational plan for excavation tasks a number of factors should be considered. Checklist 5 is available for this purpose in Annex D.

It is important that the implementer understands how the proposed machine works.

- Is there a built-in system to regulate excavation depth – if not, how will this be monitored?
- What volume of material should be carried in the bucket? Should it be full, three-quarters full or half full? The recommendation is that the bucket should be three-quarters full but the volume can be increased depending of the weight of the material.
- What is the optimum safe load that will prevent the possibility of careless cross-contamination or overturning the machine when operated on uneven ground?

GROUND PREPARATION

It is well known that obstacles such as vegetation, rubble, building debris and hard ground have a negative impact on the manual demining efficiency. Machines can greatly assist manual and MDD operations to overcome these problems. Ground preparation machines can detonate mines and some are even designed to survive such blasts. In most cases, however, the machines are not meant for mine clearance. The main purpose of using ground preparation machines is to prepare the ground for manual demining and/or MDD operations.

The first demining machines to be deployed in humanitarian demining were ground preparation machines in Cambodia during the early 1990s. These Halo Trust machines were Russian-built agriculture tractors fitted with armoured glass and steel as well as vegetation cutters. In addition to clearing vegetation in front of manual deminers, these machines also proved to be a safe and effective way of removing tripwires.

THE USE AND LIMITATIONS OF DEMINING MACHINES

As with any aspect of mine clearance, the process of ground preparation needs to be considered carefully. The main challenge in ground preparation is that it is not a stand-alone activity. Whether an intrusive machine is being used or a platform is reaching into the SHA from a cleared area, the activity needs to be followed-on with a mine clearance tool. Timing, balancing and managing these two often separate activities have proven to be problematic for most implementing organisations. When successfully managed such operations can be some of the most cost-effective ways of clearing a multi-faceted SHA. Using the right tool for the right job will have a positive impact on production and safety.

In general there are two types of machines used in ground preparation: (a) machines that can operate and be driven inside the SHA (intrusive machines) and (b) machines that will reach with the working tool into the SHA, with the platform positioned on cleared ground (non-intrusive machines).

The complexity of effectively managing the safe progress of ground preparation machines should not be underestimated. Operators should conduct either a physical time and motion study or a desk analysis to gain an understanding of what resources are being used, and for how long, when a ground preparation machine is introduced to a site. This is, in particular, the case for non-intrusive machines, since they are often dependent on working in tandem with manual assets or MDD to clear access lanes.

When using a ground preparation machine with a sub-surface capability it is important to know what the result will be and to understand that follow-on is always required. Follow-on is required because the ground will not be sufficiently penetrated — and because boom-mounted ground penetrating tools on non-intrusive machines have a tendency to bounce and skip, thus leaving skip zones.

Since 2005 more and more demining organisations have been using commercially available portable forestry vegetation cutters (strimmers), which are inexpensive, both in purchase and use. They can easily be transported with the manual demining teams and require only a limited amount of training and maintenance. In 2009 the most common forestry vegetation cutter cost under US$250 in South East Asia. Such vegetation cutters have been fitted with heavy duty wires or cutting blades capable of removing vegetation and bushes up to 30 millimetres in diameter. Since the minefields in South East Asia (and in a number of African countries) were laid more than 20 years ago the tripwire hazard is minimum and therefore such machines can be used. Forestry vegetation cutters are considered to be a part of the manual demining tool box. Often, however, they can also be used with great success as a supplement to mechanical ground preparation tools.

DEMINING MACHINES IN A QUALITY CONTROL ROLE

Due to the high productivity and cost efficiency of mechanical mine clearance, it sometimes makes sense to clear an area mechanically as a follow-on activity after manual clearance of military patterned minefields. The machines will often clear the SHA and areas next to the cleared mine rows to ensure that there are no wash-outs or migrating mines that have escaped the manual clearance process.

In nuisance minefields that have been manually cleared it often makes sense to use a demining machine to quality control the manual work carried out. It should, however, be noted that the common and most efficient practice is to deploy the demining machine first and then to follow-up with manual deminers and MDD.

METHODS OF SIFTING SOIL

There are a number of different methods of separating mines and ERW from soil in an SHA. The most common method is to use sifters, grills or crusher systems that are either purpose built or commercially available. Such systems are normally attached to, or fed by, commercial plant machinery such as front-end loaders and excavators that have been armoured.

In **rotary sifting**, soil is sifted through the rotation of a drum: smaller particles escape through holes in the drum and larger items, including mines and ERW, remain in the drum. The sifting process can be carried out inside or outside the SHA. After the sifting the soil needs to be checked by manual deminers.

A sifting bucket in Lebanon

An Armtrac sifter

Stationary sifting uses industrial sifting machines that are normally separate rocks, boulders and turf (peat) from sand. These sifters can be stationary or self propelled, but usually other machines load the suspected soil onto the system. Sifters generally consist of a conveyer belt that transports the soil on to a screener system. Only soil and objects with a smaller diameter than the screen will be allowed through. Hazardous objects are removed from the top of the screen after every sifting session or, in some systems, separated on to a conveyor belt and dropped into an inspection pit. Stationary sifting can also be done by dropping contaminated soil through a mesh screen or grill.

A variety of **small crushers** attached as a bucket to common plant machinery are another popular type of sifting system. The machine excavates the ground with the crusher bucket, which is then raised to process the materials through the crusher elements of the bucket. The crushed material escapes through openings in the bucket and AP mines will either detonate or be broken up in the crushing process. Processed material and the empty bucket are then inspected. This system should only be used in areas that are known to only contain smaller types of APM up to 100 grams of explosive weight.

ROLLERS

In humanitarian demining rollers are usually employed for area reduction and technical survey. Their main advantages are:

- Speed
- Low maintenance
- Low cost
- Ease of fabrication.

Roller dynamics

Anti-mine rollers operate under a simple principle, simulating the ground pressure caused by either humans or vehicles traversing a mined area. Given that most mines are pressure activated, rollers trigger the fuze meant for a victim and absorb the blast through their robust and survivable design.

The most common configuration for a roller system is a segmented roller, which consists of a series of discs mounted on an axle. Each disc has a hole wider in the middle than the axle, allowing the discs to freely float on the axle and conform to undulations in the terrain. The discs are often 50 kg, but some are as heavy as 100 kg, and the roller is usually pushed by an armoured tractor, pulled by an MPV, or split into two arrays attached to both the front and back of a vehicle.

A segmented roller

Methods

Rollers can be an easy way to determine whether mines exist in a hazardous area. But rollers do not detonate all mine types – so trials are a prerequisite for roller use.

When considering rolling an area it should be understood how segments will move over uneven or rocky ground, vegetation, tree stumps, root systems and various soil types. Some common sense judgement is required. For example, elephant grass, when pushed by a roller, will form a cushion over the ground, greatly reducing the roller's effect. A roller must also be operated so that it processes each spot in the field a number of times; only one pass over an area is not enough.

Mine rollers or detonation trailers have also been used to prove the safety of roads that have been cleared of AVM. A variety of rollers have been used, varying from the (rarely used) steel rollers, through the solid-tyred rollers to the pneumatic tyres used on the detonation train that is a part of the Chubby system.

The efficiency of using rollers on roads is questionable. The effectiveness of mine rolling diminishes with depth. This reduction is inversely proportional to the depth raised to the power 1.5. Soil structures absorb the forces implanted to the ground and rapidly distribute the footprint of the roller disc over a greater surface area. The benefit of adding extra weight to pneumatic tyres is small, most of the additional force being lost. There is significant benefit from using a wheel that is harder than a pneumatic tyre.

Using steel wheels at wheel loads in excess of 3,000 kg will improve the margin of safety of detonation trains significantly above that of truck wheels. Where steel wheels are not acceptable, solid rubber tyres will give a lesser, but worthwhile, improvement.

For further reading on the application of rollers see the GICHD *Guide to Road Clearance*.

MAGNETS

Along with vegetation, metal contamination is often one of the main constraints to speed of clearance. Attaching a magnet to a machine that is loosening soil in front of the magnet may reduce the time required for follow-on activities. This will reduce the number of false alarms that need to be manually investigated.

Magnets can also help collect additional evidence of hazards being present. During technical survey magnets can be used along with a flail or tiller. The flail or tiller will provide visual or audible evidence of mines while the magnet will pick up metal debris from mines and ERW. After deployment the debris can be inspected, providing additional information on the contamination. If there is no audible or visual evidence of contamination and no mine or ERW parts picked up by the magnet, the likelihood of mine contamination is very low. The exception is minefields containing minimum metal mines.

Apart from getting better value for money, another positive spin-off from mounting a magnet to a flail or tiller machine is that such machines tend to be front heavy. Attaching a heavy magnet to the rear can actually improve the machine's terrain contouring abilities.

Investing in a magnet in parallel with the purchase of a demining machine can be a cost-effective measure, but not everywhere. To estimate a magnet system's productivity, the following should be established.

- The level of metal contamination in the areas of operation. There is little point in purchasing a magnet if there are only a few sites where it can be used effectively. A pilot count over a week of metal fragments found will establish if a magnet will make a difference.[6]
- The level of ferro-magnetic metal content in the contamination. A normal metal detector will give an alarm for both conductive and ferro-rich metals. A magnet, however, will only help by reducing the ferro-rich metals in the ground.
- How the metal is distributed in the soil. Tests have clearly shown that magnets have problems picking up metal fragments that are not on or very close to the surface. When doing your sampling the depth at which the metal is found should also be recorded.

A magnet system has to be close to ground to be effective. If the top layer of the soil is loosened or ripped up with a flail or tiller a magnet system will be far more effective.

