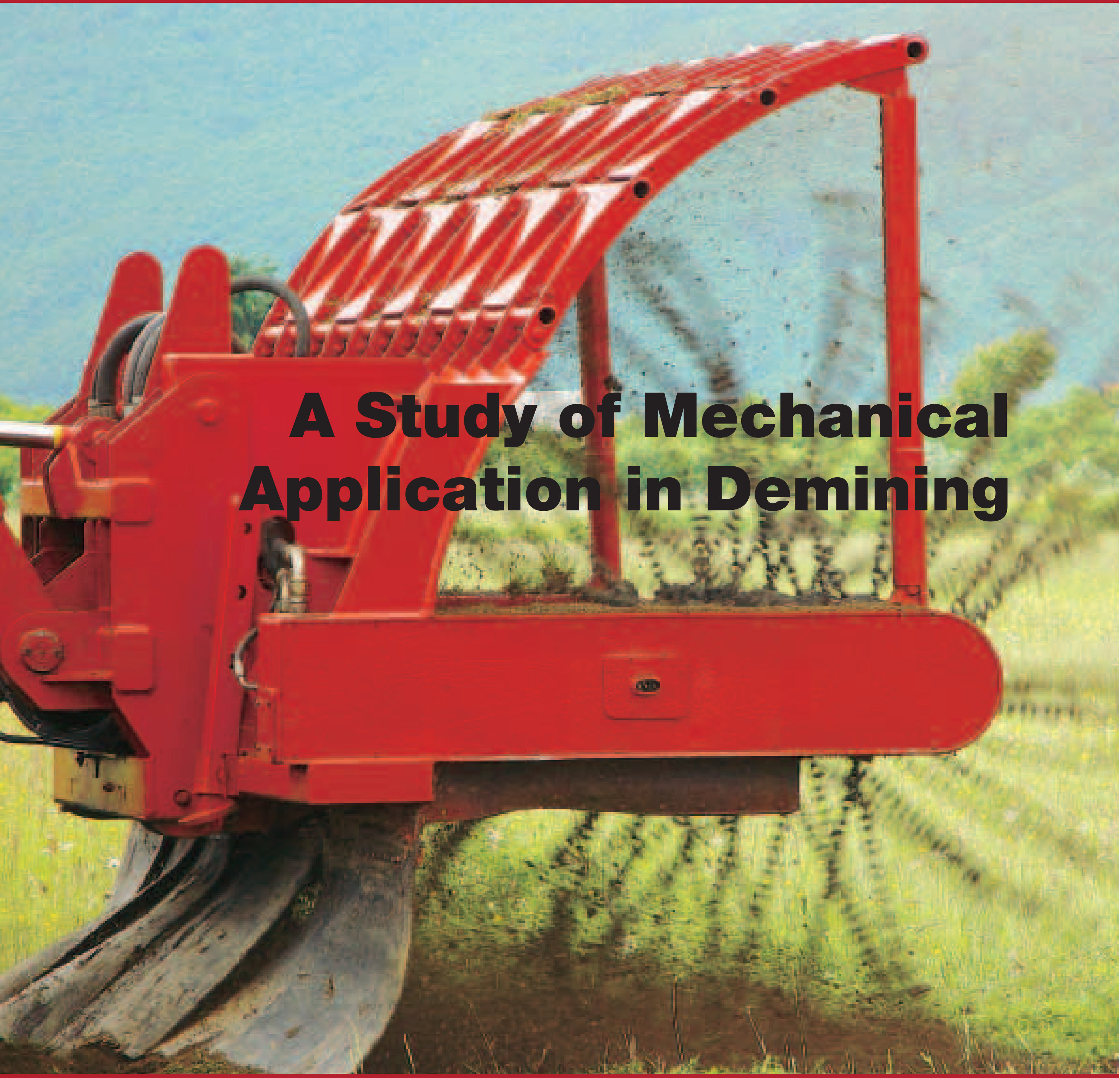
A Study of Mechanical Application in Demining



Geneva International Centre for Humanitarian Demining
Centre International de Déminage Humanitaire - Genève

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

For further information please contact:

Geneva International Centre for Humanitarian Demining
7bis, avenue de la Paix
P.O. Box 1300
CH-1211 Geneva 1
Switzerland
Tel. (41 22) 906 16 60
Fax (41 22) 906 16 90
www.gichd.ch
info@gichd.ch

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This project was managed by Håvard Bach, Head of Operational Methods Section (h.bach@gichd.ch).

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Foreword

In the global effort against landmines and unexploded ordnance (UXO) the international mine action community is constantly striving to improve the safety, efficiency and cost-effectiveness of clearance methods. It is widely recognised that machines can contribute to this endeavour and accordingly their use has increased and expanded dramatically in recent years.

In addition to the ability of machines to clear land faster than manual methods, they also offer new approaches to humanitarian demining that can reduce the total amount of land requiring full clearance. This study looks in detail at these new approaches with a view to increasing the future efficiency of demining operations.

To further this objective, the study has also generated a software model to measure the cost-effectiveness of machines in demining. Users of this model, which is known as CEMOD, are encouraged to share results and experiences so that, collectively, the machine user community can learn more about which mechanical systems, procedures or deployment methods are working better and why.

At the same time, it must be recognised that the operational methodology of machinery in demining is still very much evolving. Considerable further research is needed to enhance our collective understanding. Nonetheless, it is hoped that the research conducted offers useful perspectives on machine employment and development. The CEMOD software is available free of charge from the GICHD upon request.

The GICHD would like to express its appreciation to the Governments of the Federal Republic of Germany, Norway, Sweden and the United Kingdom for their financial support to this study.

Amb. Martin Dahinden
Director
Geneva International Centre for
Humanitarian Demining

Executive summary

Introduction

The last 15 years have seen the evolution of machines used in demining. At the beginning of the 1990s, the few machines on the market tended to be large and heavy, often based on converted armoured military vehicles. There is now a much greater array of machines of varying size and armour protection to suit the different physical environments and threat levels found in mine-affected regions of the world. Certain trends have emerged, such as the development of multi-tool systems for multiple tasks, the design and manufacture of machines in mine-affected countries using indigenous materials and skills, and the adaptation of commercial earth-moving vehicles for mine clearance purposes.

A glance at the 35 machines detailed in the GICHD's *Mechanical Demining Equipment Catalogue 2004* reveals that there is no shortage of machines to choose from. But this impression belies the fact that machines in demining remain underused and the market for them is relatively small. Of those listed, very few have been sold; most specialist demining machines cost more than US$250,000, and a cost-effective return on such an outlay is not always perceived. However, *A Study of Mechanical Application in Demining* demonstrates the vast potential of machines to make demining more efficient and faster, either independently or when combined with other clearance methodologies.

Mechanical clearance

Machines are yet to be fully accepted among deminers as a tool of equal reliability to the two mainstays of clearance methodology: manual deminers and mine detection dog (MDD) teams. This results from of a lack of knowledge as to the capabilities of mechanical demining systems and misunderstanding as to their potential application. In the early days of humanitarian demining, machines acquired a reputation for adding less value than expected. They were also blamed for a range of negative effects, such as throwing mines into safe areas, failing to detonate mines or burying them deeper, and causing mines to become more volatile for subsequent manual deminers. Although some of these allegations have been well-founded, a decade and a half of technological development has rendered many of these effects negligible or redundant. However, this statement is difficult to prove: there is not yet an internationally agreed and recognised testing and accreditation regime for demining machines, and empirical data to support the application of machines, however good in quality, is weak in quantity. Two developments would greatly enhance the understanding of mechanical application in demining: an increase in the testing of machines using an appropriate number of test targets — at least 800 for each machine tested — and closer attention to recording mechanical clearance data in live operations in order to build up empirical information.

Recent research has shown that, given suitable conditions, machines can be used as the primary clearance system. This is based on a careful examination of clearance data of machines used for ground preparation. This data showed that after the passage of machines manual deminers and MDD teams found no live items of ordnance in areas known to have previously contained them. Deminers who use mechanical systems have a good idea as to the most appropriate environments in which their machines might achieve clearance to humanitarian standards, but national demining authorities are still reluctant to accept that machines form the primary clearance method. The lack of precedents creates a lack of confidence.

An exception to the general reticence to apply machines as the primary clearance method is mechanical excavation with converted commercial earth-movers. These machines remove potentially contaminated soil down to a depth suggested by survey information. It is undisputed that areas treated in this way are free of ordnance down to the depth excavated. This technique represents the only current example of machines being employed as the primary clearance tool, but the practice is not widespread.

Risk assessment

According to the International Mine Action Standards (IMAS 09.10 — Clearance Requirements), land "*shall be accepted as 'cleared' when the demining organisation has ensured the removal and/or destruction of all mine and unexploded ordnance hazards from the specified area to the specified depth*". Once an area has been selected for clearance, it must be treated in this way regardless of the clearance method selected. However, the process for deciding on which area should be cleared and which clearance method should be used requires a rational framework. This can be achieved by using a risk assessment methodology to determine the probability of a post-clearance mine/UXO incident and the impact this might have on subsequent users of land. Machines can make a major contribution to this process by gathering information as part of technical survey. Where information about a suspect area is weak, a machine passed over the area will reveal not only the presence of ordnance but also the specific threat; this is invaluable information for any clearance plan.

Area reduction

Area reduction is a component of the technical survey process. In all clearance tasks, the great majority of efforts are conducted on ground that subsequently proves not to contain mines or UXO. Clearance data gathered by the GICHD from 15 countries suggests that of suspect areas cleared, less than three per cent actually contained mines or other ordnance (individual items of ordnance were allocated a ground coverage of one square metre). This suggests that effective area reduction is the phase of demining where the greatest increases in efficiency can be made. Thanks to their speed of operation, machines are best placed to achieve such increases. Manual survey cannot possibly cover the same area in as little time and should be used only where extremes of topography rule out the use of machines. Dogs are good at area reduction, but are far more affected by such vagaries as weather, soil conditions and vegetation. The importance of improving the speed and reliability of area reduction operations is recognised by deminers and is reflected in the research findings of the GICHD publication, *Mine Action Equipment: Study of Global Operational Needs*.

Ground preparation

Currently, most mechanical mine clearance operations are in support of manual deminers and/or MDD teams as ground preparation systems. All case studies conducted by the GICHD show a significant increase in productivity where machines are applied to assist manual or MDD methods. Tests and research have shown that increased productivity is achieved by the removal of vegetation and tripwires, the turning-over of soil and the reduction of scrap metal contamination using magnets. Machines can perform all of these functions, and much faster than any other known method. The optimal machine would be one that can perform all of these functions in one or two passes of a suspect area. Such a machine does not exist at present, but it is hoped that future research will reveal to manufacturers what is most needed.

Protection of vehicles

Many machines employed in demining are commercially available earth-movers, civilian engineering plant, or agricultural vehicles. To operate in suspected hazardous areas, operators must be protected against the expected explosive threat. Usually, the armouring of such machines is left to the respective demining body. The calculation of appropriate thicknesses, placement, welding, angles, materials and spacing of armoured plate is often military specification, information which is not available publicly. This study explains the background to the principles of armouring vehicles intended to work in suspect areas and how to assess the probable effectiveness of armour based on the threat. The information on the protection of vehicles and plant equipment against mines and UXO is designed to provide demining organisations with a check-list of practical principles, and is a starting point for those seeking information on the subject.

Cost-effectiveness

Case studies of the use of machines in demining revealed a positive effect on productivity for demining operations. However, cost-effectiveness is not automatically guaranteed in all cases and, where it is achieved, it might be improved. The Cost-Effectiveness Model (CEMOD) developed for this study provides managers with a software tool to input all costs related to the running of a machine in a mine clearance programme. A cost in US dollars per square metre can be calculated. The software can also compare machine cost-effectiveness with manual and MDD operations within the same programme. With this information, managers should be better able to use available resources to maximise cost-efficiency, allowing savings to be made that could be plied back into operations.

Summary

In sum, the GICHD believes that machines are underused in demining, in large part due to a lack of understanding by the mine clearance community of their most suitable roles and applications, and particularly of recent improvements in design. The GICHD seeks to improve comprehension of mechanical application in demining, because machines are critical to efforts to speed up the painfully slow process of clearing the world’s mined areas.

Introduction

This study is divided into six chapters: mechanical clearance; risk assessment and mechanical application; mechanical application to area reduction; the application of machines to ground preparation; the protection of vehicles and plant equipment against mines and unexploded ordnance (UXO); and mechanical cost-effectiveness.

The chapters have been selected with a view to identifying how machines can improve the effectiveness and efficiency of clearance operations. Each chapter has its own aim and methodology, but the overall objective remains the same: to highlight the advantages and improve the understanding of the use of machines in minefields.

The study was managed by the GICHD's Operational Methods Section, headed by Håvard Bach. Input was provided by Mark Buswell, Dr John Gibson, Alexander Griffiths, Leonard Kaminski, Dan Marsh, Dr Ian McLean, Dave McCracken, Rebecca Sargisson and Johan Van Zyl. A User Focus Group was established to oversee and facilitate the study. This group was made up of representatives of prominent companies and organisations in the mechanical manufacturing, operational, research and testing sectors.

As Chapter 1 explains, a choice of stand-alone mechanical systems exists — flails, tillers, rollers, sifters, combined and multi-tool systems, and adapted commercial engineering machines. The chapter reviews the characteristics of the different systems and their impact on the ground and mines within it, and considers their potential for application as the primary clearance method to remove and/or destroy mines and UXO to humanitarian standards.

Chapter 2 looks at risk assessment and mechanical application. The sub-study that forms the basis of the chapter uses risk assessment to determine the most appropriate roles for mechanical systems in reducing the dangers to the civilian population.

Chapter 3 addresses mechanical application to area reduction as part of the technical survey process. The case studies that form the basis of the chapter assessed techniques used in area reduction operations by machine and sought to establish a framework for appropriate mechanical application so as to minimise the clearance requirement.

Chapter 4 considers the application of machines to ground preparation. This reflects the potential for machines to be used to prepare the ground for other "follow-up" clearance methods. Clearance after the use of machines is currently conducted by manual deminers and/or MDDs.

Chapter 5 looks at the mine and UXO threat to vehicles and plant equipment operating in the field. The authors discuss the effect of each type of threat on unprotected vehicles and put forward suggestions on how to enhance the protection of vehicles and their occupants.

Chapter 6 aims to establish standards for calculations of the cost and productivity of a machine operating in a minefield. A software package, CEMOD (Cost-Effectiveness Model), was specially developed to support this objective.

The study's main conclusions and recommendations complete the body of this report.

Following the bibliography and a list of acronyms, Appendix 1 provides the list of members of the study's User Focus Group. Appendix 2 provides a glossary of technical terms used in the study report.

Chapter 1

Mechanical clearance

Summary

Manufacturers, research and development agencies and field operators have largely ceased to regard mechanical clearance — the use of stand-alone mechanical systems to fully clear minefields — as achievable. Yet, this sub-study has found evidence from the field to suggest that full clearance may sometimes be the result of ground preparation by certain machine systems, notably flails, mechanical excavators and tillers. Based on the record of demining machines gained since the late 1980s, machines perform best where soil is not saturated with water or as dry as dust, and where terrain is not too steep or too rough. Steep gradients pose one of the most significant limiting factors on the ability of a flail to operate. Rocky ground is also an important obstacle. However, the precise circumstances under which humanitarian mine clearance by machine may occur remain to be determined.

Introduction

Background

Since the start of humanitarian demining at the end of the 1980s, the use of stand-alone mechanical systems to fully clear minefields — mechanical clearance — has been hailed as the ultimate goal to which all mechanical development efforts should be directed. A decade and a half later, expectations have greatly diminished. Manufacturers, research and development (R&D) agencies and field operators have largely ceased to regard mechanical clearance by machine as achievable. As a consequence, mechanical systems have typically been deployed in clearance operations in conjunction with manual demining and MDDs, for ground preparation, area reduction and, as part of the quality control process, cleared area confirmation.

Terms of reference

A choice of stand-alone mechanical systems exists — flails, tillers, rollers, sifters, combined and multi-tool systems, and adapted commercial engineering machines. This chapter reviews the characteristics of these systems, their impact on the ground and mines within it, and considers their potential for mechanical clearance.

The term "mechanical clearance" is here defined as the application of machines as the primary clearance method to remove and/or destroy mines and unexploded ordnance (UXO) from a given area to the quality of clearance laid down for clearance by the International Mine Action Standards (IMAS). Manual or MDD teams may, of course, be subsequently used as independent quality assurance (QA) of the area.

Insufficient information is available on the physical consequences for the ground and any mines under or on its surface from the beating of a flail, the grinding of a tiller, or other forces exerted by various systems. Testing of machinery using live, surrogate or dummy mines has been limited. Some manufacturers, national testing agencies and mine action centres have conducted testing and accreditation of vehicles in order to gauge their level of effectiveness, but these could be further developed.

Missed mines and any possible relationship to mechanical systems are not extensively recorded. Often, they are only noted when they are the cause of an accident or incident. Independent QA is still not widely carried out, particularly outside Europe, and records that are kept may be jealously guarded, incomplete or inaccurate.

Chapter layout

Following this introduction, the remainder of the chapter has five sections.

Section 1 addresses flail systems. It describes how flails function and explains some of the physical limitations on their capability for ground processing.

Section 2 reviews tiller systems, describing how they function and the physical limitations that may affect their capability for ground processing.

Section 3 discusses mechanical excavation, giving an overview of the technique of soil excavation and subsequent treatment/cleansing of potentially mine-affected, excavated soil.

Section 4 gives a brief overview of mine rollers and steel-wheeled vehicles, describing their successful role in area reduction and the reasons for their unsuitability for mechanical clearance.

Section 5 contains the conclusions, findings and recommendations of the sub-study research and assesses the implications for the possible use of machines as the primary clearance tool in the future.

Additional empirical evidence of machines clearing to humanitarian standards is provided in Annex 1 to this chapter.

Flail systems

Introduction

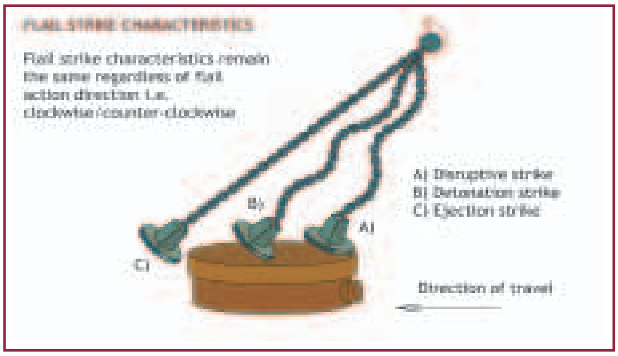
The most common type of mechanical system currently on the market is the flail. Flails have a long pedigree: prototypes saw service in the 1914-1918 war and were used extensively during the 1939-1945 war. From then until the early 1990s, however, flail systems developed slowly. It was the emergence of humanitarian demining that provided the impetus for advances in flail technology. More R&D funding has been invested in improving flails than in any other system.

Flails have largely developed as a result of market forces — improvements carried out by private mechanical engineering firms in the business for profit — but also through the work of national militaries. All operate according to the same principle: a rotating axle, shaft or drum with attached lengths of chain-link along its surface that impart violent impact to the ground when rotated at speed. Some flail designs have an advantage when encountering anti-tank mines. The stand-off provided by the distance of the chains to the flail unit axle allows the blast to dissipate somewhat before contact with the vehicle hull is made.[1] Mostly, however, flails are regarded as a tool against anti-personnel mines and small items of UXO.[2]

Flail strike characteristics

There is a lack of information on the sub-surface physical effects of mechanical clearance systems on mines. A length of chain hitting the ground at speed forms the core working methodology of all flail systems. The target is the ground and/or mines and UXO contained within it. The impact of the flail with its target is referred to as a *flail strike*. Three characteristics of flail strike are identified: a disruptive strike, a detonation strike and an ejection strike (*see Fig. 1*).

Fig. 1. Flail strike characteristics



Adapted from an original in Lower (2001).

Disruptive strike

A disruptive strike refers to a strike of the flail resulting in a mine or UXO becoming physically damaged. In the worst-case scenario, ordnance is damaged but is still functional, potentially becoming more dangerous than before it was struck. Preferably, and more usually, a disruptive strike will result in the ordnance being broken up to a point where it no longer functions. Fully functioning mines can be disrupted rather than detonated when struck by a flail so that the fuse mechanism fails to function correctly. In addition, mines that are disrupted may have become inoperative at some stage of their history since being laid and would not have functioned in the conventional manner. There is no known method to predict the ratio of mine break-ups between functional and non-functional anti-personnel mines.

It may be acceptable that when a flail is deployed to prepare ground for later clearance by other methods, mines are broken up to the extent that they are inoperable. The mine is no longer a threat to subsequent clearance personnel. The broken pieces are frequently found in a radius not significantly greater than the radius previously covered by the intact mine. Sometimes, however, random fragments can be strewn over a wide area. The spread of mine fragments may depend on the type of mine struck and the soil type and depth in which the mine was laid. The greater the depth, the less the spread of mine fragments but the less the corresponding likelihood of destroying the mine.

According to a number of operators, certain flails are capable of breaking up specific mine types into fragments no bigger than a thumb nail. If such systems are deployed across a suspect area for more than one sweep, results can be so effective that further clearance methods bear more resemblance to quality control (QC) than actual clearance. Small fragments of explosive material do, though, remain and would be signalled by MDDs, were they to be subsequently used. Metal fragments/small mine components would also be located by metal detectors. This approach has limitations, possibly dictated by mine type, soil type and topography; the parameters of these limitations are yet to be determined. The implications, though, are that given suitable conditions against suitable mine types, it may be possible to predict situations where flails could operate as a stand-alone clearance system.

Detonation strike

A detonation strike refers to a flail strike upon a mine or the soil above it causing it to detonate as a result of the impact of the chain initiating the fuse sequence. Detonation greatly helps area reduction as the presence of mines is immediately indicated. Detonations are not always complete. On occasions the fuse will function but the main body of the mine fails to explode (for example, because of moisture ingress). These are known as *partials*. Experience shows that mine type, soil conditions, engine power, ground penetration ability and the forward speed of the machine may influence whether a mine will detonate or break up when flailed.

Depending on the type of mine, a detonation may result in particles of mine casing fragments being distributed over a wide radius. Although the threat from the mine has been removed, detonation during mechanical ground preparation — where the task of the machine is to prepare the ground for primary clearance by other means — causes complications for subsequent operations over the same area for manual or MDD teams. If the mines were of a large metal content, thousands of metal splinters are indicated by metal detectors. For MDDs, explosive molecules create extensive contamination over the area to be cleared.[3] Thus, manual and MDD clearance operations over ground previously prepared by machines where the majority of mines were detonated is safer but may sometimes be more time consuming than if they had only been broken up.

Ejection strike

An ejection strike is a flail strike resulting in a mine being picked up and thrown clear of the flail unit. This effect is commonly known as a *throw-out*. In general, flail operators have found throw-outs to be a relatively rare occurrence, although the exact frequency is not known. It is likely, but difficult to prove, that throw-outs are caused by an incomplete strike of a chain link upon a mine. Instead of being broken up or detonated, the mine is raised from the ground to become briefly entangled in the mêlée of the rotating chains before being disgorged forwards in the path of the vehicle or to the side.

If the mine is thrown in front of the continuing path of the machine, it is unlikely to escape detonation or break-up a second time. Mines thrown into a previously cleared or non-suspect area pose more of a problem by creating suspect ground out of mine-free land.

Throw-outs are the principal contention among detractors of flail systems as a primary clearance tool. According to a number of field operators, mechanical engineers have made improvements to flail systems such that certain machines have almost completely eliminated the problem of throw-outs.[4]

Physical forces of flailing

A length of hammer-tipped chain link slammed onto the ground will be attended by a variety of violent physical forces, each affecting the result against a mine/UXO target in different ways. What these forces consist of, and their exact contribution towards a flail system destroying mines and UXO, is not entirely understood. In order to smooth out the problems of flail technology, it is important that the effect of these physical forces is as fully understood as possible. The impediments to flail efficiency can perhaps be negated, 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 (*see below*), to name only a few.

The features of a particular flail design may overcome some physical limitations while simultaneously accentuating the negative effects of others. It is a fine balance. A system effective in one soil may be less effective in another. The individual components that make up a flail need to be rationalised. The nature of soil mechanics may play a crucial role.

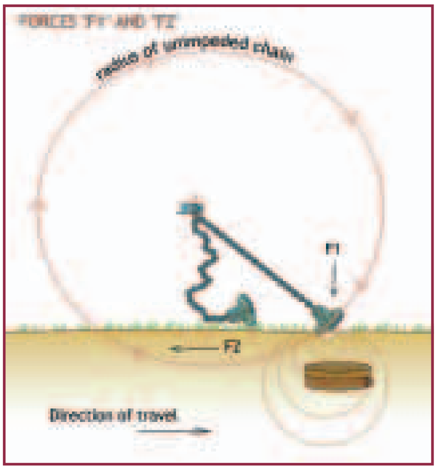
It is sensible to attempt to unravel what is happening to the chains as they hit the ground, drag through it, and continue their rotation through the next 360° cycle. Understanding of what actions occur in the ground when struck by a flail also requires investigation. To date, only limited scientific research has been conducted, notably the study by DRES (now Defence Research and Development Canada — Suffield) on behalf of the Canadian Centre of Mine Action Technologies (CCMAT).