A Bozena 5 fitted with a magnet

There are numerous types of permanent magnets.[7] Magnetism itself is a phenomenon by which materials exert an attracting or repelling force on other materials. Magnetic force can be measured in different units: Tesla or Gauss.[8] Tests have shown that the magnet needs to have a strength of at least 5,000 Gauss (500 mT[9]). To a degree, all materials are influenced by the presence of a magnetic field, but those that have easily detectable properties are iron, some types of steel and the mineral lodestone.

A magnet's capability to attract ferro-magnetic material depends mainly on:

- The strength of the magnet
- The distance of the object from the magnet
- The area of the object facing the magnet
- The mass of the object.

Tests have shown, not surprisingly, that the stronger the magnet and the closer to the ground it is used the more metal will be collected. It is important to note, however, that metal objects trapped in the soil surface layer will not be sprung out by the magnet as it is likely that magnetic forces on the object will cause a horizontal movement due to polarity: this horizontal movement may decrease the likelihood of the object being released from the soil. This is why magnet use is often considered more effective when some surface disruption has occurred.

Permanent magnets

There are two main groups of permanent magnets: composites and rare earth magnets. Among composites, the ferrite (ceramic) magnet is the most common. It is made of a sintered composite of powdered iron oxide and barium/strontium carbonate ceramics. Due to the low cost of material and manufacturing methods ferrite magnets are the cheapest permanent magnets. The magnets are non-corroding, but brittle and must be treated like other ceramics. The strength in the magnetic field corresponds with the mass of the magnet.

Permanent magnets can be demagnetised if exposed to:

- Heat (a red hot magnet loses its magnetic properties)
- Hammering and/or jarring (which reduces the strength of the magnet).

A serious point to note is that a permanent magnet is just that – permanent – therefore metal debris must be physically removed by scraping or using a separator plate. Transporting a permanent magnet also needs thought – a magnet stuck to the flatbed of a lorry can be difficult to offload.

Electromagnets

Electromagnets consist of an iron core surrounded by a coil of wire. The strength of the magnetic field depends on the current put through the wire and the number of turns in the coil. The wire is usually made of copper. The biggest advantage is that an electromagnet can be switched on or off when needed – and therefore it is easier to remove metal debris from an electromagnet and it is also easier to move around.

Most electromagnets are made to order. They can be made in most shapes and forms and are therefore suitable for mounting on a demining machine. In general, when a stronger magnet is needed, it is easier to purchase an electromagnet rather than a permanent type magnet. The power requirement for an electromagnet is low and can be provided through the engine moving the platform. A typical electromagnet mounted on an intrusive mine clearance machine covering the same width as the working tool will consume very little power.

An electromagnet operated from an excavator

An electromagnet

MINE-PROTECTED VEHICLES

Mine-protected vehicles (MPV) are most commonly used in road clearance operations as a platform for a detector array or a sensor system. Examples are a wide array detector system mounted to the front of a MPV or a sensor array mounted behind an MPV. MPVs can also be used for area reduction/ technical survey and for clearance.

MPVs have proved to be an effective way of bringing the operator close to a remote-controlled demining machine without exposing the operator and equipment to risk. By controlling a demining machine from inside an MPV the operator can be positioned in an optimal location in terms of view, wind and dust while being protected from blast and fragmentation hazards.

The Casspir MPV: one fitted with steel wheels and one with rubber tyres

The operating costs of an MPV are reasonably higher than a truck. Organisations need to assess the requirement for MPVs before purchasing. There are restrictions on import and export of such vehicles and, because of their heavy armour, MPVs are subject to more wear and tear on moving parts than other vehicles of similar size.

A Casspir fitted with steel wheels

In general, MPVs can be divided into two groups: those designed solely to protect the occupants and; those designed not only to protect the crew but also to survive an AVM blast with minimum damage.

FOLLOW-ON AFTER MECHANICAL DEMINING

In most cases mechanical demining requires some kind of follow-on activities to ensure that the residual hazard is minimal for the beneficiaries after the cleared ground is handed over.

If demining machines are operated correctly and under conditions that are suitable for the specific demining machine this will reduce the requirement for subsequent follow-on using other demining methods, such as manual demining or MDDs. When machines are used in technical survey, follow-on may only be required where there is confirmation of hazards, i.e. audible or visual evidence of hazards through detonations. In such cases a simple visual inspection of the area may be sufficient.

MDD AND MANUAL CLEARANCE IN SUPPORT OF DEMINING MACHINES

MDDs

MDDs are often used in support of mechanical demining for follow-on once an SHA has been cleared of vegetation for instance, with a flail. When MDDs are used for follow-on they will search ground that has previously been cleared by a demining machine to verify that mines are no longer present. If the machine has been used in a ground preparation role MDDs can be one alternative for clearance. Normally there needs to be a period between the mechanical intervention and the follow-on clearance with MDDs.

To support road clearance operations, MDDs can be used to carry out follow-on behind the machines along the road being cleared.

MDDs also have an important role in clearing areas that machines can not access or for other reasons cannot cleared, such as areas close to buildings.

For more information on methods when using MDDs in support of mechanical demining see the GICHD, 2008, *Guide to Road Clearance* and the GICHD 2003, *Mine Detection Dogs,* Training, Operations and Odour Detection.

Mine detection dogs working in an area previously covered by a flail in Azerbaijan

Manual clearance

The most common approach in supporting manual deminers is to use the demining machine to define the perimeters of the mined area. Once this has been done the mines, AVMs and/or APMs are then manually cleared. The advantage of this approach is that patterns are not disrupted and the risk of damage to the machine is minimised while all mines can be accounted for.

Manual clearance is also a method for follow-on once areas has been mechanically cleared or prepared. Manual clearance is not as fast as machines, especially when working in large open areas. For this reason manual demining is not considered to be an effective method for follow-on in large areas. But manual clearance is needed to clear areas that cannot be cleared or reached by the machine. Examples of where the machine cannot work are steep areas, areas around bridges and other man-made structures, and ground that is too rocky or uneven.

ENDNOTES

1 For further information on throw-outs see the study Throwing out Mines: Effects of a Flail, GICHD, 2004.

2 See Chapter 1 in A Study of Mechanical Application, GICHD, 2004.

3 The MV-4 and the Scanjack 3500.

4 www.itep.ws/pdf/Flail_hammerhead_testreport.pdf.

5 More information on hammer design can be found in A Study of Mechanical Application in Demining, GICHD, 2004.

6 Counting metal fragments as part of routine operations as a measure of productivity is not a practice that GICHD recommends.

7 Rare earth or neodymium magnets, samarium-cobalt magnets, ceramic magnets and alnico magnets.

8 1 Tesla is equal to 10,000 Gauss. 1 Gauss is the force of Earth's magnetic field at sea level.

9 miliTesla.

CHAPTER 4

MANAGING DEMINING MACHINES FROM A COST PERSPECTIVE

MANAGEMENT OF DEMINING MACHINES FROM A COST PERSPECTIVE

Mechanical demining assets are usually relatively sophisticated pieces of equipment and are often deployed in parts of the world where service and support pose significant obstacles to the effective management of these assets. Without skilful management, a demining machine can lose money like no other programme asset.

In many countries machines can be found abandoned somewhere, out of sight and out of mind. The reason might be that the machine was not suitable for the purpose it was bought or built for. Another common reason is that the mechanical component of the demining programme cannot be sustained financially.

Good management of machines means ensuring that other clearance assets are effectively combined with machines so that machines and machine operators are not left waiting for new tasks but employed to the fullest of the machine's capacity. A typical shortfall in operational management is that managers do not have an overview of the time required for completion of each task. It is critical that the survey capacity of the programme is capable of identifying suitable tasks for mechanical demining. For reasons of logistical efficiency, it is advisable to provide mechanical demining operators with clusters of tasks. These are basic operational planning issues, but they are not always addressed appropriately.

The driving skills of the operator and the way the machine is operated have significant implications for downtime. Operators must ensure proper fuel handling, equipment lubrication and strict application of manufacturer's maintenance schedules. Good operators are vital but are still as nothing without a good management system in place to support them.

Proper maintenance of mechanical demining equipment is essential for a successful operation. To ensure the maximum life expectancy of the machine, and to keep the warranty valid, it is mandatory to follow the service requirements.

FIELD RECORD-KEEPING AND REPORTING

Recording of machine clearance data is poor throughout the demining industry. Yet thorough record-keeping is crucial for management of any demining operation and helps managers identify bottlenecks early. Record- keeping enables managers to track progress and efficiency, and assists in donor reporting and drafting proposals.

An example of a format for a weekly report for a mechanical demining unit (from IMAS 9.50) is given in Annex E. An example of a daily maintenance log sheet for demining machines is in Annex F,

If the data from such a log is collated electronically, it is easy to display, for example as a pie chart, to gain a clear idea of how the machine is being used. The reporting form can also be used to analyse trends in performance or constraints over time, which are extremely useful when programming and budgeting mechanical assets. For example, if analysis shows that all machines in a programme spend 10 hours a month waiting for transport, this suggests that logistics support needs to be scrutinised and improved.

APPROPRIATE MACHINE USE

A manager needs to know the work capacity and characteristics of each machine type in the project. When there is a range of machines available, machines must be used where and when they are most effective. Excessive downtime can often be traced to inappropriate tasking of a machine type. Examples cited from different programmes include assigning large machines to small tasks or to areas that could be cleared more effectively by other assets. Other examples include using machines to tow overly-heavy loads, driving too fast on poorly maintained roads and using the machine for long hours without adhering to maintenance schedules.

Such abuse can be avoided by having clear guidelines for when and how machines are to be used, and enforcing these rules. Good training and staff discipline are vital to ensure that procedures are followed and respected.

MANAGING DEMINING MACHINES FROM A COST PERSPECTIVE

Management of the transportation vehicles for the demining machines is essential. Managers must ensure that transportation vehicles are operational at all times. When transportation vehicles are not available, due to repair or other reasons, this leads to costly downtime — for the demining machine and also an increased cost if outside transport capacity has to be purchased.

COST ANALYSIS

A mechanical demining component can increase productivity and reduce costs. It is, however, important to be aware of the overall cost of such a component. A proper cost analysis taking all project costs into account is crucial. Chapter 6 of the GICHD publication *A Study of Mechanical Application in Demining* discusses a method to establish cost effectiveness in mechanical demining. The GICHD Cost-Effectiveness Model (CEMOD)[1] is one tool that can be used for cost analysis. This model cannot be used for all situations without some modification.

Part of a cost analysis is to obtain an overview of the running costs of a mechanical project, as well as the subsequent investments that need to be made. The cost of capital investments such as mechanical workshops and transportation vehicles needs to be included in the overall project budget.

TAKING ALL COSTS INTO CONSIDERATION

When purchasing a demining machine, it is not only the initial cost of the machine that needs to be considered. Costs associated with commissioning, running and maintenance have to be included. Here is a list of charges and costs that should be covered when establishing a machine's overall cost:

Examples of start-up costs

- Tendering procedures and preparations of the tender documents
- Cost of the demining machine and working tools
- Cost of a transportation vehicle and support elements such as a mobile workshop for the machine
- Insurance of the machine[2]

- Shipment and customs clearance including import duties and taxes
- Storage while awaiting customs clearance
- Registration fees, if applicable
- Training of operators and mechanics
- Commissioning of the machine, including costs related to manufacturer's travel and work during introduction of the machine
- Transportation in country by road or air and the permits required
- Costs associated with testing/accreditation (transportation, repair, staff and running costs)
- Other equipment for the mechanical operation such as radios, camping equipment, digital cameras, GPS, software and more
- Spare parts, tools, welding machines, oils and lubricants and their shipping costs.

Examples of costs associated with running and maintaining the machine

- Fuel, oils and lubricants
- Replacement chains, hammers and bits
- Maintenance and scheduled service
- Costs for unexpected major repair and associated costs
- Replacement filters for liquids and air
- Replacement of tyres, belts and tracks
- Transportation and shipment of spare parts and sometimes fuel, lubricants and hydraulic fluids
- In-country transportation of the machine, staff and support assets
- Cost for support (training, maintenance etc.) from the manufacturer
- Staff salaries and other related staff costs
- Additional training and revision training of staff.

Remember that costs associated with a mechanical demining project can be significant. For instance, the cost for replacement of hammers and chains can have a surprisingly and unexpected impact on project funds if not planned and budgeted.

ENDNOTES

1 CEMOD is available from GICHD.

2 For guidance on insurance see A Guide to Insurance for Mine Action Operators, GICHD, 2004.

CHAPTER 5

MECHANICAL DEMINING OPERATIONS

MECHANICAL DEMINING OPERATIONS

GENERAL

Mechanical demining can be the most cost effective way of clearing and releasing land. Machines are, however, a major capital investment and should be a part of the national plan for addressing the mine problem. The type and number of machines in a mine-affected country should be appropriate for the scope of the problem and the specific conditions.

Mechanical clearance must be part of an integrated approach to using all mine clearance tools, with the appropriate organisational structure, logistical and administrative support to provide sustainability, minimum downtime, safety of staff, etc.

The success of a mechanical demining operation depends on interaction and coordination with other demining components such as survey, community liaison and other assets. When setting up a mechanical demining site a number of factors need to be considered, not for the mechanical intervention itself but also for support functions.

STANDING OPERATING PROCEDURES

SOPs are living documents detailing the sequence of work at a demining site as well as the responsibilities and duties of the personnel involved. They also describe the reporting and marking of physical areas that have been cleared and those not cleared. The SOPs further explain how the various demining tools are to be used and to which standard.

Each organisation must develop its own SOPs for mechanical demining. Such SOPs must be based on prevailing local conditions and the type of machine used. It is crucial to ensure that SOPs are realistic and that staff are trained on the SOPs before operations start. SOPs should be based on national mine action standards, where they exist, and be in compliance with the IMAS.

A list of suggested items to be included in mechanical demining SOPs can be found in Annex G.

MANAGEMENT OF DEMINING MACHINES

It is important that management understands the challenges involved when taking on a mechanical demining component. Management needs to be knowledgeable about the possibilities and limitations of various machines. Challenges include financial planning and donor relations, logistics, operational planning, cooperation with the host government and other agencies involved in mine action, security and human resources.

The management system should include clear procedures for tasking and reporting as well as administrative procedures between the head office, country office and the field level. The procedures implemented should be fit for purpose, user friendly and not unnecessarily bureaucratic in their design.

The selection process of staff is important and worth spending time on during the initial phase of a mechanical demining project. Care must be taken to follow the NMAS and legislation, if such exist, when identifying suitable staff. For instance the operator of a demining machine might need to fulfil the requirements to operate a plant, agriculture or forestry machine in the country. Time spent on developing proper job descriptions, advertising and selection of staff will save time and reduce problems at a later stage.

Financial procedures for expenses and monitoring of expenses need to be controlled, transparent and linked to procedures used by head office. The latter is for donor and contract reporting purposes. A mechanical project will have many daily expenses for which it is worth implementing a petty cash system so that smaller amounts can easily be drawn without complicated approvals.

It might also be worthwhile to identify local partners with whom to establish long-term agreements. Such agreements can be with fuel providers, transportation companies, courier agents and others. This can also result in cost savings in the long run.

Staff training of is key to the success of a mechanical demining project. Managers need to allocate time for training of international and national staff during the project set-up to ensure that all staff are aware of the procedures to be implemented and used.

At the working site(s) a plan should be prepared (on a sketch map using a scale of 1:500) to identify where demining machines and other assets will be working. This map can also be used for daily operational planning as well as staff briefings.

When deploying a machine, the site manager is responsible for ensuring that a plan has been made on how to use the machine as effectively as possible. The machine should be parked and maintained as close to the working area as safety allows. This is especially important when the machine is deployed on a vector task, such as a road or power line, where it is critical to move the mobile workshop and the site admin area along with the progress of the machine.

INTERNAL QA AND QC

As an integrated part of the overall demining process it is crucial to incorporate a quality management system. It is the implementing organisation's responsibility to establish and report on good routines for QA and QC.

The main reason for an internal QA and QC process is to ensure a continuous level of quality for the land cleared and subsequently handed over to its owners. When an external QA/QC body does not exist in country it is necessary to increase the level of internal quality management procedures. For mechanical QA/QC specifically, the process should investigate that:

- Personnel have the required qualifications to carry out their duties (especially important for machine operators and mechanics)
- The machine is being used in the way it has been accredited for
- The manufacturer's operating manuals are being followed
- The working tool is set up in accordance with standards
- The machine is operated in accordance with the SOPs (i.e. depth, speed and overlap) and the tasking orders
- Maintenance is carried out in accordance with specifications
- Machine use is recorded and reported in accordance with SOPs.

DEPLOYMENT

During deployment of demining machines a number of factors must be taken into consideration. A few such examples follow.

Operational maintainability and sustainability in the area where the machine will be deployed must be ensured for the duration of the task. It needs to be established if fuel, logistical support, local labour and other support functions can be sourced close to the site or if these need to be brought from other locations.

The **mine situation** at the site needs to be evaluated. Operators need to know what kind of hazard can be expected in order to minimise risks. It should be established if the machine will be working in areas where APM or AVM or a combination of both are to be expected. The type of AVM that can be encountered also needs to be evaluated. In addition, the hazard from ERW should be considered.

Infrastructure, including information about road and bridge load bearing capacities, width and height of tunnels and other features should be collected and evaluated. Seasonal changes may also make roads impassable for the machines. Roads or choke points to be avoided should be identified at an early stage of the deployment plan.

It needs to be known if the machine can, in fact, cope with the terrain and vegetation in the area — and if the type and possible output of the machine is suitable for the size and type of task.

SWEEPING OPERATIONS

Obstacles such as wide ditches, boulders, wire fences, stone walls, telecommunication cables, trench lines or large ERW items could all affect the progress and safety of the demining machine. Its route to and within the site area needs to be "swept" before deployment, by scouting from the air, by manual teams on the ground or by entering the SHA with mine-protected vehicles. Sweeping operations might also be used to put flags and markers in the SHA.

MECHANICAL DEMINING OPERATIONS

CONCEPT OF OPERATIONS

In mechanical operations, the following concerns need to be addressed:

1. The type of task: will the machine be used for ground preparation or for mine clearance, and what mine types and ERW are expected in the hazardous area?

2. Will the machine be used in support of MDDs and/or manual deminers or will the MDDs and/or manual deminers be working in support of the machine? A sequence of work for the machine and other assets must be prepared to ensure safety distances and that all assets are working to their fullest capacity. Are admin areas for the various assets needed and where will they be set up?

3. Site management structure: this must be clear. If clearance is to be done by several organisations it must be determined which organisation is in charge of coordinating all clearance assets at the site.

4. MDDs: if they are to be used for follow-on, they must be given time to acclimatise and for on-site training. MDDs should start work in areas completed by the machine following the appropriate soak time.