The following is a simplified extrapolation of the findings of the study published in 1999 by DRES.[5] Some of the terminology has been altered for ease of understanding. The DRES study is largely theoretical, based on tests carried out at their test facility and never in live minefields. The findings require further verification, and it is possible that results would be different if the principles stated in the study were put to use in real field conditions. However, the Canadian study increases our understanding of the limitations of flailing as well as its potential.

The main forces

Two main forces have been identified in attempting to rationalise the physical phenomena endured by the chain links of a flail in operation, and in the ground it strikes *(see Fig. 2 overleaf)*.

Fig. 2. Force 1 and Force 2 characteristics



Adapted from an original in Shankla (2000).

Force 1

Force 1 (F1)[6] is the physical force which describes the sequence of actions that occur the moment an individual chain impacts with the ground. These actions would change slightly, depending on the hammer shape and whether a hammer is fitted to the end of a chain. The chain has extended itself straight due to the centrifugal force imparted on it by the high-speed rotation of the shaft to which it is attached.

From the moment the ground interrupts the trajectory of the end of the chain in its circular path, F1 plays its part. F1 takes place in the ground struck by the chain, but not along the chain itself. The 'F' in F1 is impact force. It can be expressed as a function of hammer mass (or in the case of a chain without hammer, the end link or links), angular velocity, flail radius and stopping time. Stopping time is represented by the ground, which provides resistance to the path of the chain. The power of the stopping time is reliant upon the characteristics and composition of the soil, a subject dealt with below.

F1 is responsible for the positive function of a flail: the initial impact of the end of the chain causes the mine to detonate or shatter. It therefore stands that F1 should be maximised so that detonation or shattering is the result.

Force 2

Force 2 (F2)[7] refers to various forces unleashed the instant F1 is played out. The chain is still being propelled at approximately the same speed as at F1, but is no longer straight as it fights against the ground into which it has been driven, and is dragged along until continuing upwards and away from the ground in its next cycle. F2 is the horizontal drag through and across the ground that has been penetrated as a result of F1. F2 accounts for three possible consequences when flailing. All of them negatively affect flail performance.

1. Bulking

Sometimes referred to as overburden, bulking is the loosened soil created by the action of the flail dragged through and across the impacted ground. Bulking is an effect well understood by the construction engineering and agricultural industries.

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 flail, overburden may serve to conceal missed mines under a depth of loosened soil, exacerbating the difficulty of locating missed ordnance 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 so that some current models of metal detector are unable to detect mines and UXO buried as a result of it. The amount of overburden created increases the deeper a machine is required to flail. A ground penetration depth of 20 centimetres will produce roughly twice the amount of overburden created by flailing to a depth of 10 centimetres.

Fig. 3. SWEDEC test area demonstrating overburden/soil bulking.

Fig. 4. Beaten zone of a flail system. Small sections of the ground show where chains may not have achieved a complete strike.

2. Throw-outs

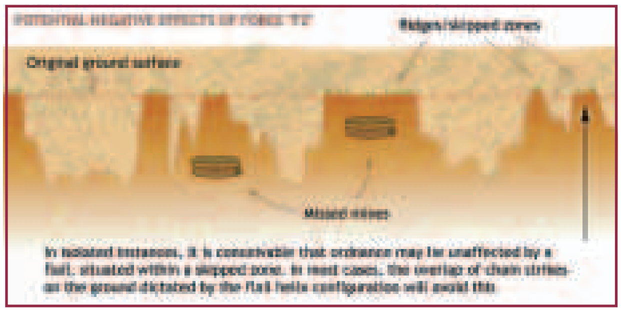
Throw-outs have been explained above in the section describing an ejection strike. Throw-outs occur as a result of the F2 phase of flail action. A length of chain having not achieved a hit on a mine during phase F1 may contact it during its subsequent horizontal path (F2) through and across the ground, picking it up and propelling it out of the flail rotunda.

3. Ridges/skipped zones

The pattern created by the points at which chains are attached to the flail shaft is referred to as helix configuration. A flail helix configuration is usually designed so that when chains have hammers connected which are of greater circumference than chain links, all strikes upon the ground should be overlapped by adjacent hammers. The intended result is that no section of ground is missed by the flail. At reoccurring intervals, F2 defeats this aim. Once the impact at F1 has played out, the chain length buckles as the horizontal plane does not permit it to remain straight, as during its unimpeded flight prior to ground strike. The chain kinks and buckles in a snake-like motion. During phase F2, the overlap of impacting chains achieved at F1 is disrupted, allowing points of ground along the path of the machine to be skipped over.

It is conceivable that a mine/UXO could be situated within such skipped zones, which appear as ridges with an unbroken surface, islands within the trail of the machine, unless these are covered by overburden. Some flail manufacturers have minimised this effect by a combination of improvements to flail helix designs and, through increased rotation speed, achieving more strikes to the ground per metre. For certain flails, ridges/skipped zones remain a problem. On some flails, such likely shortcomings are immediately predictable due to the sparse positioning of the chains attached to a shaft.

Fig. 5. Skipped zones (illustration exaggerates effect)



Adapted from an original in Shankla (2000).

The manner in which a machine is operated will also have implications on the degree that ridges/skipped zones present a problem. Better results are recorded by machine operators when ground penetration depth selected is 10 centimetres or less. The lesser depth of penetration appears to minimise the ''snaking'' effect of chain lengths as they are dragged through and across the ground. Certain clearance contracts may dictate that systems must penetrate beyond 10 centimetres. The result may 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 reduces productivity.

The DRES study argues that the increase of one of the force components leads to a corresponding decrease in the other and vice versa. Therefore, if the positive F1 is increased, the negative F2 will decrease to a corresponding degree. If this is the case, overburden, throw-outs and ridges/skipped zones can be reduced although not eliminated. Elimination of F2 would require a flail to use rigid arms instead of chains which give way when striking the ground. A stiff limbed flail (''fixed link'') would cause tremendous shock to a machine that could not possibly be absorbed by all but the heaviest chassis.

Fig. 6. Aardvark MK IV, Balkans.

DRES constructed a fixed link flywheel at their test facility. The violence imparted to the flywheel was so great that the fixed link was adapted to incorporate a ''knee-joint'' in the middle of each fixed link in order to absorb some of the shock. Currently, this design is showing high potential, achieving good results in tests against surrogate mines.

There are other means of increasing F1 at the expense of F2 for conventional chain flails. An increase of power to the flail shaft results in greater revolutions per minute, causing a much enhanced initial strike onto the ground (F1). The horizontal drag through and across the ground (F2) is curtailed. Where practicable, selection of a lesser ground-penetration depth may create advantages. Slower forward speed of the machine reduces productivity but is a preventive measure against ridges/skipped zones as it concentrates more strikes upon the soil per metre.

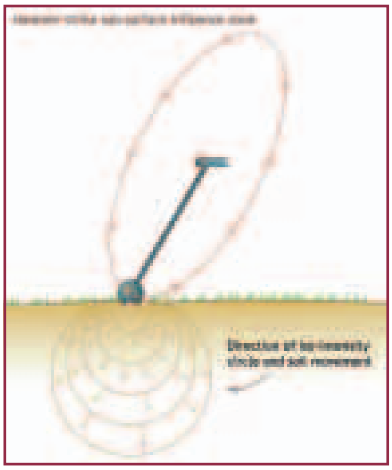
Impact stress distribution and soil movement

When the end of a chain impacts with the ground, a reaction is set off in the soil. Shock waves travel in roughly isotropic circles (i.e. equal in all directions) from the point of impact, travelling out in ever-widening but ever-weakening arcs in the manner of the ripple pattern caused by an object thrown into a pool of still water.

The area beneath the surface of the ground affected by shock waves as a result of being struck by the end of a flailing chain is referred to as the influence zone. The DRES study indicates that if the blow is delivered hard enough, ordnance within the influence zone may detonate or break up:

> *"The hammer impact forces the soil located under the hammer to give way and move. The pattern of soil particle movement depends on soil conditions. The impact of the hammer causes the soil particles located directly in front of it to move in the direction of travel with the same speed as the hammer. Hammer movement also affects the other soil particles located to the right and left side of the hammer. The cohesion and adhesion properties of the soil particles influence the relative movement of soil particles. Some of this movement is in the direction of the hammer and some towards the sides of the direction of hammer travel. Soil particles go forward and at the same time they may move to the sides until they are outside of the influence of the hammer, and finally, the hammer passes them and they come to rest."*

Fig. 7. Sub-surface influence zones



Adapted from an original in Shankla (2000).

The pattern of movement of soil particles underneath the hammer suggests the existence of an influence zone underneath the hammer. To simplify understanding, it can be assumed that the influence zone has a circular shape and moves with the hammer. The iso-intensity circles that are attached to each other at the hammer impact point create the influence zone. As the radius of the zone increases, the soil movement decreases. The smallest circle of the zone has the highest intensity as the soil particles close to the hammer have the highest tendency for movement. The largest circle that is representative of the soil particles some distance away from the hammer have the least tendency for movement.

The path of the movement of soil particles are lines drawn perpendicular to each circle's perimeter. Arrows show the path of movement of the soil particles. The magnitude and direction of the movement of each soil particle depend on its location within the influence zone. Soil particles located directly under the hammer will have the same velocity as the hammer. The velocity of soil particles would decrease towards the perimeter away from the centre of the influence zone. The points located outside of the influence zone would have no velocity and hence will not move.

Soil underneath the hammer is considered to have a semi-infinite dimension. At the start of the hammer impact, soil particles located beneath the hammer are displaced downward. After rearrangement of soil particles, when there is no margin for further soil compaction underneath the hammer, soil particles start to move to the sides. The influence zone is thought to move with the hammer. The movement of the hammer will affect soil particles located in a width equal to the largest diameter of the influence zone.

Depending on the location of the soil particles, the influence zone will be affected by one of the iso-intensity circles. The movement of the soil particles will be proportional to the intensity of the corresponding circle. Direction of movement of the soil particle will be perpendicular to the perimeter of the circle where the particles would be located. After this movement, the soil particles will attain a new position. A flail moving over a buried mine will, *depending on its forward speed*, initiate a series of impact points, each giving rise to a series of iso-intensity circles with their respective zones of influence.

Fig. 8. Soil stress distribution on a target

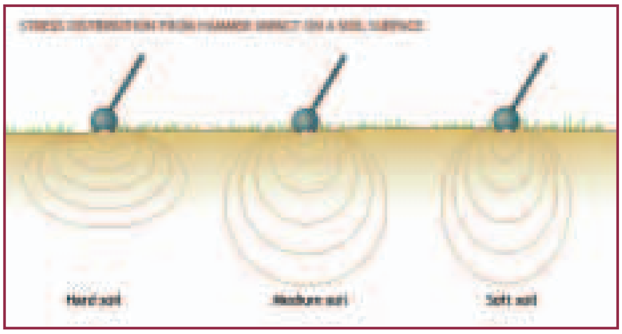
Adapted from an original in Shankla (2000).

An anti-personnel mine buried within the reach of these influence zones will experience increased pressure depending on the mine's location with respect to the point of hammer impact and the intensity of the impact. It is suggested that designers working on improving flails for mine neutralisation should focus on flails that create influence zones of the required duration and intensity, and of a diameter that is greater than the depth of ground required to be clear of anti-personnel mines.

It is the influence zone comprised of iso-intensity circles as a result of F1 that may account for the destruction of mines/UXO when a direct hit from a flail hammer (or chain link) is not achieved. A possibility exists that this indirect violence may be an effective way of destroying mines/UXO, largely because it presents an opportunity to minimise flail ground-penetration and the consequent negative effects of this as earlier identified.

Stress distribution in soil is not a new science, but not much of the knowledge in this field has been used by flail designers. Figure 9 overleaf shows soil stress distribution with contiguous and uniform iso-intensity circles. For ease of explanation, it was assumed by the DRES study that soil is elastic, homogeneous and isotropic. Actual soil is never all of these things at any given time but varies greatly in type and consistency, and can be afflicted with roots, stones and foreign objects. It can be assumed that the size and velocity of an influence zone imparted by a flail strike depends to a large extent on particular soil conditions.

Fig. 9. Effects of soil on impact zones



Adapted from an original in Shankla (2000).

Limitations imposed by soil, terrain and vegetation: extreme situations

Difficult ground and terrain are among the most limiting factors in the deployment of mechanical assets. Severe gradients, heavy vegetation, boggy ground, rocks and boulders can all determine whether a machine can be set to work in a particular suspect area. Different machines will be defeated by different levels of difficulty. Some ground and terrain limitations are related to problems suffered by the prime mover to which a flail may be attached, e.g. difficult traction or lack of power to operate uphill, and as such do not fall within the scope of this study. Other constraints may be due to the inability of a flail tool to contend with extremes of soil and terrain, factors of relevance to understanding flail action or appropriate identification of mechanical tasks.

Based on the records of demining machines since the late 1980s, machines perform best where soil is not saturated with water or as dry as dust, and where terrain is not too steep or too rough. Steep gradients pose one of the most significant limiting factors on the ability of a flail to operate. Manufacturers claim that current models of flail can move up inclines of 25º-45º (though only one machine was said to be capable of 45°). Most machines operate within the 30º-35º range, and even these figures refer more to ''hill-climbing ability'', the ability of the prime mover to drive up a hill.[8] It is doubtful that a flail tool can actually operate at gradients in excess of 30º. This restricts the use of flails over many types of terrain.

Rocky terrain is an obstacle to the effective deployment of flails. In broad terms, rocks begin to cause serious problems for flails when they are of five centimetres in diameter or more. The degree to which rocks create difficulty depends on the particular consistency of local stone, the power of the flail and the mass of the chains and hammers. Rocks and stones provide a shield to mines that lie beneath or near to them, greatly increasing the probability of a missed mine or an ineffectual, glancing blow.[9] Individual chains of the flail cannot connect with nooks and crannies protected by rocks. This problem has proved particularly acute in Lebanon, where the United Nations-coordinated operation in the south of the country has barred flails from attempting mechanical clearance.

The work-limiting parameters of soil and terrain are particular to individual machines. MDD and manual teams have similar restrictions of soil and terrain, except that their parameters are somewhat wider. When a machine is operated in a physical environment which suits its capabilities, full clearance is often achieved.

Ground penetration depth

The degree of ground penetration depth when operating a flail has significant implications on the forces at play during flailing. Currently, one of the main uses for machines in mine action is ground preparation. The ground preparation role for mechanical application is explained in Chapter 4. The sub-study on which the chapter is based concluded that machines are of more assistance to manual and MDD teams as well as more economically viable if they both cut vegetation *and* break up the ground. Currently, the IMAS state that clearance on a suspect area must be conducted to a depth indicated by a technical survey or at least down to the default depth of 13 centimetres. Many national mine action centres and commercial contracts stipulate that clearance should be conducted down to 20 centimetres.

Yet, according to a number of machine operators, maintaining a ground-penetration depth of the flail of 10 centimetres or slightly less appears to achieve better results.[10] Moreover, according to the DRES study, beating the ground with a flail with limited indentation to the ground may have a destructive effect on mines/UXO while at the same time reducing the negative effects caused by F2. It is asserted that this is a result of stress distribution and soil movement upon impact of a flail. Although not yet known, it is likely that there is an optimum ground-penetration depth at which flails are most effective. This would probably vary depending on the model of flail.

Effects of hammer geometry

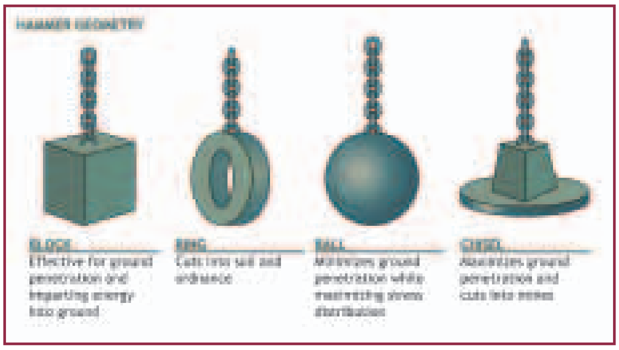
The ability of a flail to produce energy in soil sufficient to detonate or break up anti-personnel mines may be affected by hammer mass and geometry. The DRES study was based on the assumption that flail chains are fitted with a hammer. Flail chains without a hammer were not considered. Many flail operators interviewed during the research of this sub-study do not re-attach hammers onto chains, even when using systems for which hammers were part of design specifications. It appears that this omission is related to cost and wear-and-tear problems. Also, if a machine is employed purely in the ground preparation role rather than for clearance, hammerless flails appear to be effective.

The shape of a hammer may have a crucial role in flailing that is only partially understood by the demining community. It was earlier argued that the force component F2 may be the culprit behind soil bulking, throw-outs and ridges/skipped zones. This in turn was connected to the ground penetrating action of the flail. The ability of an individual flail to penetrate the ground is influenced by the shape of the hammer attached to it. Sharp-edged, chisel-shaped hammers will tend to cut deeper than rounded hammers. A blunt-edged or rounded hammer will reduce the ploughing action and surface disruption thereby minimising the effects of F2. Chisel-shaped hammers may increase the likelihood of a mine being shifted from its position without being rendered inoperable.

The DRES study argues that reduced surface indentation and penetration afforded by rounded hammers minimise the negative aspects of flails and accentuate their potential role in clearance. This has yet to be proven, and after initial field tests appears unlikely.

If, however, this concept does prove to be correct, something resembling the shape of a ball may be the optimal hammer geometry. It is not currently known if the fitting of rounded hammer shapes would have implications on a flail's ability to deal with vegetation. Hammers do play a role in vegetation cutting, but it is mainly the chain links themselves that fulfil the cutting action. The answer to this must await future test results and/or empirical evidence.

Fig. 10. Selection of hammer types



Adapted from an original in Shankla (2000).

Engine power and shaft height above the ground

The effect of engine power on a flail's ability to defeat mines has been briefly touched on. As suggested by the DRES study, in order to improve flail performance, force component F1 must be increased at the expense of F2. Theoretically, one way to achieve this is to increase the power from a prime mover to the flail attachment. The hammer or chain-link hits the ground with greater force. The influence zone is increased and thereby the potential to break up or detonate mines. A lowering of the flail shaft to the ground will also accentuate the force of a chain strike.

At the same time, though, the stand-off distance, which may be an advantage to flail systems in general, is compromised. This is due to the flatter angle between the shaft and the centre of the hammer mass at impact. However, both increase of power and decrease of flail shaft height above the ground also increase the potential for flail link to penetrate soil. This would in turn increase the negative effects associated with force component F2. To counteract this, a possible solution is a rounded hammer, which would increase the impact on the ground and reduce the ill-effects of ground penetration.

Some flail machines rely on the same power source for forward drive of the vehicle and 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. As a consequence, the flail slows down and chain impact weakens, as does its 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.

Machines with a guaranteed uniform flow of power to the flail head gain a distinct advantage. Despite difficult terrain, they can maintain rapid and powerful strikes against the ground, delivering a near-constant influence zone beneath the ground. Possibly, with an optimal hammer design, force component F2 would be reduced. High power also maintains a higher number of chain strikes per metre. A number of authorities have asserted that at least 70-80hp per metre of flail shaft must be maintained to achieve rotation speed sufficient for effective mine destruction (and reduced effects of F2). This is an approximate figure, which requires further testing.

Fig. 11. Armtrac 100.

Forward speed

Much of how a flail affects mines/UXO relies on a combination of the gearbox of the prime mover and the way it is driven by the operator. A balance must be found and maintained whereby a machine is driven slow enough to allow the flail to achieve a high number of strikes on ground within its path, but fast enough so as to maintain productivity. Too great a forward speed risks small segments of ground not receiving strikes from the flail (i.e. skipped zones). This can be partially alleviated by greater power to the shaft as the flail will turn faster and strike more often.

During research in Lebanon, two operators of the Armtrac 100 flail, one from the mine clearance company, BACTEC, the other from the Lebanese Armed Forces (LAF), found that forward speed of flail machines had a significant effect on what happens to mines. Operators from both organisations report that as the vehicle is driven faster, more anti-personnel mines (mostly the Israeli No 4 and sometimes the Italian VS 50) tend to detonate than break up. At slower speed, more break-ups occur than detonations. It is not known if this is caused by the soil, which is very rocky with large boulders, or the types of mine found in Lebanon, or a combination of the two. (The speeds here referred to are not exact and were simply described as “faster” and “slower”.) This phenomenon is not recorded in any other theatre of operations using this machine. It is therefore unlikely that the vehicle itself is the cause.

Dog handlers working for the U.S. company, RONCO, indicated that when deploying dogs on clearance subsequent to a flail, mine break-ups are the preferred result as contamination covered less ground than detonations. LAF flail operators reduce forward speed in accordance with this. It is not fully understood why changes in forward speed affect the result against some anti-personnel mines. The GICHD intends to investigate this, as well as the suggestion by the Mine Action Coordination Centre for Southern Lebanon that anti-personnel mines struck by a flail but not detonated can sometimes be rendered more dangerous than had they not been flailed at all.

Mine type

Mines may be anti-personnel or anti-tank and come in different shapes, sizes and designs. The types of mine encountered, as well as their condition, affect whether or not a flail will successfully destroy them. Fuse sensitivity, for instance, can be a result of design, or the result of its conditions of storage, handling or emplacement. The amount of time a mine spends in the ground and the climatic conditions it has endured will also influence whether or not it is still functioning. Water ingress, for example, is a suspected reason why mines might fail to operate as intended. Certain mines tend to degrade faster than others. For instance, the Soviet PMD 6 has a wooden body that disintegrates particularly quickly underground. In Eritrea, a region with a fairly dry climate, local people state that it is rare to find a PMD 6 still intact 10 years after it has been laid. Often, this mine will be broken up by flail action instead of detonated.

It is generally recognised that flails do not consistently destroy thick-cased, above-surface fragmentation mines. They are usually taken up by the action of the flail, but will frequently survive intact with the increased inconvenience of being removed to a new and sometimes unknown location. On the positive side, tripwires are ripped out and fuses are usually broken off. If a flail is put to work in a suspect area where fragmentation mines are mixed with sub-surface blast mines, it must be assumed by the relevant clearance agency that back-up by alternative clearance techniques must be subsequently employed on the understanding that anti-personnel fragmentation mines are the likely residue.

A subject that has aroused much concern is the possibility that, with certain types of mine, a strike that achieves neither detonation nor complete break-up may render the mine in a more sensitive state than before the intervention. There is little evidence to support this case, but it cannot be discounted. In sum, far more research is required regarding the factors posed by mine type when flailing.

Tiller systems

Introduction

The second largest family of purpose-built demining machines is the tiller. Most tillers are based on tank or forestry machine chassis. Accordingly, tillers are often characterised by their heavy weight and large size, although lighter designs are beginning to enter the market. In general, the tiller working tool consists of a rotating drum fitted with overlapping rows of steel alloy teeth or bits. The teeth grind and chew up the ground as the tiller drum is lowered to a selected depth. Anti-personnel mines, smaller items of UXO and, for certain models, anti-tank mines, are either detonated or broken up as the steel bits impale them.

Due to the large size of most tillers, difficulties are often experienced when operating in countries where infrastructure is poor. Once working, however, clearance results appear to be good. Suspect ground is "brutalised" by these powerful machines and, if operated correctly in a suitable environment, few items of ordnance are likely to escape destruction by the bits of a tiller drum.

The majority of tiller systems are manufactured in Austria, Germany and Sweden. Currently, there are five manufacturers of tiller machines in the weight range of 14-53 tonnes. In addition, there are two combined systems: the STS MineWolf tiller/flail, which has a light tiller attachment and weighs 24.7 tonnes with the tiller fitted, and the Redbus Mineworm (part of the combined Land Mine Disposal System — LMDS) weighing 15 tonnes.

Fig. 12. Bofors Mine-Guzzler.

Limited research has been invested in understanding the physical effects unleashed in the ground and against mines by the action of a tiller. Compared to flails, there is a dearth of empirical data. In some cases, specific tillers that gave lacklustre performance in controlled tests went on to refute test results with successful application in the field.[11]

Tiller bite characteristics

Tillers work by the action of sharp blades, tines, teeth or bits fixed to a rotating drum pushed by the heavy bulk of the prime mover. The tiller unit interjects with the soil directly, taking a bite out of the ground to a depth selected by an operator from 0 to 40 centimetres. The impact with ground and ordnance within it is referred to as a *bite*. Three characteristics of tiller bite with regard to its effect on a mine/UXO are identified. These are similar to those of flail strikes and are therefore dealt with briefly:

Fig. 13. Opposite-revolving tiller drums, Rhino.

Disruptive bite

A disruptive bite on a mine/UXO from a tiller unit refers to where ordnance becomes physically damaged by involvement with the tiller bits. Items of ordnance can be broken up to the point where they are rendered harmless or only partially damaged, whereupon the item may become more volatile than before the action of the tiller. It is probable that mines/UXO are disrupted when the fuse of the item has failed to function (i.e. the mine was a dud), or the angle of attack from a tiller bit was such that direct contact with the fuse was avoided and the casing was ruptured before the ordnance was able to function correctly. Where ordnance is broken up sufficiently so that it no longer presents a threat, disruptive bites have a positive outcome.