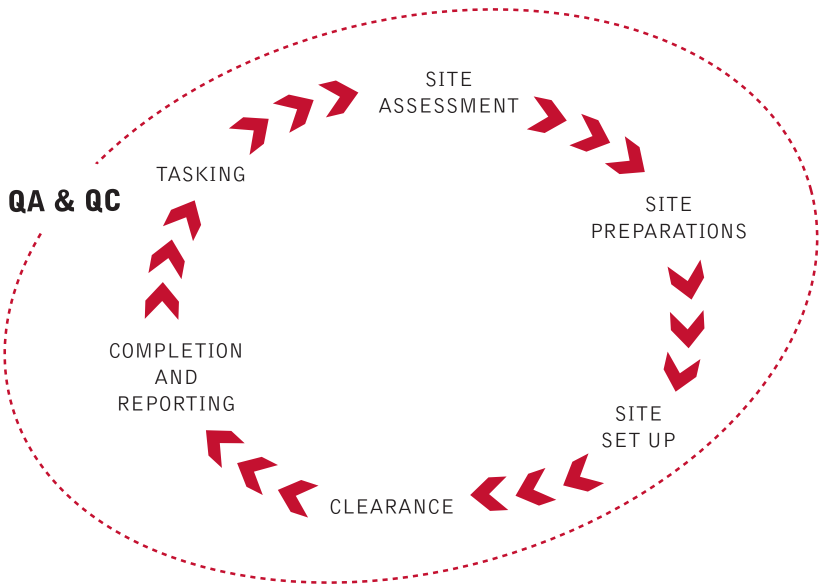
5. How and when will internal and external QA/QA be carried out at the site?

6. Safety issues:
   - Safety distance to the machine if remote controlled. The safety distance might be reduced if the machine is operated from a protected vehicle
   - Location of sentries
   - Requirements for follow-on and internal safety distances
   - Procedures for mines that have been damaged but not detonated by the demining machine
   - MEDEVAC procedures and medical support
   - Helicopter landing sites and preparations of such
   - Recovery drills.

7. Local communities, police and local officials should be informed about the demining operation.

8. Are people living close to the site? In some cases, people will have to be evacuated from the hazardous area during operations.

Figure 8 | The mechanical demining operation cycle



MECHANICAL DEMINING OPERATIONS

TASKING

The national authority, or the body acting on its behalf, is responsible for coordination, tasking and QA/QC. This authority should have a priority setting system for SHAs and then request organisations to clear specific areas.

The process of issuing such requests is called tasking. The normal way is to issue a tasking portfolio consisting of all available information related to the task. Typically this folder will contain maps, survey reports, copies of minefield records, victim reports and the tasking order for the specific site. The tasking order will say which operator has been given the authority to carry out clearance. The order will also include timelines, estimated size of the task, suspected mine contamination and sometimes the clearance methods to be used. In some cases operators will be required to prepare a detailed implementation plan for each task while in other cases this will be done by the issuing authority. In both cases the tasking order will dictate the implementing organisation's reporting requirements.

TASK ASSESSMENT

A task assessment should be carried out before starting clearance operations. The assessment gathers as much information as possible for planning purposes to ensure the subsequent smooth deployment and operation. As a minimum, it should include:

1. Review of survey documents; survey protocols, IMSMA reports, minefield records, maps, photos (including aerial photos) and previous clearance reports.

2. A hazard assessment. The type of hazard needs to be identified in order to choose the appropriate tool and protection level.

3. An assessment of topography, terrain features, infrastructure, access roads, seasonal changes and vegetation should be completed. It should identify if the site is suitable for demining machines.

4. Local points of contact for information regarding the clearance task and logistical and medical support should be established.

5. An environmental assessment of the site should be undertaken with local communities.

6. The logistical requirements at the site must be identified. The aim is to ensure a smooth and efficient operation and to prevent delays in mechanical clearance operations. If possible heavy equipment should be securely stored at the site to save time and resources.

Task assessment in the Bungu area of Sudan. The assessment team included the survey project manager, the technical advisor for manual demining, the operations manager, the survey officer, the team leader, the medical coordinator and the senior mechanic

7. Requirements for other clearance assets that support the mechanical operation —e.g. other demining machines, manual clearance assets and/or MDDs — need to be assessed.

8. A site visit: if several organisations will be working together, all take part in the visit. The visit should establish which areas are suitable for mechanical demining.

9. An evaluation of whether the task site is large enough for a specific demining machine to be cost efficient, or if it could be more effective to use other assets.

Checklist 3 in Annex D covers task assessments for mechanical demining operations.

SITE SET-UP AND PREPARATION

The two main considerations in setting up a mechanical demining site are practicality and safety. Such sites invariably have the following common features.

- **Refuelling area**: this should be easily accessible for both the demining machine and the fuel trucks that are refuelling the fuel bladder or reservoir. The refuelling area must have fire-fighting equipment and be managed so that there is no fuel spillage. Smoking is not allowed within and around the refuelling area. The area needs to be marked and at a safe distance from other site areas, particularly the explosives store. The refuelling area might also need to be guarded.
- **Maintenance area**: this is for the mobile workshop where all routine maintenance and minor repairs are carried out. It might also have a store with a welding machine, tools, spare parts, lubricants and more.

A locally built workshop container in Kurdistan

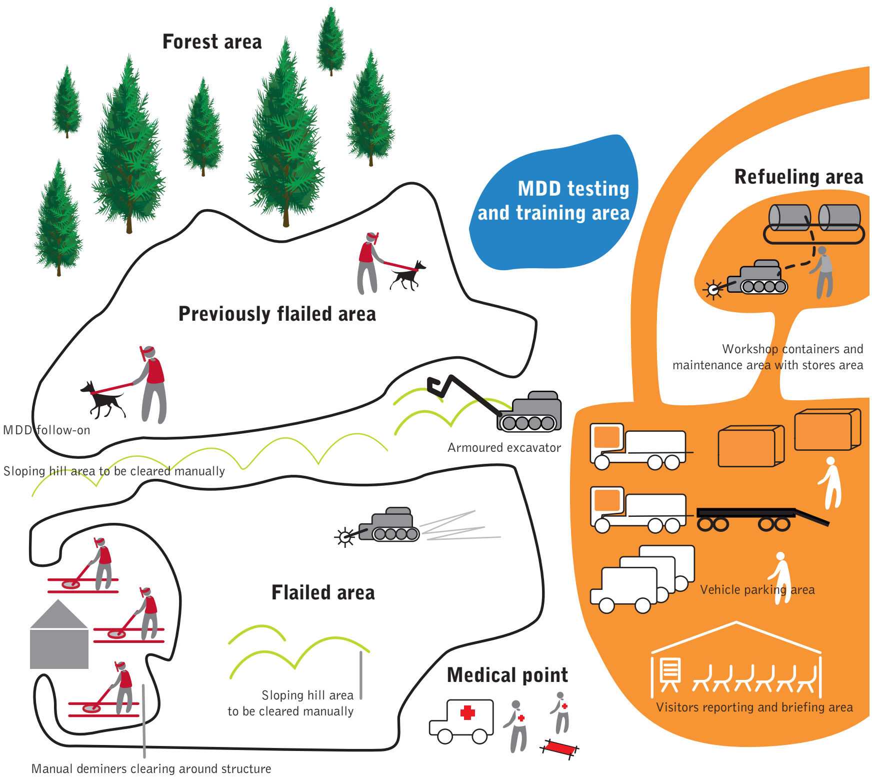
- **Vehicle parking area**: this is for parking all team and visitor vehicles and should be clearly marked. A parking area ensures that the access road to the site is kept open for emergency vehicles.
- **Visitor reporting and briefing area**: this normally has a sketch map used when briefing staff and visitors. The map should record daily progress on area cleared, mines detonated and follow-on.
- **Resting areas**: these are for manual deminers during their rest periods. These areas should be shaded and provide drinking water.
- **Communications area**: this is where site staff communicate with operations staff and with the outside world, e.g. to request medical evacuation or other assistance. Communications should be maintained at all times during operations.

Site briefing at the MSB mechanical demining site in Lebanon

- **Medical area**: for the site's medic, possibly equipped with a medic/safety vehicle.[1] Such a vehicle can be shared by several sites if they are near to each other.
- **MDD testing areas** (if MDDs are used): these will be set up for daily training and testing of the MDDs.

A mechanical demining site in Jordan

Figure 9 | Drawing of a mechanical demining site



SITE SAFETY

There are some potential dangers in a mechanical demining operation, in addition to the actual mine hazard. Chains, for example, can break loose from the flail shaft during operation, with the possibility of seriously injuring staff. Staff must also be protected from stones and rocks thrown out by the machine's working tool. The best accident prevention is to ensure that staff members are a safe distance from the machine, which should be operated in a direction away from any staff.

Falling trees can be a hazard during vegetation clearance. Demining machines can use a towing wire to move larger trees or to remove other obstacles at the SHA. Staff should be aware of the danger of the wire snapping. Towing wires should never be used for loads heavier than the limit prescribed in their certification.

Operators must be well aware of the capacity of their demining machine — and of the terrain features in the area to be cleared. Obstacles such as ditches, boulders and hillsides, particularly in poor visual conditions, can cause the machine to overturn. This can cause serious injury or death to the operator, and delay operations. Seatbelts should be worn as directed by the manufacturer.

Bounding and fragmentation mines with tripwires also pose dangers. The tripwire may connect to a mine to the side of the machine: if triggered by the machine's working tool mine fragments can penetrate the operator's cabin.

Understanding of the expected hazards in the area is crucial to the safety of operators. For instance, if the area is expected to contain cluster munitions with shaped charges the area is probably not a suitable mechanical task.

DAILY CHECKS AND CLEANING

Demining machines need to be checked prior to starting operations to ensure safety of personnel involved and to minimise the risks of costly downtime and repairs. Any faults must be rectified before the machine is deployed.

All maintenance and service should be recorded in a logbook which should accompany the machine. Daily cleaning and checks before and after operations are mandatory. This gives operators a chance to repair the machine before operations and allows more time to order parts.

Examples of checks are:

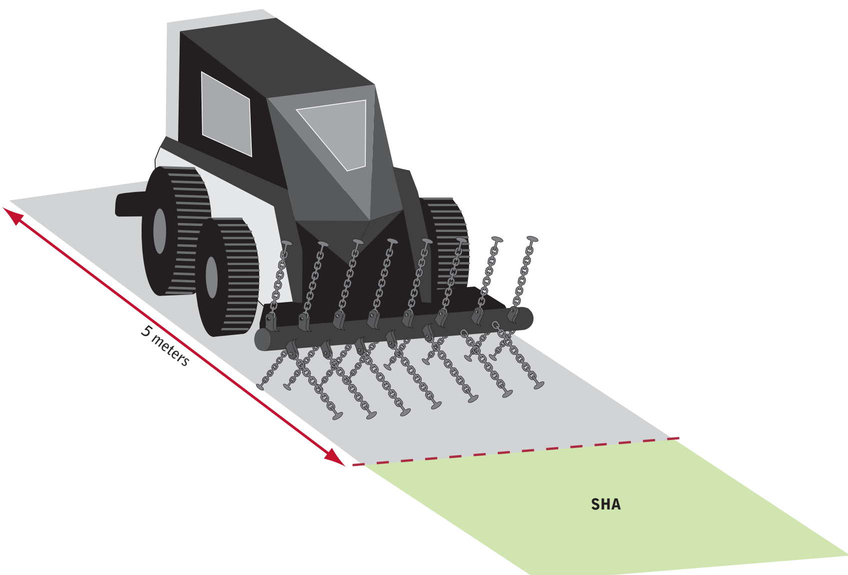
- Visual routine checks such as inspecting chains, hammers, bits, tracks, wheels, hatches and other moving parts of the machine
- Checks for serviceability and fluid levels
- Daily checks as detailed in the manufacturer's support documentation.

ON-SITE TESTING

Each time a machine is deployed to a new area or a new type of task, an on-site test should be conducted to evaluate its performance in the new conditions. This test will help determine the optimal forward operating speed of the machine.

Normally the test is carried out in a safe area with conditions similar to the SHA. The test is done in one run with the demining tool engaged for a distance of a minimum of five metres. During the test run the performance and depth achieved will be evaluated and operational procedures adjusted accordingly.

Figure 10 | On-site testing



COMMUNICATIONS

All mechanical demining tasks require internal communications procedures as described in the organisation's SOPs and in the NMAS. Normally the mechanical team leader will be in radio contact with the following staff during operations:

- Site supervisor
- Machine operators
- Medic
- Sentries
- Other teams working with the mechanical team.

External communications with the organisation's headquarters and the NMAA are sometimes also required. SOPs should include a chart indicating the communication structures and various call signs.

MARKING DURING MECHANICAL DEMINING

Marking should comply with IMAS 10.20: Safety & Occupational Health – Demining Worksite Safety. SHA areas must be clearly marked. Marking at each task site has to be clear and consistent. Mechanical demining operators need to develop their own SOPs in compliance with NMAS for marking their demining sites. Marking has to provide visitors and staff with clear indications of where it is safe to move. During the course of the operation marking must be maintained and replaced as necessary.

The use of flags for guiding the direction of travel for the demining machine is recommended. This is very important under dusty conditions when visibility is limited. Such marking helps the operator to achieve the necessary overlap between passes.

OPERATIONAL CONSIDERATIONS

Practical considerations when preparing for a mechanical demining task include:

- Overlapping must be ensured to avoid skip zones and missed mines
- A suitable location for observation of the operations must be established
- Appropriate methods for avoiding obstacles must be established
- Appropriate procedures for recovery of the machine must be identified
- Procedures should be set for recovery of the operator in case of machine breakdown or a mine accident
- Procedures are needed for dealing with thrown-out, broken or damaged mines, parts of mines and sometimes even undamaged and fully functional mines; in some cases the explosives chain may not have been broken and the mine is fully functional, posing a hazard to demining personnel and others
- A drill for areas that have been covered with a machine that has lost chains or hammers must be decided
- Other procedures needed are for Notifications to Airmen (NOTAM), as described in NMAS, and for receiving visitors at the site; a safety briefing should also be prepared.

OPERATOR SAFETY

The operator's safety must be ensured at all times. This can be done through the following arrangements.

- The demining machine operator needs to have communications with the site supervisor at all times
- Extraction procedures must be in place in case of an accident where the operator is injured. These must be trained and checked on a frequent basis
- The machine cabin needs to be clear of all loose items. Good housekeeping is crucial. Tools and other items necessary for the operation of the machine must be stowed outside the cabin or safely secured inside the cabin. Tools and other items that are not secured in the cabin increase the risk of injury to the operator if a mine is detonated

> All the necessary safety equipment must be available in the machine. This includes fire extinguishers and first aid kits. These items must be accessible, safely stowed and secured, fitted with instructions and clearly marked. Fire extinguishers must be regularly checked and operators must know how to use them.

FIRST AID AND MEDICAL EVACUATION

Mechanical demining sites must be set up with medical support in accordance with existing SOPs and NMAS. Safety vehicles must be fuelled, equipped with a stretcher, with the keys in the ignition and in a fully functioning condition. The safety vehicle should also have a route card with directions to the nearest medical facilities and distances between turns and intersections indicated. The vehicle should have a dedicated driver familiar with both the vehicle and the local area.

A helicopter landing site may be needed if helicopters are available for medical evacuation. Landing sites must be set up according to standards existing in the country. Staff should be trained on how to guide the helicopter and how to load a casualty.

Medical evacuation drills should be practiced, checked and recorded regularly.

OBSTACLES

An obstacle is an item or a physical land feature that will hinder the manoeuvring of the demining machine. Obstacles can be trees, rock formations, water wells, rivers, cliffs and more. Obstacles can also be man-made, such as irrigation ditches, plantation terraces, battle trenches, wire entanglements, structures and abandoned vehicles. All large obstacles are to be avoided wherever possible.

If the machine impacts a large obstacle it may result in damage to the machine or the machine becoming lodged on or in the obstacle. If this happens it will result in the need to recover the machine, possibly risking the lives of the recovery team. To mitigate obstacles an observer can be used to guide the machine operator.

If a wire obstacle is encountered it should be removed by manual demining teams or pulled out of the hazardous area using a demining machine. Should the demining machine become entangled in wire the observer should instruct the operator to stop operations and remove the machine from the hazardous area. The operator should then carefully remove the wire and make sure that the machine has not been damaged.

To remove the wire from a working tool, the tool can be put in neutral and manually reversed. While removing the wire the engine should be completely turned off. The mechanic or operator should be equipped with a wire cutter and heavy duty gloves.

If the tool is too heavy to be manually reversed, the wire can be attached to a fixation point while the demining machine, with the tool in neutral, is reversed.

There needs to be plan for all potential obstacles that may confront the machine. The limits of each obstacle need to be assessed and with the best ways of overcoming the obstacles determined. Obviously it is more difficult to negotiate obstacles when the machine is remote controlled: but they can be negotiated by using observers or relocating the operator. In some cases a portable protective shield or an MPV can be used to protect the operator while operating the machine from a closer location.

A protective shield protecting the operator of a remote-controlled demining machine

RECOVERY DRILLS

If a demining machine breaks down within an SHA manual and/or mechanical drills can be used to clear a safe path to the machine. A wire from a recovery vehicle can be attached to the damaged machine. Under normal conditions the recovery vehicle needs to be twice the weight of the machine to be towed, unless snatch blocks can be used. Some demining machines are equipped with a winch for self recovery. In such cases the wire is to be secured to a fixation point outside the SHA if possible.

A Bozena 5 detonating an AVM mine (9kg TNT)

Before accrediting a machine for operations national authorities should ensure that a suitable recovery vehicle is available. Mechanical operators need to develop, and include in their SOPs, drills that are safe, specific, realistic and suitable for their respective machines. Recovery drills need to be practiced regularly.

TECHNICAL SURVEY

When demining machines are used for technical survey tasks the most common method is to conduct the survey using the machine to create cut lanes into, and through, the SHA. This method is used to identify the minefield pattern for subsequent manual clearance of the actual mines. The exact parameters of SHAs are difficult to establish, particularly in non-patterned minefields. For this reason it can sometimes be worth starting the technical survey from inside the SHA and working outwards until a hazard is, or is not, identified.

Technical survey can be performed by any demining method. Machines, however, can survey faster than manual teams and MDDs. Reducing the area requiring manual clearance dramatically increases the speed of overall operations and enhances the safety of operators. Using machines in technical survey reduces the need for scarce and expensive follow-on assets.
The aim of the technical survey is to gather evidence of the presence of mines through audible and visual indications. Sometimes, when no indications are being observed, the mechanical technical survey can serve as an effective and critical part of the documentation phase of the land release process and contribute to the increase speed of releasing land.

“Land release” is a generic term to describe the process of freeing land previously suspected to be hazardous. This suspicion is eliminated by either some form of assessment or survey, or by full clearance. Machines can play a vital role in the land release process.

GROUND PREPARATION

Demining machines are commonly used as a preparation tool for manual and MDD demining. In this role machines can be used in different ways depending on type, tool and power. Demining machines can also be used to remove of vegetation and tripwires, and as a ground penetrating tool to break up hard soil.

There are also machines, not very commonly used, that will prepare the ground through the removal of vegetation and tripwires, breaking up the ground and removing some of the metal contamination with a magnet. The addition of a magnet can greatly increase the speed of manual demining in areas where metal fragments is slowing progress, as well as the benefits of vegetation and tripwire removal.

MECHANICAL DEMINING OPERATIONS

Two factors slow manual demining; metal contamination and vegetation. Both of these factors can be mitigated by the use of suitable demining machines.

Demining machines can also be used to provide access by lifting heavy obstacles and removing rubble that would need to be cleared by other methods.