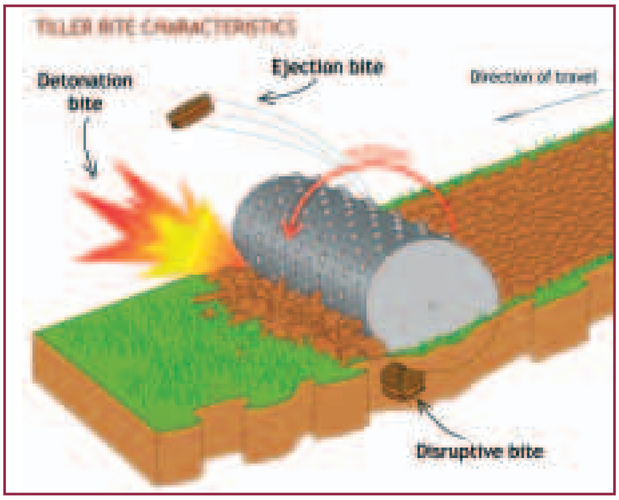
Detonation bite

A detonation bite refers to the destruction of ordnance where the item is detonated. The interruption of a tiller bit upon a mine/UXO or the pressure exerted when caught between a bit and the ground (especially hard ground) may cause the fuse mechanism to actuate. Partials, where the fuse functions but the main charge does not, are considered a detonation bite.

Ejection bite

An ejection bite describes a mine that is picked up from its position in the ground and thrown to a new location. As with flails, an ejection bite leads to a throw-out. Throw-outs with tillers are not common. Those that occur generally result in an item of ordnance being thrown in a line ahead of the machine and not to the side. The opinion from the field is that throw-outs from tillers are less of a problem than with flails.

Fig. 14. Tiller bite characteristics



A. Griffiths

Physical forces of tilling

The action of tilling is fundamentally different to that of flailing. Whereas flails not only affect a target directly, but also, potentially, indirectly through sub-soil waves of energy, the action of a tiller is direct. Beyond the physical reach of the tiller bite, the potential to destroy ordnance disappears.

Certain tiller operators have remarked on a number of negative effects of tiller action upon soil and ordnance within it. These are slipstreaming, burying, soil bulking, throw-outs and bow wave. In the main, these observed phenomena are not written down and have not been verified by scientific examination. Some of these phenomena have been noticed during machine tests conducted by the Swedish Explosive Ordnance Disposal and Demining Centre (SWEDEC), but they did not form the subject of those tests. In future, these effects may be subjected to greater technical scrutiny but, in any event, they appear to be rare. Based on available evidence from the field, they represent possible rather than probable outcomes and do not appear to seriously threaten the clearance abilities of most tiller systems.

Slipstreaming

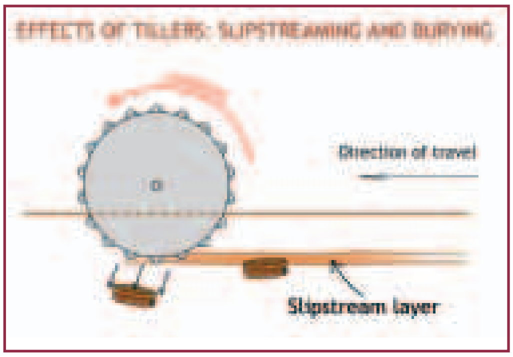
Slipstreaming refers to the theoretical phenomenon whereby the rotating action of the tiller drum creates a thin layer of free space between the end surface of the tiller bits and the surface of the ground beneath. Although as yet unproven, this space may contain aerated, loosely-packed debris such as broken-up soil, small stones and mulched vegetation. On occasions, depending on the design of the teeth fixed to the drum, the soil type being engaged and the mine type concerned, ordnance may become situated within 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.

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 up 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 in all conditions all the time. 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 fuses may escape destruction by "hiding" in the slipstream. Of the existing tiller machines, drum rotation speed varies from approximately 100 to 700rpm. As mentioned, reducing rotation speed is believed to be one method of preventing slipstreaming. It remains to be seen if drum rotation speed reduction might lead to other performance limitations.

Fig. 15. Slipstreaming and burying



A. Griffiths

Burying

The possible deeper burying of ordnance under the influence of a tiller drum may be a cause for concern. As a tiller penetrates the ground, mines located below the ground penetration depth selected by the operator may, in theory, be pushed down further by the downward force of the drum.

The design principle behind tiller systems suggests that bulk and weight are required for the performance of their intended function. The majority of tiller systems weigh between 32 and 46 tonnes. It may prove that the great mass required for tiller systems to do their job inexorably leads to some ordnance escaping destruction by becoming buried deeper into the ground. Given that a pressure-activated mine subjected to pressure from above should detonate, it is probable that such mines are inoperative. It may also be the case that mines located deeper than the tiller action were already at that depth. The question, however, remains open.

Bulking (overburden)

As with flails, the grinding and churning action of tilling creates a layer of loosened, aerated soil referred to as bulking (overburden). Some of the overburden is swept under and behind the vehicle, some pushed ahead of the tiller unit in the form of bow wave and some deposited to the side from the bow wave into windrows. As with flails, non-destroyed ordnance may be buried within the bulked soil invisible to the naked eye. Due to aeration, the depth of soil is increased, further concealing ordnance that may have remained within the original soil bed beyond the ground-penetrating ability of the machine.

Throw-outs

Like flails, tillers may potentially pick up items of ordnance within their path and throw them to a new location. Unlike flails, tiller throw-outs tend to be in a line in front of the path of the vehicle and seldom to the side. The rotating bits cannot move in random directions as occurs to the chains on a flail. This is an advantage as it can be reasonably expected that such ordnance will be neutralised at the second opportunity. With most tiller systems, drum rotation is often of a clockwise direction. This means that the teeth of the drum bite into the ground from above. Anti-clockwise rotation is understood to be where the teeth come up from underneath, in opposition to the direction of travel of the vehicle. (Clockwise rotation is taken as the direction of flail/tiller rotation when observing the right-hand side of the vehicle.)

Most tillers rotate in a clockwise direction although some tillers that combine a double roller configuration rotate the drums in opposing directions. It is logical that where tiller throw-outs occur, they are most frequently as a result of anti-clockwise tiller drum rotation, although this is unsubstantiated. If correct, the already-infrequent occurrence of tiller throw-outs could be further reduced by a preference for clockwise tiller drum rotation. However, some operators believe that clockwise drum rotation increases the possibility of mine burying. The Minebreaker 2000/2, for example, was designed with an anti-clockwise rotating drum in order to avoid compaction of mines into soil. As with the problem of slipstreaming, throw-outs may also be lessened by the reduction of tiller drum rotation speed. Conceivably, the greater the rotation speed, the greater the propensity for ordnance to be flung out from the ground.

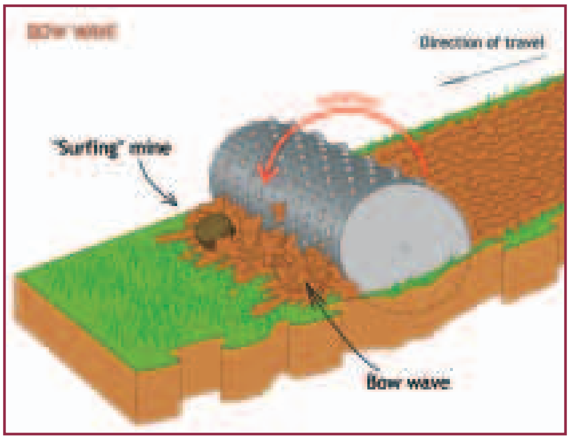
Bow wave

Bow wave refers to the loosened earth moving slightly forward of the rotating tiller drum as the machine moves forward. The soil in a bow wave is produced by the bulking effect. The assertion that bow wave may be a tiller problem is not universally accepted. Within the demining industry, some contend that it is marginal and is not a factor affecting safety. However, bow wave has been identified as a concern by tiller operators in Bosnia and Herzegovina and Croatia.

Bow wave has the appearance of water pushed in front of a ship at sea. Ordnance may be situated 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 teeth 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. As a machine finishes a sweep in a suspect area, ordnance within the bow wave may be pushed to the edge of the area to be deposited and left there as the machine changes direction to begin a fresh path.[12]

The amount of bow wave may increase the greater the ground penetration depth selected by an operator. However, some operators claim that mines and other ordnance located at 10 centimetres or more below the surface are less likely to escape destruction due to bow wave than items closer to the surface. This seems to be supported by tests of the Mine-Guzzler conducted by SWEDEC, which was found to be more effective against mines at 10 centimetres and 20 centimetres than those nearer the surface. Potentially, items placed at greater depths are less afforded the opportunity to rise up and become caught within the bow wave.

Fig. 16. Bow wave in front of a tiller



A. Griffiths

As the soil builds up ahead of the tiller drum, the excess tends to spill out to the sides of the path of the vehicle, leaving small windrows either side of the machine wake. Mines that have been displaced by the tiller but that have avoided destruction by moving with the bow wave may be deposited to the sides within these windrows. Where this occurs into the path of the next sweep, it can generally be assumed that the item will not escape destruction with the next line of clearance followed by the machine. If the mine is contained within the windrow deposited on the cleared side of the vehicle path, a problem is presented.

Limits of soil, terrain and vegetation

Like flails, tillers are at the mercy of particular conditions of topography and soil. As with flails, in steep or close terrain tiller machines are restricted more by their heavy prime mover than by the efficacy of the tiller tool. Of the five tillers on the market at the time of writing, hill-climbing ability claimed by manufacturers ranges between 24° and 30º. Tillers tend to be bulky and difficult to manoeuvre over extreme topography. When it comes to soil type, it is the tool itself which is subject to limitations.

Tillers do not perform well in sodden conditions, possibly as the backstop provided by harder soils does not come into play. Nor do they function impressively in rock-strewn soil. Large stones and rocks tend to protect mines/UXO from the intrusions of an oncoming tiller bit. Where the rock type is hard, damage to tiller bits can be expected. As claimed earlier, the presence of light to medium vegetation possibly enhances tiller performance, allowing the bits to grip the soil reducing slipstreaming. Most tillers operate less effectively in vegetation of 10 centimetres in diameter or more. The restrictions on tiller performance presented by soil, terrain and vegetation are similar to those experienced by flails.

Ground penetration depth

As tillers cannot be expected to affect buried ordnance through indirect energy (F1) and beyond the actual reach of the bits attached to the rotating drum, the maximum effective ground penetration depth achieved by three of the five tiller systems available on the market is 50 centimetres (in soft soil). Of the remainder, none achieves less than 20 centimetres.

Where survey has not indicated the likely depth of ordnance, all tillers on the market can achieve the required IMAS default clearance depth of 13 centimetres. All tillers also achieve sub-surface ground preparation (*see Chapter 4*), which both cuts vegetation and breaks up the ground. As noted above, tillers appear to perform better when ordnance is found at depths of 10-20 centimetres. Other tests and statements from users suggest that the optimum performance of most tillers is achieved when mines/ UXO are cleared at between 10-30 centimetres, with the tiller drum set at penetration depth of 30 centimetres. However, where mines are found at deeper than 20 centimetres, performance begins to deteriorate. It is not known whether this deterioration is uniform to all ground conditions and against all mine/UXO types. There may be exceptions.

Engine power

As a generic type, tillers are heavyweight tools assisted by mass to bite into ground at greater depths than most other mechanical mine clearance solutions. Intrinsically, such weight requires considerable engine power to drive both the prime mover and the tiller drum. Large mass helps a tiller to absorb the shock wave of detonations.

A massive prime mover is also needed to counteract the forward (or backward) drag imparted by the rotating tiller drum. Without great size, the machine would be propelled or retarded by the tiller attachment as well as its own engine and gearbox. This need for resistance to the propulsion effect of a churning tiller drum is in part the reason all tillers employ caterpillar tracks, giving them greater contact with the ground.

Unlike the chains of a flail, tiller drums are forced into direct contact with ordnance and cannot rely on the stand-off and force-absorbing flexibility enjoyed by flails. Without greater mass, a tiller might suffer unacceptable damage.

Tiller machines currently on the market are able to drive tiller drums at 190-700rpm in light to medium soil — an achievement requiring considerable power when penetrating ground at 20 centimetres or more. If such power is the goal of tiller manufacturers, large size is an inescapable feature.

As experience with tiller systems increases, it is becoming more apparent that a high speed of tiller drum rotation may not be as crucial as had been thought. Higher tiller drum revolutions per minute may even be a significant contributing factor to occasional throw-outs and the potential for slipstreaming. The destructive action of a tiller bit upon a mine/UXO may not actually require great speed, as the mass behind each bit should ensure penetration of a mine/UXO casing or the pressure activation of a serviceable fuse.

Optimal engine power is specific to each machine. Whether there may be scope for the reduction in engine power and therefore rotation speed remains to be seen. Reduction of revolutions per minute may reduce slipstreaming and throw-outs, but may also introduce other, as yet unknown drawbacks.

Forward speed

Forward speed is largely dependent on the speed of tiller drum rotation. If tiller drum revolutions per minute are low, so too must be the forward speed. This would reduce cost-effectiveness. Despite other possible negative effects mentioned above, faster revolutions per minute of the tiller drum allow greater forward speed and therefore increased productivity. Like flails, the helix configuration of the tiller bits attached to the drum is positioned in such a way that the optimal forward speed must be found and maintained in order that each centimetre of ground is affected by a tiller bit and that skipped zones do not occur. According to tiller operators in Bosnia and Herzegovina and Croatia, limited fluctuations in forward speed do not appear to affect the ratio of break-ups to detonations, as occurs with flails.

Mine type

With the exception of one machine, existing tillers are designed to destroy anti-personnel mines but are able to survive anti-tank mine blasts. The Rheinmetall Landsysteme Rhino and STS MineWolf both employ a tiller attachment for suspect areas where anti-personnel mines alone are expected, but use a flail attachment for areas where anti-tank mines may be present. The ability to engage with anti-tank mines using a tiller drum is largely due to the significant mass of most tiller systems, enabling them to absorb greater explosive blast pressure.

As with flails, mines/UXO encountered by tillers will be destroyed by actuating fuse mechanisms, or by breaking up ordnance that fails to detonate. With regard to anti-personnel fragmentation mines (e.g. the POM-Z), no evidence has been obtained to suggest that tillers are more effective than flails. Since tillers destroy mines and UXO by the direct contact of the tiller bits with ordnance, the efficacy of tiller systems is less connected to the factor of mine type than is the case with flails. When a mine is situated beneath the physical ground penetration ability of a flail chain, indirect energy in the form of influence zone may destroy only some types of ordnance. A tiller relies on the physical contact and pulverising power of its hardened steel bits, discriminating less between the varying fallibilities of mine/UXO types.

Mechanical excavation

Introduction

Of all the mechanical ground processing options, excavation of soil from suspect land is arguably the most tried-and-tested method of ensuring that suspect ground is rendered clear to a stated depth. The method involves moving suspect soil for subsequent inspection for mines/UXO, leaving the optional return of cleared spoil to its original location.

The HALO Trust employed the technique using adapted front-end loaders and tractors throughout the 1990s in Afghanistan, Cambodia, Eritrea, Georgia (Abkhazia), the Russian Federation (Chechnya), and the Federal Republic of Yugoslavia (Kosovo). A similar technique was adopted in Bosnia and Herzegovina by Norwegian People's Aid (NPA), using a front-end loader, and by European Landmine Solutions (ELS), using an excavator. Menschen gegen Minen (MgM) has also been at the forefront of the excavation method, particularly in regard to soil sifting. Other systems using the excavation technique are the Mineworm (as part of the Redbus LMDS), Armtrac Sifter, MgM Rotar Mk-2, and the Night Vision & Electronic Sensors Directorate (NVESD) Floating Mine Blade.

Fig. 17. Converted (armoured) Russian RABA front-end loader conducting rubble clearance, The HALO Trust, Kabul, 1998.

The HALO Trust programme in Afghanistan is evidence of the tangible benefits of mechanical over manual clearance. HALO estimates that from the moment a manual deminer encounters a buried mine until the moment the mine has been destroyed by a charge placed *in situ*, an average of 25 minutes will have elapsed. The HALO programme operates in cycles of 21.5 days.

HALO calculates that the number of mines destroyed by mechanical means per cycle would take manual deminers 6.8 cycles to match.

Often, the inspection of potentially contaminated soil is carried out in an area prepared for the purpose. Some machines process soil on the move, with cleared soil released along the path of the vehicle. Most machines employed in the excavation role are specially adapted commercial engineering vehicles, upgraded with add-on armour plate and transparent armour (reinforced glass). These typically include front-end loaders, tractors, excavators and bulldozers. They represent an effective alternative to the purpose-built mechanical systems sold on the market as specific mine clearance vehicles. In demining tasks among rubble and destroyed infrastructure in built-up areas, excavation is the only mechanical clearance process that has met with success.

The excavation and processing technique

Mechanical excavation involves the removal of suspect soil to a depth indicated by survey that mines are expected to be found. The general method for mechanical excavation has four main stages:

1. The parameters of a minefield are established using minefield maps, general survey, technical survey, area reduction by MDD/manual/mechanical system or by any other method that will reveal the border between a safe and a mined area (*see Fig. 18*).
2. Potentially mined soil is excavated. If the excavation method is by tractor or 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 (load capacity for a typical loader bucket is around 2.5 cubic metres). Some specialised mined soil excavation systems process and clear soil picked up *in situ* while moving along a clearance path within the suspect area.

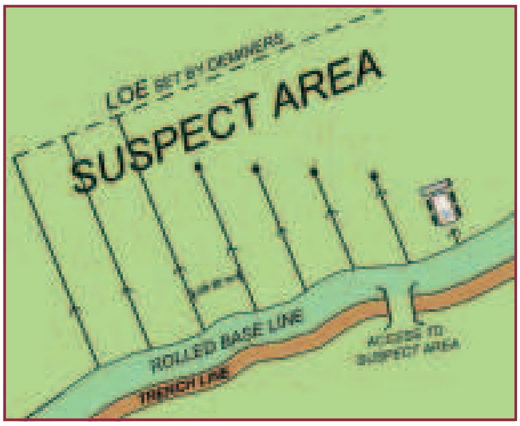
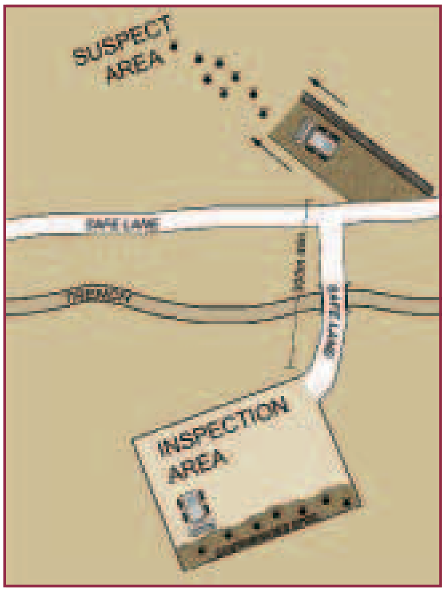


Fig. 18. Locating the true mined area

Starting from a safe base line, the true area affected by mines should be delineated prior to mechanical excavation in order to save significant time.

Fig. 19. Suggested positioning of inspection area in relation to suspect area



3. Suspect soil is processed to separate mines/UXO from soil. Once this is achieved, ordnance is destroyed by explosive ordnance disposal (EOD) staff. The method of soil excavation and processing depends upon the machine used:
   - **Sifting *in situ***: soil is sifted through the machine separating earth from solid objects as the machine moves along a path of excavation.
   - **Manual inspection area**: a flat, open area with a hard surface is prepared where suspect soil is spread out for visual examination and check by metal detector. The inspection area needs to be outside the danger template of the adjacent suspect area where soil is being excavated (*see Figs. 19 and 20*).
   - **Sift inspection area**: an area separate to the excavated area where soil is put through a sifting mechanism, separating loose soil from ordnance.
   - **Crushing**: suspect soil can be fed through an industrial rock crusher of the type used in rock quarrying. The crushing chamber is robust enough to absorb the detonation of anti-personnel blast mines. Larger UXO or anti-tank mines are located by an on-board metal detector, warning the operator of a possible mine/UXO. Ordnance is removed from the conveyor belt for subsequent disposal before entering the crushing chamber. Mine-free, loose soil emerging from the chamber is fed into a pile for later redistribution in the original suspect area.
4. Soil free of ordnance can be left at the point of processing (if in a separate inspection area) or preferably redistributed to the original suspect area (automatic in the case of on-board, *in situ* soil processors).

The machines

Mechanical excavation and sifting operations are carried out by a variety of machine types. Many are commercial engineering vehicles, adapted for work in mined areas. Some adapted commercial vehicles are fitted with special-to-task demining

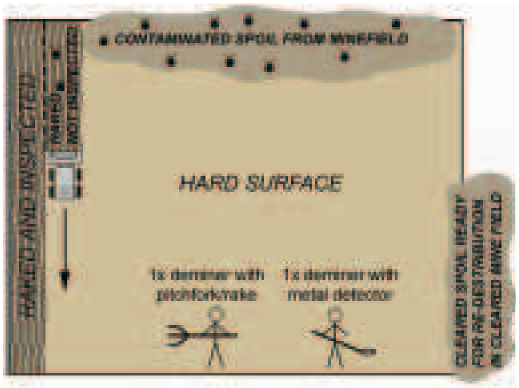


Fig. 20. Inspection area

As contaminated soil is being raked by loader bucket, deminers should remain under protection or situate themselves out at an appropriate safety distance. They return to inspect soil once the machine has raked one row of one-bucket width.

Fig. 21. Deminer inspecting excavated soil in inspection area, Cambodia.

attachments. Mechanical excavation is also conducted by machines exclusively designed for the role, as described below.

Commercial engineering vehicles

The workhorse of excavation ground processors is the front-end loader. Excavators are also extensively used, particularly in rubble clearance. With its hydraulic, extendable arm, an excavator can reach over obstacles such as walls, ditches and earthworks in order to excavate in suspect spot locations where it would be physically impossible or damaging to infrastructure to deploy a full-size bucket. Commercial excavators can be employed where conditions are too tight for front-end loaders and tractors such as in built-up areas.

Fig. 22. A "gill" in operation.

Front-end loader buckets have been adapted by HALO with the addition of a steel grill, which it calls "the gill", so that machines can operate in suspect areas where anti-tank mines may be present. As seen in Fig. 22, soil is sifted through the gill, allowing soil and objects up to the size of common anti-personnel blast mines through but retaining any anti-tank mines or large UXO encountered at the surface of the gill where it can be easily seen by the operator and subsequently dealt with. It is not the aim to deploy gill-fitted front-end loaders into anti-tank minefields, but where the mine situation is unclear, machines so-equipped can be deployed with greater confidence.

Clearance method

Once an area is confirmed as mined, the vehicle moves into the suspect area from an established safe line. The driver contacts the ground with the bottom front blade of the bucket and drives forward. Using manual controls, the bucket is angled to skim off soil to a desired depth. With a half- to three-quarters-full bucket-load of suspect soil (in order to avoid spillage), the vehicle reverses down its own track to a safe route previously established between the suspect area and the pre-prepared soil inspection area.

To avoid wasting time, the soil inspection area should be as close to the suspect area as possible while observing a calculated safety distance. The machine dumps its load of potentially contaminated soil at one end of the inspection area. Various local, cheaply-made devices have been developed to assist the spread of contaminated soil in an inspection area. The spreading of soil into thin layers for ease of visual inspection can also be achieved by skimming, using the bottom blade of a loader bucket (*see Fig. 20*).

Sifting and crushing

Once suspect soil is excavated, one option of processing it so that it is rendered free of ordnance is to sift it and then feed it through a crushing mechanism. Two systems have been used: the Redbus Land Mine Disposal System (LMDS) Mineworm which sifts and crushed debris *in situ*, and industrial rock crushers which are static, fed with suspect soil from a separate location.

Fig. 23. Redbus LMDS, Bosnia and Herzegovina.

The Mineworm is the follow-up vehicle of the two-machine Redbus LMDS. Mineworm follows in the wake of the ground-beating Bigfoot machine. The remote-controlled Mineworm excavates soil to a pre-selected depth (to a maximum of 55 centimetres) using a front-mounted soil-breaker and root-cropper. This feeds loosened soil into a rotating blade excavator which lifts soil up and onto an on-board conveyer leading to an industrial fragmenter.

Before the fragmenter, a magnet removes larger metal objects for later inspection. UXO tend to be captured by this, whereas smaller metal items such as detonators, or objects of limited metal content such as anti-personnel blast mines, should be fragmented. Cleared spoil is then deposited at the back of the machine. The entire process is conducted in the suspect area as the machine moves along its path.

Mineworm has undergone trials and development in Bosnia and Herzegovina. The system began full-scale operations there in 2003 (along with Bigfoot).

Industrial crushers have been used for the processing of excavated suspect soil. The HALO Trust operates crushers adapated from the quarrying industry. Soil is fed into a hopper/sifter where small particles are dropped before larger particles and fed into a crushing chamber. The size of crushed debris released from the chamber is adjustable. This is usually set to enable destruction of the smallest known anti-personnel mine types. Crushers have been fitted with metal detectors producing audible alarms so that when larger metal particles such as UXO or metal-cased mines are encountered, the crusher conveyor belt stops and reverses in order to prevent the item from entering the crushing chamber. Such items are dealt with by EOD staff. The crushed, hazard-free soil is eventually returned to the site from where it was originally excavated.

Sifting

Various earth sifting mechanisms are deployed to process suspect soil. Most are adapted agricultural sifters such as that used by the Pearson Survivable Demining Tractor and Tools (SDTT) or the Armtrac Sifter. Some sifter attachments are purpose-built for mine clearance operations, notably the MgM Rotar Mk I and II and the Mine Collector.