AREA CLEARANCE

Area clearance is the typical and most suitable task for demining machines When demining machines are used to clear larger areas a number of factors needs to be taken into account. If there is a requirement for follow-on behind the machine, the capacity must be sufficient so that vegetation does not re-grow before follow-on is started. If, for instance, a machine that is clearing 10,000 square metres per day (100m x 100m) is used, the follow-on assets will need to be matched so that they can clear the corresponding number of square metres.

During area clearance demining machines can benefit from working in tandem to increase the clearance rate. Having two or several machines working at one site will have effects on logistics and command and control. There will be additional requirements for fuel, maintenance and spare parts and more support and follow-on personnel will most likely be required at the site. Since the clearance will progress at a higher rate when operating several machines at one site, forward planning is also of increased importance in order to ensure that machines are kept operating at all times.

If a remote-controlled machine is used for area clearance the operator needs to be repositioned continuously in order to not to be too far away from the machine.

When setting up an area clearance task a lot of work can be avoided through proper planning. The way a machine initially approaches and opens up an SHA will dictate how effectively the demining organisation can deploy tools available for the given task. It is crucial to approach a task in such a way so that all assets available immediately can be deployed.

For cost effectiveness a large machine will require larger clearance tasks. A smaller machine is more flexible in its deployment and be transported easier between smaller tasks.

ROAD CLEARANCE

Correctly used mechanical demining will speed up clearance of roads significantly. A well managed mechanical component is essential for an effective road clearance project. One fact that needs to be recognised, however, is that mine clearance machines destroy the road surface and that road reconstruction will be required after clearance has been completed.

It is crucial that a machine chosen for road clearance can survive an AVM blast and also has sufficient power to penetrate the road surface. If possible mechanical demining along roads should only be carried out in areas recognised as hazardous and not along the road as a whole.

Coordination of assets is key during road clearance since not only clearance assets need to be coordinated but coordination is also required between the road clearance operator and the road constructor.

For further literature on road clearance see the GICHD, 2008, A Guide to Road Clearance. Annex D in this handbook also contains a checklist for road clearance.

OTHER USES FOR MACHINES

A demining machine can be constructed so that it may be used for other purposes than mechanical demining. It can easily be fitted with different construction tools. A blade, for instance, can be used for smaller earth moving tasks following the demining operation. Adding a tool to a demining machine at a low cost can make the machine much more versatile and enable it to perform several support tasks.

Some demining machines can be used to lift, transport and remove vegetation that has been previously cut in the SHA. This will speed up the removal and also reduce the labour required. Other machines can also be used for digging ditches to further assist local communities and to ensure irrigation of the cleared areas.

MECHANICAL DEMINING OPERATIONS

During road clearance the damage to the road will be severe and will normally require a road construction contractor to repair, or rebuild the road. If damage has been caused to access routes and road networks it is important to ensure that this is repaired and that roads that have been damaged are left in the same condition they originally were. The road should be repaired or reconstructed as soon as possible after the clearance operation. If the carriageway of the road has been made soft by the demining machine, vehicles will not be able to pass and might be forced to drive on the un-cleared verge of the road with the risk of hitting a mine.

ENDNOTES

1 See IMAS 10.40, First Edition, 1 October 2001 Safety & Occupational Health Medical Support to Demining Operations.

CHAPTER 6

MAINTENANCE AND LOGISTICS

MAINTENANCE AND LOGISTICS IN MECHANICAL DEMINING

Without a proper logistic system in place, with qualified staff for maintenance of the demining machines, failure is inevitable. All machines require maintenance and therefore the deployment plan must include provision of an adequate maintenance and logistic capability. Due consideration must be given to the requirement for a mobile support workshop – and for stocking levels of critical spares and consumables.

MINIMISING MACHINE DOWNTIME

When the machine is scheduled for maintenance, careful planning can ensure that the necessary tools and spare parts are available for all necessary maintenance and repair jobs to be carried out at the same time. Normally, scheduled maintenance should be outside usual machine working hours to maximise the output of the project.

Downtime of demining machines is often caused by poor maintenance as a result of untrained staff, inadequate supplies of spare parts and improper facilities and tools. Downtime can also be attributed to slow maintenance and repair work, avoidance of responsibility and blame being casually attributed by management to others. The blame for poor maintenance and underemployment of demining machinery lies, without exception, with management.

MAINTENANCE OF DEMINING MACHINES

Effective operation and maintenance is largely a matter of the attitude and motivation of the personnel performing the work. Machine operators and maintenance personnel must have a disciplined and conscientious approach to the care of their equipment. Managers must demonstrate their concern for safe and efficient operation and maintenance by ensuring that all personnel comply with recommended procedures and good practices in their respective fields.

MAINTENANCE AND LOGISTICS

MAINTENANCE ROUTINES

Maintenance of demining machines is absolutely crucial to ensure that the machine remains operational at the lowest cost possible. Service must be carried out as recommended by the manufacturer. Checks and service can, for instance, be daily and then after 100, 300, 600 hours and so on with various parts and liquids replaced or checked during each service. If the manufacturer is brought to the country to service demining machines, the contract should include training of project staff in maintenance and operation of the machine. The best way to ensure that every maintenance point is covered is to introduce an auditable checklist procedure where the person carrying out the maintenance has to sign and verify that all required actions have been carried out. Annex F shows an example of a daily maintenance log sheet for demining machines. This log sheet can be used as a template and adapted for specific machine types.

TRAINING REQUIREMENTS

Mechanics and machine operators need to be trained to conduct repairs in a timely and effective manner. They need to understand that time wasted is money lost. On the other hand, they must also not rush to replace parts unnecessarily, without thinking about the expense of repeatedly doing so. Good diagnostic work to understand the root problem is essential. For example, broken components that could be repaired are often discarded when mechanics believe there is no penalty for doing so or when there is no reward for trying to save money. These and similar problems can easily burden logistics while driving up expenditures.

Training a local mechanic in Kurdistan

WORKING CONDITIONS DURING MAINTENANCE

Good working conditions for maintenance personnel have a dramatic effect on productivity and efficiency. Working in the open air all year without adequate shelter from the elements can degrade the capabilities of a maintenance workforce. Specifically hydraulic systems and bearings need to be protected from dust and sand.

Maintenance of a demining machine

Critical to effective machine operations are workshop facilities that are fit for purpose. Most often a mechanical project will require a mobile workshop in the field. Such workshops should be capable of dealing with the most common problems including mine detonations and the most common breakdowns.

SERVICE AGREEMENTS

The ordering of spare parts is often at the root of machine downtime problems, along with poor fitting of parts and limited understanding of the complete system. When coupled with a lack of technical expertise, the result is often frustration and machine downtime. Frustration and strained relationships may develop between the implementer, suppliers, the manufacturer and sometimes the contracting agency. One solution to these prevalent problems is to negotiate (and budget for) a service contract with the manufacturer of the machine. A service contract could take many different forms and can include:

- Training and certifying of local mechanics
- Holding records of spare parts ordered for individual machines
- Delivering spare parts as a part of the contract
- Conducting critical machine hour services that might be beyond the skill of project staff
- Revisits for follow-up, maintenance and additional training
- Conducting routine maintenance QA checks after a defined number of hours of machine use
- Conducting QA checks on certified mechanics.

The service contract should also include provision for the manufacturer to visit field operations to gain a full understanding of where the machine is deployed and, equally important, any logistical constraints. This will enable the implementer and the manufacturer to design a supply process tailored to local conditions. Involving the manufacturers directly in the field use of the machine can improve their knowledge and understanding about the use of their machine and potentially lead to enhanced performance of the machine.

TECHNICAL HANDBOOKS AND MANUALS

Handbooks and manuals must be included as a part of the package when purchasing, or leasing, a demining machine. Manufacturers should also make an electronic version of their handbooks and manuals available to their customers. This will enable an organisation to easily translate the publications into a local language. When machines are locally produced or adapted handbooks and manuals are necessary to ensure that proper that maintenance and repair work is undertaken as originally intended.

It is mandatory for the manufacturer to provide exact specifications of the operating temperature limitations for the various components of the machine. A list outlining the specifications for fuel, oils and lubricants approved by the manufacturers of the various components of the machine must be included. It is absolutely essential that such instructions are implemented and followed.

DRAWINGS AND BLUEPRINTS

Drawings and blueprints should be provided as a part of the purchase/lease package. If machines are produced locally, drawings of the machine, including changes to the platform, should be provided to the customer. Below is a list of schematics that should be provided to the customer:

- Electrical system including fuze specifications
- Hydraulic system
- Fuel system
- Cooling system
- Break system.

MACHINE LOGBOOKS

All demining machines should have a machine log book, in a ring binder so that pages can be added. Below is an example of information that should be entered into the machine logbook daily:

- Consumables used
- Spare parts used
- Fuel used
- Breakdowns and other problems
- Tasking orders
- Machine deployment plans.

The machine logbook should also include daily, weekly, monthly and other inspection and maintenance records.

LOCAL SERVICE PROVIDERS AND LEAD TIMES

Mechanical demining operations are, most often, undertaken in countries where the lead time for delivery of goods can be long. Operators should therefore identify local service providers who, on short notice, can deliver spare parts that are interchangeable and of comparable quality to the ones already fitted to the machine. For spare parts that cannot be found locally, suppliers should be identified in neighbouring countries. An agreement should also be made with one of the major courier agencies for fast shipments, if possible within 24 hours.

For spare parts that are too expensive to have in store, such as hydraulic pumps, agreements can be made with suppliers to provide these on short notice. Some consumables and spare parts might be subject to import tax as well as high shipment cost when brought in from abroad. When manufactured in-country, such consumables are often cheaper and can be adapted to specific local conditions.