Fig. 24. MgM Rotar Mk 1 sifting

Initial excavation of suspect soil can be executed in a variety of ways before being deposited into and processed by a sifter unit. Excavation and sifting to extract mines and UXO from soil is done *in situ* as a vehicle moves along a path within a suspect area, or suspect soil is excavated by tractor/front-end loader and brought to a sifter system for processing at a location outside the area. There are numerous ways to achieve the same aim, which is to remove suspect soil, process it through a sifting system to separate soil from mines and UXO, and dispose of the ordnance.

Mine rolling

Introduction

Although not exclusively aimed at defeating mines, the first rollers were mounted to British Mk IV tanks in the 1914-1918 war. Current designs of anti-mine rollers have retained the simplicity of their predecessors. Anti-mine rollers were most widely employed by the Red Army of the Soviet Union. The design of rollers used in present-day humanitarian demining owe much to these.

"Rolling" could also be said to include the use of mine-protected vehicles fitted with steel wheels (no tyres) which have been used in a similar manner to conventional rollers.

Fig. 25. Armoured Terex front-end loader with Pearson roller. Eritrea - Ethiopia border, 2001.

Operational methodology

Anti-mine rollers

Rollers used in humanitarian demining have generally been mounted to adapted front-end loaders and tractors. Rollers are usually used in the area reduction role. The aim is to speed up the process by which manual clearance teams reach the real perimeter of a suspect area. Locating mines/UXO constitutes the greatest amount of time spent in any clearance operation when conducted by manual or MDD teams.

Anti-mine rollers are intended to activate sub-surface mines that are in a live, serviceable condition. They cannot influence mines which have, for whatever reason, become non-operational. As a result, anti-mine rollers do not have the same potential to destroy mines as do flail or tiller systems. Anti-mine rollers capable of withstanding blast from an anti-tank mine exist in military service, but have not yet been fully employed in humanitarian demining. Pearson Engineering and NVESD are in the process of developing anti-tank mine rollers for humanitarian demining.

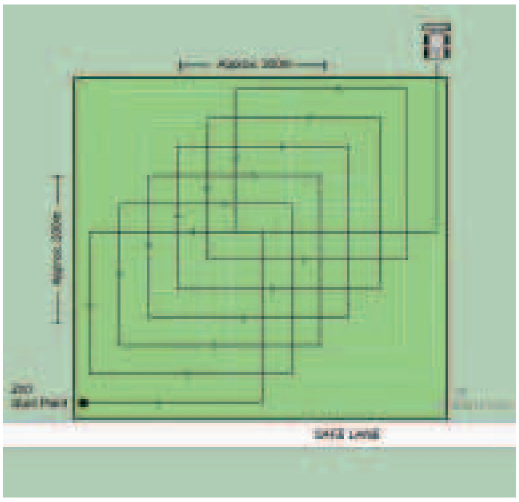
Rollers are not suited for mine clearance as they can destroy functioning mines only, and these only where conditions allow. Even fully-operational mines cannot be guaranteed to activate under the weight of a roller disc. The depth of ground in which a roller is likely to detonate a mine is determined by the weight of the roller, soil types and conditions. It cannot be conclusively determined.

As well as for area reduction, rollers are useful for post-clearance verification, and establishing confidence in a community by demonstrating the absence of live mines. Rollers typically used in mine clearance consist of segmented, heavyweight discs, each turning on a central axle. As the prime mover goes forward, the individual discs of the roller contact the ground. To a degree, the discs conform to undulations, bumps and rises in the ground.

For best results, a roller should be used in a set pattern over a suspect area. Patterns that have been used include rolling four times in four different directions. Rolling an area repeatedly is likely to be more effective than rolling just once. This is likely due to the soil compacting after each pass. At least this is supported by Pearson Roller trials conducted by the CCMAT and the Thailand Mine Action Centre (TMAC) in March and April 2003.

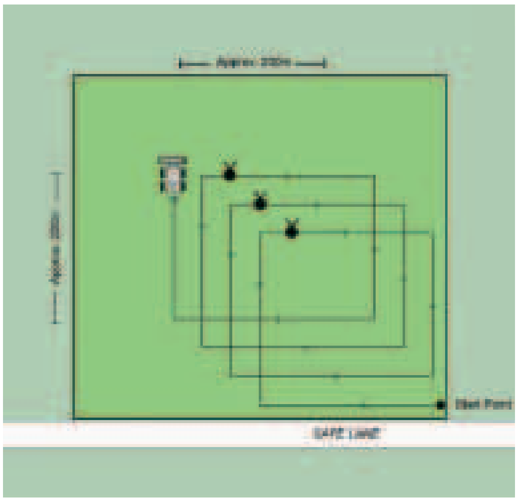
In situations where information as to the location of mines is accurate, a roller need not be used for locating mines by detonation. A roller can cover the ground close to the expected safe clearance start line in order to help corroborate that the land is truly clear of live mines before deploying manual or MDD teams. Once the presence of mines has been verified, direct clearance assets can be deployed into the reduced area where mines are actually located.

Fig. 26



Phase 2 of HALO Trust rolling operation. Grey lines are pattern from first roll. Concentric box pattern ensures that the middle of the area is rolled four times from four directions.

Fig. 27



Rolling area using concentric box pattern where mines were not expected but were subsequently encountered. In this example, an approximate mine pattern is revealed. Rolling should stop and clearance assets take over.

Rollers have been "home-made" using available local components in various programmes worldwide, particularly in Afghanistan. The only commercially produced anti-mine roller in common use in humanitarian demining is the Pearson Engineering segmented Area Reduction Roller (ARR). The ARR weighs one tonne per metre of width, available up to a width of 3.5 metres. Each individual disc exerts a ground pressure of 50 kilograms. It has been used by TMAC and The HALO Trust, which has area-reduced more than four million square metres using it.

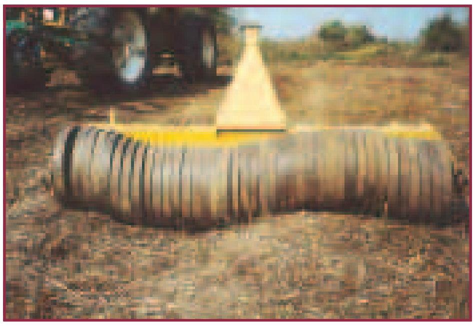


Fig. 28. Pearson Engineering anti-personnel mine roller.

The U.S.-produced Armadillo anti-mine roller has not yet been widely used in mine clearance programmes. Its ability to conform to bumps and undulations in terrain is good. Each weighted disk is mounted to an individually mounted suspension system.

Steel wheels

The attachment of steel wheels to mine protected vehicles evolved in the 1970s and 1980s, mainly in Namibia, South Africa and Zimbabwe (then known as Rhodesia). Specifically, steel wheels have been fitted to the South African Casspir MPV, developed by Mechem.

Steel-wheeled Casspirs have been used in a similar manner to anti-mine rollers; the vehicle drives in a pattern within a suspect area with the aim of detonating live mines to indicate mine patterns or sporadic presence. Covering ground in overlapping patterns without missing areas is more of a challenge than with anti-mine rollers. The wheels do not form a contiguous width beneath the vehicle but are spaced as with any standard wheeled machine.

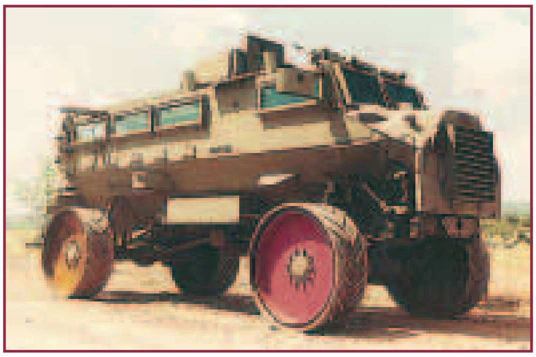


Fig. 29. Casspir MPV.

The steel wheels are an optional extra and can be fitted to Casspirs employed for mine clearance. When used to pressure-activate mines, the effectiveness of the steel-wheeled Casspir depends on the type of mine encountered. In recorded clearance tasks in Mozambique, the South African clearance organisation Mechem tended to detonate 89-96 per cent of PMN-1s and PMN 2s, 70-76 per cent of OZM-72s, 7-8 per cent of PMD-6s (they tend to become non-operational very quickly and were often merely crushed) and approximately 2 per cent of POM-Zs.


Fig. 30. Pearson Engineering SDTT. The Pearson Roller is attached to the tractor. Used in Thailand.

Conclusions, findings and recommendations

Conclusion 1.

There is scope for stand-alone mechanical systems to be used for clearance to humanitarian standards.

Findings

Although there is limited data to back up the assertion that machines achieve primary clearance of land contaminated by anti-personnel mines to humanitarian standards (as set out in Annex 1 to this chapter) it is supported by growing empirical evidence from implementing agencies as well as testing regimes. Evidence from the field suggests that few anti-personnel blast mines are left behind in a functional condition after treatment by certain machines in suitable terrain. Manual and dog teams are thereby relegated to picking up fragments.

Flails and tiller systems have set precedents for use as stand-alone, primary clearance assets: but this is by coincidence. These were set by machines employed in the ground preparation role where follow-up clearance assets did not encounter functional mines after a machine. There exists no official international proscription of using machines in the primary clearance role. It is simply that a culture of "not doing it " has developed within the demining community. Machines are often allocated to working where mines are not expected. This approach should be carefully reconsidered. The demining community is not trying hard enough to extract the clearance potential of machines in order to use their speed and potential cost-efficiency.

With regard to flails and tillers, it is difficult to exactly understand from existing research the interrelationship between a ground penetrating tool, its force, soil types and mine/UXO types. If further research is not conducted, a time may come when enough real-time, empirical data comes to the fore to accredit some machines as a choice for primary clearance. A development that must precede such an outcome is that more stringent and comprehensive data collection for recording clearance performed by machines be made. To date, most clearance data lacks detail, making the extraction of comparative analysis difficult at best.[13] Without improvements in this field, empirical support for greater use of mechanical systems cannot be marshalled.

With the few examples provided in this paper, it can be seen that — provided a machine is up to the task and that conditions of soil, terrain and mine type are favourable — mechanical demining systems exist that are able to clear areas where no hazardous ordnance remain to threaten follow-up MDD or manual teams. ''Full'' clearance is being achieved, certainly by mechanical excavation, but also with flail and tiller systems in some cases where mine type and conditions are suitable. One outstanding aspect of these examples is that primary clearance was not the expected result. Full clearance has sometimes been achieved where the sole aim was to prepare ground for subsequent clearance methods. "Full" clearance of land occurred as a fortuitous by-product. A significant problem lies in recognising what conditions are most favourable for machines to succeed as primary clearance systems.

It is known that topography, soil mechanics and mine type together with the choice of mechanical system play a critical role in the success or failure of a system to achieve full clearance. What is not known is specifically what the most favourable conditions are. Until these factors are better understood, it will be impossible to gain full control of whether or not a machine consistently succeeds as a primary clearance asset: success or failure will be more a result of random circumstances rather than controlled certainty.

Demining operations conducted by mechanical excavation and sifting currently serve as proven examples of successful primary clearance. To the depth penetrated by a front-end loader bucket, clearance is as good as guaranteed. If the quality of this method of clearance were ever to come under scrutiny, it is more the subsequent treatment options of contaminated soil that might benefit from fine tuning.

Despite the apparent success and ease of the mechanical excavation and/or sifting process, it remains an underemployed clearance technique. The reasons for this are not exactly known; it could be that this methodology has somehow escaped wide notice within the demining community. A more likely cause is the comparatively low productivity that this technique affords. A tractor could not hope to excavate contaminated soil at the rate a tiller or flail can process land, despite the proven efficacy of the former over the remaining doubts about the latter. Assumedly the operational advantages of mechanical excavation and sifting will be continuously reduced as tiller and flail designs improve and their optimal conditions are better understood. It is likely, however, that excavation will remain a good option in more extreme conditions, particularly in built-up areas.

Recommendation 1.

If a particular machine or mechanical system can demonstrate that, given suitable conditions against an appropriate target (ordnance type), it can be used as the primary clearance tool, it should be so used. Manual or MDD team follow-up can be streamlined in order to compensate for the likely residual threat left by that machine.

Conclusion 2.

Machines are rarely, if ever, deliberately employed in the primary clearance role.

Findings

Examples are scarce where machines have been used as a primary clearance system and followed by a dog team or a small team of manual deminers intended to compensate only for a known residual threat left by the machine. Residual threat refers to specific ordnance that a specific system has a tendency to be unable to destroy. The residual threat particular to a machine should be stated by the operator. Remains of these mine types should be cleared by subsequent demining methods — manual or MDD teams.

The aim of using machines is typically not to clear land, but to prepare ground for post-machine full clearance by manual and MDD teams. However, clearance sometimes appears to be the inadvertent result.