Local agreements should also be made for provision of capable service technicians so that major repairs can be done locally instead of having to fly in international staff at high cost and longer delay.

STORE MANAGEMENT

Stores need to be managed. A big project should have a full-time store manager. For a smaller project, this can be an additional responsibility for a staff member. Stores need to be secured, easily accessible and well organised. Documentation of the contents of the stores and other documents related to store management must be maintained. Examples of such forms are inventory sheets, sign out sheets, order forms and fault reports. It is recommended that a simple database for stocktakes and store management is created.

SPARE PARTS MANAGEMENT

Spare parts management is crucial to ensuring that a mechanical demining project is cost efficent and productive. It should ensure that the right spare parts and resources are at the right place (where the broken part is) at the right time. Large quantities of spare parts are sometimes considered uneconomical: expensive components such as fuel pumps and hydraulic engines might never be needed but tie up scarce financial resources. On the opther hand, a missing critical spare part can mean that the operation stops for weeks or even months. One staff should be designated to deal with all matters pertaining to spare parts, including prevention of theft, inventories and stocktakes, signing for and handing out the parts, and ordering the new parts needed.

WORKSHOP FACILITIES

Workshop facilities can be both mobile and stationary. Under most circumstances there is a requirement for operators to have both. Tools and equipment will vary but both types of workshop need to be able to cope with the repairs required in their situation. For a mobile workshop, it is important to know the conditions under which it will be used, and how it will be transported. The workshop must be able to withstand the environmental conditions under which it will be used and transported. Workshops must be safe for mechanics to work in, protected from theft and sufficiently equipped. They should have fire-fighting equipment such as extinguishers, fire blankets and equipment for dealing with oil spillage. They also need first aid equipment, with eye wash facilities.

A mobile workshop from outside

Inside a mobile workshop

SAFETY DURING MAINTENANCE

Carrying out maintenance is a danger in itself. Heavy mechanical parts can accidentally move and injure people in their way. Only authorised personnel with appropriate training and protective gear should be allowed to carry out maintenance of demining machines. Annex B provides some guidelines for mechanical safety.

Maintenance training on the MV-4

RISK ASSESSMENT

When constructing, carrying out maintenance or making improvements to demining machines a risk assessment should be undertaken. A risk assessment normally has three parts:

- Risk of injuries to humans
- Risk of mechanical damage
- Risk of environmental damage.

The various risks are listed and solutions to minimise or eliminate each risk are identified. For instance; a leakage of hydraulic fluids can destroy the hydraulic pump in a machine. This is the risk identified. The method of minimising this risk is to install a warning system which informs the operator if hydraulic fluid level reaches a threatening level so that the operator can shut down and repair the leakage.

Another example is the risk of injury to the operator's hands if a hatch is not locked in its open position. This risk is minimised by installing a device to ensure that the hatch cannot be left open without being locked in the safe position. Another solution to this problem, even if it is not the preferred one, is to put a sticker on the hatch informing about the risks of not locking the hatch in the open position.

FUEL AND HYDRAULIC FLUIDS MANAGEMENT

Machines use fuel — a simple statement often ignored in the enthusiasm to use them. There is no point deploying a machine that uses 40 litres of fuel an hour if fuel is not readily available. A proper fuel management plan must be in place. The fuel management plan should include such considerations such as:

- Establishing a baseline of the fuel usage for the demining machines together with cost estimates for periodical fuel consumption
- Establishing from where fuel can be collected and the time required for fuel deliveries, together with alternative fuel sources
- Forward planning for future demining sites and their fuel provision
- Monitoring and recording fuel consumption
- Monitoring the quality of the fuel
- Fuel storage and supply at the demining site
- Health, safety and environmental aspects.

A plan for how to refuel the machine at the demining site must also be put in place. This can be done through stationary fuel tanks at the site or through a mobile refueling system that can be removed from the site daily. Stationary fuel tanks require a safety and security system.

Extreme care must be taken when using fuel barrels for refueling. In addition to the obvious dangers of spillage it is vital to prevent pollution of the machine's fuel system. The barrels might be contaminated by sediments from corrosion, sand or water, or all three. Most machines contain a water separator on the diesel filter, but dirt might clog the system and cause downtime.

A mobile refuelling system: a pick-up fitted with a fuel tank

The fuel and fluids used on a demining site pose several health risks to the staff. If diesel is swallowed, medical advice should be obtained immediately: there is a small risk of short-term lung damage if vomiting occurs or if droplets of diesel are inhaled. Long-term skin exposure to diesel may result in inflammation of the skin. The use of diesel to clean skin and hair should be strongly discouraged as this can cause kidney damage. Longer-term exposure to diesel can cause adverse health effects but a short exposure will not normally have any long-term effects.

Breathing large quantities of diesel vapour or drinking diesel-based fluids may cause non-specific signs and symptoms of poisoning such as dizziness, headache and vomiting. A severe form of lung damage may occur if liquid diesel is inhaled directly onto the lungs, for example, while manually siphoning a tank or from inhaling vomit after swallowing diesel. This is why it is important not to make someone vomit if they have swallowed diesel. Diesel engines should only be operated where good ventilation can be ensured.

To put out a diesel fire, normal foam should be used and a normal fire kit should be worn in combination with breathing apparatus. Spillages and decontamination run-off should be prevented from entering drains and watercourses.

Most demining machines use some type of hydraulic power system — in an environment that is usually dusty, violent and often very hot. All these elements threaten the durability of a hydraulic system. Hydraulic hoses need protection from wear and chaffing. This can be achieved by securing hydraulic hoses to the chassis and by shielding them with plastic armouring or metal mesh.

Before opening the filling caps to a closed hydraulic system, make sure that the surrounding area is cleaned of dust and dirt. A hydraulic flushing system is hard to find in most mine-affected countries and a contaminated hydraulic system can be very expensive to repair. Hydraulics hygiene has been shown to be key to a successful maintenance regime.

It is important to ensure good ventilation when working with hydraulic fluids. They contain chemicals which can have adverse effects on humans. The effects of breathing air with high levels of hydraulic fluid vapour are not fully known. Drinking small amounts of some hydraulic fluids or drinking water contaminated with hydraulic fluids can cause pneumonia, intestinal bleeding or even death.

OILS AND LUBRICANTS

As with fuel and hydraulic fluids, oils and lubricants must be available when needed during operations. The quantities are smaller but the requirement for high quality products is still applicable. There should also be a system for safe storage and disposal of used oils.

ENDNOTES

1 The GICHD Mechanical Demining Equipment Catalogue lists under each machine the type of support manufacturers offer within a purchase package. These packages would obviously be the negotiation starting point for an enhanced service support package.

CHAPTER 7

ENVIRONMENTAL EFFECTS OF MECHANICAL DEMINING

MECHANICAL DEMINING AND THE ENVIRONMENT

It is well known that mechanical demining can cause environmental damage. Operators need to be aware of this and take every measure possible to mitigate the risks while land is being cleared. It is also crucial to involve the affected communities in the demining operations and to adhere to the NMAS in place.

Environmental considerations during mechanical demining

Operations should always be carried out without damaging property or infrastructure, to minimise the impact on the environment. Planning of mechanical demining operations should take into account the effects of the mechanical intervention and any supporting activities.

Demining organisations should ensure that land treated in their operations is left in a state suitable for its intended use once demining operations are completed. Particular attention should be given to property, infrastructure or land required for subsistence or economic purposes so that these activities can resume effectively after the demining operation.

Ensuring that mine action does no environmental harm must be fundamental to demining programmes. Environmental issues must be carefully considered and staff trained on these issues. If the net result of demining is environmentally damaged land, nothing has been achieved. Mine-free but useless land is not an end product to be proud of: the desired result is land clear of mines and available for sustainable productive use.

Operation, repair, maintenance and servicing of machines used during demining should minimise or completely avoid making an environmental impact, in accordance with the requirements outlined in the NMAS.

Routine community liaison about mechanical operations should include advice to property owners and local authorities about any possible damage to property or infrastructure. If necessary, advice on how to minimise damage should be given to property owners of land adjacent to demining worksites.

ENVIRONMENTAL EFFECTS OF MECHANICAL DEMINING

TYPES OF ENVIRONMENTAL DAMAGE

There are four major environmental damage issues when considering the application of machines:

- Erosion
- Deforestation
- Ground pollution
- Soil structure damage.

Erosion

Erosion is the gradual wearing away of land by water, wind and general weather conditions.[1]

Gully erosion in Lesotho

When planning mechanical demining, an erosion risk assessment should be carried out. Local people depending on agricultural outputs will not benefit if the process used to clear an area leads directly to erosion. Demining machine operators must ensure that machinery is not used in a way that will destroy agricultural land. Operators should have SOPs that include environmental aspects and national authorities should develop guidelines in line with any existing national legislation.

A non-specialist can do this by considering the non-exhaustive checklist of factors shown in the environmental checklist in Annex D. If the answer to any of the questions in this checklist is “yes” then the next step is to consider if there are actions that can be taken to mitigate against erosion while still enabling machine use.

Erosion and soil damage in Afghanistan caused by a temporary river from deforested mountains, destroying fields and terraces

When working in areas with a high risk of erosion it might be possible to overcome erosion problems by using one of the methods described below.

- Leave 3 to 4 metre wide strips of vegetative cover at intervals across the site horizontal to the likely route of erosion — accepting the trade-off that the clearance process will be slower in these strips, and that manual deminers will be needed
- Ensure that the topsoil structure is not broken up by the mechanical process, perhaps by using the machine in a ground preparation role (only removing vegetation) and then follow-on with manual clearance or MDDs

> Together with local beneficiaries, construct terracing as part of the site handover process
> Follow clearance operations with reseeding (with indigenous grasses) and/or planting shade/boundary trees
> Schedule clearance so that the site can be cultivated as soon as possible after the clearance has been completed.

Where mechanical operations involve the removal of vegetation, or is carried out on ground that may be subject to erosion, demining organisations should take measures to ensure the regeneration of vegetation and to limit erosion. Such measures should be described in the NMAS and might include the following:

> Reseeding and replanting (e.g. grass, trees, ground cover)
> Return of processed soils to the affected site (for instance, soils that have been mechanically sifted)
> Planting or construction of wind barriers
> Preparation of drainage systems
> Performing the mechanical operation when the soil and vegetations is least vulnerable
> Avoiding deep tracks by using proper equipment and operating during the right season.

The table in Reference Document Number 9 sets out the common types of erosion, the consequences and some control measures. The consequences are generally severe. Also note how important vegetation is in erosion control.

ENVIRONMENTAL EFFECTS OF MECHANICAL DEMINING

Deforestation[2]

Deforestation is often closely linked to erosion and mechanical demining can include the removal of trees. Therefore when developing a site clearance plan operators must set a vegetation policy and decide what is acceptable in terms of tree removal. This should be done with the end-users of the land, i.e. the local community, and in accordance with NMAS. The following questions need to be answered:

> What will the site be used for after clearance — housing, grazing, rain-fed agriculture, irrigated agriculture or industry?
> Can some vegetation be left along stream courses and/or irrigation channels?
> Can the area be subdivided into fields, leaving trees on boundaries?
> Can local generic crops be grown under some tree species?
> Do local generic crop types need some shade?
> Is wood commonly used for cooking?
> Do local people manage their forest resources? Does, for example, charcoal burning take place?

Deforested hills in Vietnam

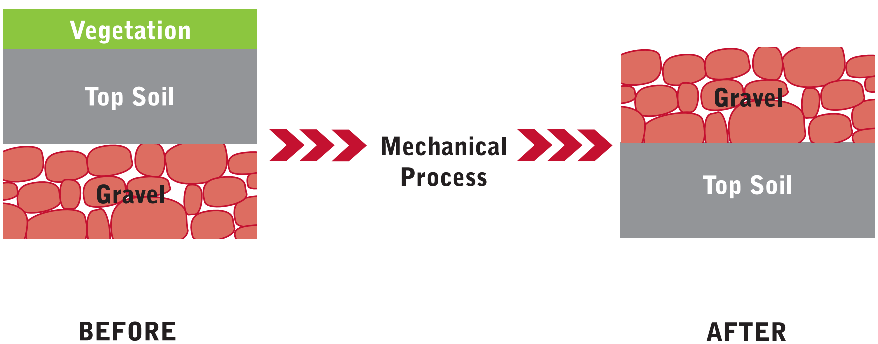
ENVIRONMENTAL EFFECTS OF MECHANICAL DEMINING

Soil degradation

Soil degradation occurs when the changes in the depth of soil or its physical or chemical properties reduce its quality. Soil degradation includes loss of the nutrient-rich topsoil through erosion, loss of organic matter, salinisation, acidification and loss of structural stability. These processes can be accelerated through mechanical demining.

When using excavation techniques, particular care must be taken to ensure that valuable productive topsoil is managed with due care through the clearance process. During excavation soil layers must not be mixed. This helps to ensure that the land is still productive after clearance.

Figure 11 | Topsoil clearance: what NOT to do



Hydraulic fluids, diesel and oil

It is important to be aware of possible chemical pollution when planning mechanical demining operations.[3, 4] Measures must be taken to deal with fuel and lubricant spillages. SOPs should cover how fuel and lubricants will be replaced, and what measures will be taken with waste products. For example, a well-managed programme will require the use of waste trays and barrels in the field, and will have an established disposal regime in compliance with national law.

When hydraulic fluids enter the environment through spills/leaks in machines or from storage areas and waste sites this will cause severe environmental pollution. Components requiring hydraulic fluids should be fitted so that removal from the system for maintenance minimises the loss of fluid, does not require draining the reservoir and does not require extensive disassembly of adjacent parts.

Having no rules in this area of work will inevitably result in an unprofessional disregard for others. A demining organisation must ensure that it instils a sense of responsibility in its workforce. Throwing lubricants into rivers or allowing seepage into groundwater supplies is simply a manifestation of poor and irresponsible management. Leakage of diesel from large storage tanks is a significant source of groundwater contamination, particularly where the storage and handling of fuels is poor. Diesel contains water-soluble components, which have a very low taste and odour threshold. Drinking water contaminated with these fuels is unacceptable to consumers.

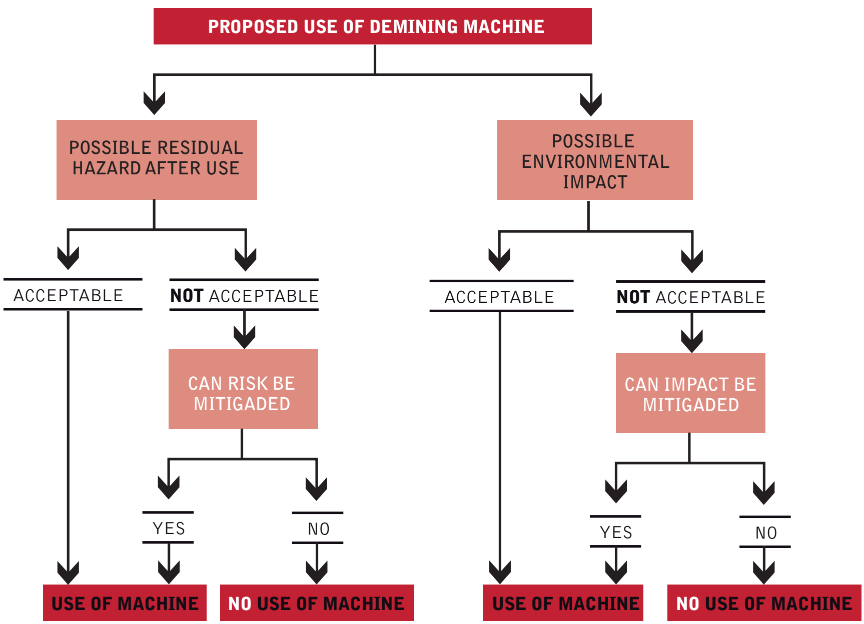
Used lubricating oils and filters typically contain quantities of hazardous substances that can pose a risk to the environment and human health. Improper management or handling of used lubricating oil or filters can release dangerous elements into the environment, negatively affecting water, air, ground, plants and animals, as well as human health.

Fuels must be stored in tanks above or below ground. These tanks must be of an appropriate standard to prevent leakage and must be regularly checked for leaks. It is also important to ensure minimum leakage during refueling.

ENVIRONMENTAL MANAGEMENT PROCESS

The process of planning a mechanical demining operation should include an environmental management process. This should involve discussing the risks and control measures with the local community. The diagram below shows such a process.

Figure 12 | Environmental issues in community discussions



If discussions with the local community, experts and other stakeholders reach a "no" point then another approach to the demining task must be found.

ENVIRONMENTAL CONCLUSIONS AND RECOMMENDATIONS

In preparing this publication, the Food and Agriculture Organization (FAO) was consulted about the impact of demining machines.[5] From FAO's point of view, mechanical demining is nothing other than a heavy duty rotary cultivator. In terms of soil damage it is considered as severe. Steps to mitigate the mechanical impact could be:

- Avoid carrying out demining during periods of the year with strong winds and/or heavy rainfall
- Attach a seeding-plus-compacting unit right behind the demining machine or ensure that seeding is done straight after clearance (this, obviously, can prove difficult when the demining machine is followed by other means of clearance)
- In particularly sensitive areas, do "strip-demining", returning to demine the remaining areas once the seed on the previously demined parts has grown
- Plant a crop immediately after mechanical demining: if ground penetration was not too deep and there is topsoil on top, this can minimise the effect of mechanical demining

For diesel and hydraulic fuels, and especially the risk of spillage, FAO gave the following advice:

- Mechanical demining equipment is normally of recent manufacture. Therefore, from a technical point of view, there should be no spillage, and no problem with diesel and hydraulic fuel on the cleared ground. If there is, it is most likely to be caused during servicing of the demining machines. Care should also be taken to reduce spillage of oil in and around refuelling areas, and to employ skilled service personnel and machine operators. Demining programmes should have sufficient funds allocated for training in machine servicing

- In very sensitive ecosystems, it could be made compulsory to use hydraulic fuels based on bio-products (plant oil). For hydraulic clutches, and especially fittings for the quick connection and disconnection of hydraulic hoses, it should be compulsory to use dry couplings
- For extremely sensitive ecosystems, water-hydraulic systems are increasingly available. But such systems have not yet been seen on demining machines.

ENDNOTES

1 See: www.dpi.vic.gov.au/dpi Agriculture and Food / Erosion

2 Deforestation is the conversion of forested areas to non-forest land for use such as arable land, pasture, urban use, logged area, or wasteland. Generally, the removal or destruction of significant areas with forest cover has resulted in a degraded environment with reduced biodiversity.

3 Information extracted from Robert P Chilcott, Health Protection Agency, Compendium of Chemical Hazards: Diesel, www.hpa.org.uk

4 Information extracted from World Health Organization, Geneva 1999, Rapid Health Assessment Protocol for Emergencies, Chapter 9, Chemical Emergencies, www.crid.or.cr/digitalizacion/pdf/eng/doc13866/doc13866.htm

5 Telephone conversations and emails with Josef Kienzle Agro-industries Officer (Equipment and Institutions), Rural Infrastructure and Agro-industries Division, and Theodor Friedrich, Senior Officer (Crop Production Systems Intensification), FAO Crop and Grassland Service (AGPC) Food and Agriculture Organization, Rome, Italy.