Yet, at the same time, there are numerous cases where machines repeatedly fail to adequately destroy even the easier target of sub-surface anti-personnel blast mines. This may be because a particular machine is simply not up to the job, or that it is not being operated correctly. The comparative efficacy of different machines varies widely. Another cause may be extremes of soil or terrain. For example, the soil can be very hard and on occasion mines are apparently protected from the blow of a flail hammer by large rocks. There is much to be gained from a better understanding of the physical limits imposed upon a demining machine by its operational environment.

Recommendation 2.

Further efforts should be made to understand the optimum physical conditions in which particular machines can be expected to act as the main, primary clearance asset. This would include factors of topography, soil, ordnance type and machine.

Conclusion 3.

In general, throughout the industry, machine clearance data is poor.

Findings

Detailed data gathering on the effectiveness of mechanical clearance is the exception rather than the rule. Records of clearance statistics, post-clearance accidents and missed mines are difficult to secure. Tests using an adequate number of live or surrogate mines to establish a machine's true clearance potential are few, and those that do exist do not explore a wide range of scenarios where terrain, soil and mine type may be a critical issue. This has been a major handicap for the research carried out for this study. Even where they are collected, statistics and clearance data from different organisations can be of widely ranging reliability. Furthermore, care must be taken that statistics are not manipulated to support a particular line of argument.

Recommendation 3.

The mechanical demining community would benefit from a coordinated, standardised method of recording mechanical clearance data. This data could enable machine operators to argue for the expanded employment of mechanical assets.

Endnotes

1. For example, the STS Minewolf and RLS Rhino employ interchangeable flail and tiller attachments but both use the flail attachment when operating in areas where anti-tank mines are expected.
2. Typically for ordnance up to an 82mm mortar shell.
3. Phelan and Webb (2003).
4. For example, the Armtrac 100 has addressed the problem by introducing extended cowling over the flail unit. Engine power, flail rotation speed and suggested adjustments to vehicle forward speed are also intended to decrease the possibility of throw-outs.
5. Shankla (2000).
6. Referred to as FN in the DRES study.
7. Referred to as FH in the DRES study.
8. SWEDEC (2002).
9. According to an Armtrac 100 operator for the organisation BACTEC, working in southern Lebanon in 2002: "*Rocky soil tends to quickly degrade chain links and hammers, requiring them to be replaced more often*".
10. Based on interviews with machine operators in Bosnia and Herzegovina in May 2002 and in southern Lebanon in August 2002.
11. SWEDEC 7/2001, Eksjö, Sweden.
12. This occurrence was observed by Håvard Bach, GICHD, during operation of the MgM Rotar in Namibia in 2001.
13. CROMAC, for instance, serves as an example to the industry for full and comprehensive clearance data. Worldwide, there is significant disparity of quality of operational statistics.

Annex 1.

Examples of machines achieving clearance in demining operations

The following are a few examples of where machines have cleared land leaving little or nothing to be found by subsequent clearance methods.

ELS supporting NPA in Bosnia and Herzegovina

In Bosnia and Herzegovina (BiH), European Landmine Solutions (ELS), a commercial mine clearance company, provides mechanical mine clearance support for other organisations that deploy MDD and manual teams. ELS has mainly used the Armtrac 325 and 100 in the ground preparation role.

From April 2000 to the end of 2002, NPA contracted ELS to conduct ground preparation on many of its clearance sites. In general, the terrain in BiH is a mixture of rolling and steep hills, interspersed with agricultural plains and forest. The climate is temperate European and the soil is of medium consistency, seemingly well-suited to flails. Patterned, intensive minefields are not common in BiH.

Fig. 1. Armtrac 325.

During the NPA/ELS contract period, one apparently functional mine was found after the preparation of ground by flail. This was a Yugoslav PMA-2 anti-personnel blast mine, believed to be in working condition. It was discovered by an NPA deminer during the follow-up clearance of an area following ELS machine preparation. NPA believes it probable that the mine was never contacted by a chain from the Armtrac as the machine passed too far to one side of the mine, located near the base of a large tree. This is the only known missed mine incident as a result of ELS preparing 781,634 square metres of ground for NPA. All other mines were detonated or broken up before manual deminers or MDD teams conducted final clearance.

NPA in Angola

Fig. 2. Hydrema MCV 910 (series 2).

Beginning in 1998, the NPA programme in Angola has carried out mechanical ground preparation using Aardvark and Hydrema flails. These machines were used on suspect ground where survey produced unreliable information. The suspect areas dealt with were believed to be of low mine content. Since 1998, approximately 2.5 million square metres of suspect land have been mechanically prepared by the NPA machines in Angola. Of this area, one throw-out is recorded. No incidents of missed mines as a result of deminer clearance or civilian accidents have been recorded.

Aardvark Project Afghanistan 1990-1995

The United Nations Mine Action Programme for Afghanistan (UNMAPA) employed Aardvark flails in an attempt to speed up the rate of clearance and improve cost-effectiveness. Neither of these aims was met due to problems of management, logistics and operating procedures. Large areas were, however, mechanically prepared. UNMAPA stated that: ''*Flails are most effective against anti-personnel blast mines, achieving virtually 100 per cent detonation*''.[1] This is probably an exaggeration as there must have been incidents of anti-personnel blast mines being broken up, however the technique of flailing minefields obviously impressed those involved in the programme. Unsurprisingly, the Aardvark flails were not consistently successful against thick-skinned anti-personnel fragmentation mines such as POM-Zs, a common problem among tiller and flail systems.

Minebreaker 2000 in Afghanistan

Fig. 3. Tiller drum configuration – FFG Minebreaker 2000/2.

The German military (Bundeswehr) engineer contingent in Afghanistan employed a Minebreaker 2000 to clear ground in the area of Bagram Airbase in support of U.S. military operations (not as part of the International Security Assistance Force). From 17 November 2002 to 23 April 2003, the Bundeswehr Minebreaker mechanically prepared roughly 38,000 square metres of ground. Soil was of clay quality and vegetation consisted of mainly thick, high grass.

The area was later manually cleared by Polish Army engineers who confirmed that the Minebreaker had detonated or broken up approximately 80 sub-surface anti-personnel blast mines. All items of UXO were detonated or broken up. Two Iranian YM-1 anti-personnel mines were located that had escaped destruction. This mine type requires sustained

1. Handicap International, 2000.

pressure of at least one second in order to activate. The tiller rotation speed of Minebreaker was unable to apply this.

The HALO Trust mechanical excavation

HALO mechanical operations began in Kabul, Afghanistan in 1996. Since then, HALO has operated machines in mine clearance programmes in Abkhazia, Afghanistan, Angola, Cambodia, Chechnya, Eritrea, Kosovo, Mozambique, Nagorno-Karabakh, Somaliland, Sri Lanka and Sudan. As of March 2003, HALO has used mechanical application in a total of 11,804,416 square metres of land. No accidents occurred to demining personnel. No missed mines have been recorded by subsequent users of the land.

Croation Mine Action Centre (CROMAC) clearance projects for the year 2002

The GICHD commissioned CROMAC to provide clearance data for all demining activity within Croatia from January to December 2002. Clearance operations were conducted in a total of 232 suspect areas, and machines were employed to prepare areas by breaking the surface of the ground in 167 tasks (concurrently clearing vegetation). Of these, 104 were to prove free of mines and were cancelled out. In 63 tasks, machines encountered anti-personnel mines. Of these 63 sites, no mines were found intact by follow-up clearance methods (manual or MDD). The 63 sites covered 5,530,192 square metres. All mines had been detonated or broken up. Remaining fragments were cleared by manual or MDD teams.

Lebanese National Demining Office (LNDO)

Demining operations in Lebanon are carried out by engineers of the Lebanese Armed Forces (LAF), coordinated by LNDO. Confidence in the clearance capacity of flails (in this case an Armtrac 100) is sufficiently high that LAF demining standards allow for full clearance in order to reduce casualties. They use the flail for full clearance only in scattered minefields where the threat is higher than that in uniformly distributed minefields, as experience has shown that, in general, in Lebanon, it is quicker to clear patterned minefields manually.

Chapter 2.

Risk assessment and mechanical application

Summary

IMAS state that land shall be accepted as "cleared" when the demining organisation has ensured the removal and/or destruction of all mine and unexploded ordnance hazards from the specified area to the specified depth. However, the complete removal of risk cannot be assured in mine clearance (even though it is probably achieved in many cases) owing to the inaccuracy of much available information combined with the inherent limitations of clearance methods. A detailed set of tolerable risk criteria should therefore be established prior to clearance. For example, leaving components of broken-up mines in situ *should be an option unless stipulated otherwise by the relevant mine action authority.*

The way to more effective and efficient demining is through acquiring more information about the hazards occupying an area, rather than assuming a worst-case scenario. Machine development should therefore focus on technology that is able to acquire as much information as possible about the minefield prior to clearance. Numerous possibilities are already available on the open market for this to happen now. Furthermore, demining organisations should recognise that in areas where a machine has not indicated the presence of mines it is possible that no subsequent clearance method is required.

Insufficient research has so far been conducted into the reliability and capability of all clearance methods. Records need to be far more thorough and should include details about the conditions in which mines were undamaged by machine use, judgements of whether mines are still operational following machine use and any trends or links between the machine type and its effect on various mine types and variables such as terrain and soil conditions.

Introduction

Background

In Chapter 1, we looked at the potential for mechanical systems to be employed for clearance. We also learnt that, throughout the industry, machine clearance data is poor. Yet, information is central to the effective management of mine action. This chapter looks at how information should be collected — and decisions taken — based on a notion of what constitutes acceptable risk.

Given the threat from mines and UXO to the local population, risk assessment is a key component of mine action, especially in humanitarian emergencies. Although the human impact of explosive contamination is generally well documented, investigation of the effectiveness of the application of machines to risk reduction has tended to be limited and fragmented.

Terms of reference

The sub-study that forms the basis of this chapter looked at how machines can be applied to a minefield, using a risk assessment process to determine the most appropriate roles for mechanical systems in reducing the risks to the civilian population. Risk assessments are an integral part of mine clearance and EOD operations. However, the methodologies are very much underdeveloped and examples of specific procedures are rare. This chapter considers the risk to those who use affected land both before and after clearance operations, as well as the risks to deminers carrying out their work. In some cases, a sensible prioritisation of tasks can be achieved through a risk assessment, which inevitably has consequences for both land users and demining personnel

This sub-study is based on both field and library research. Field visits were conducted in Croatia, Lebanon, Thailand and Viet Nam and an analysis made of secondary sources from Kosovo. The chapter has been researched and written by Mark Buswell, Leonard Kaminski and Rebecca Sargisson, who are employed by the GICHD.

Chapter layout

The chapter first establishes a basic understanding of the concept of risk. Second, it proposes a risk assessment model, which takes into account the application of machines to minefields. Third, examples of the roles of machines in a mine clearance operation are analysed to demonstrate how risk management can maximise the benefits of mechanical application. Finally, the chapter presents the conclusions and recommendations of the sub-study.

Theory of risk

Everyday life involves risk. There is a chance, for example, that we will be the victim of an accident or crime. Most of the risk associated with everyday life, though, is deemed tolerable, because the likelihood of a harmful event occurring is low or the impact of the occurrence may be low.

Let us consider the simple act of crossing a road. The level of risk is assessed by the person crossing the road based on information available at the time and on the person's experience with crossing roads. Thus, "*having looked in both directions (side to side), we decide it is safe to cross the road. This does not mean there is no traffic on the road but rather we have determined on the basis of experience that the risk of being struck by the vehicles we can see in the distance is, to us, acceptably low. It can also involve value judgements on the risk. For example, if late for a vital meeting we might be prepared to accept a much higher risk than normal*".[1]

This example highlights the two basic issues that affect the process of risk assessment: *available information* and *tolerance*.

Available information

The decision to cross the road is based on information, such as the speed of the traffic, the distance to be crossed, weather conditions and visibility, combined with our experience of crossing roads in the given conditions. Thus, we can adjust our walking speed to suit the traffic conditions because we have learned to judge how fast we need to walk to avoid danger.

Tolerance

After gathering information we then need to decide if the risk is worth taking, based on the likelihood of being hit and the damage that may occur. We may accept higher levels of risk in certain situations, such as in situations of economic necessity (the urgent appointment may mean the difference between keeping a job and losing it).

On occasions, we may decide that the level of risk is unacceptable. While it may be difficult to remove all risk from crossing the road, we may be able to reduce the risk by waiting or finding a more suitable crossing point. Risk could be avoided entirely if the road is not crossed.

Responses to risk, therefore, should be flexible and reflect the level of threat present at a specific time and place. For example, lengthening your journey to find a safer crossing point is uneconomic if the likelihood of being struck by a car is low at the current crossing point.

Risk management

There has been a tremendous improvement in many aspects of the quality of our lives. We now live longer than at any time in history. Although accidents at work still occur, the trend averaged over the years has been downwards. This progress in the quality of our lives is readily acknowledged but, paradoxically, it has been accompanied by an increasing expectation of a society free of involuntary risks. The rapid technological developments of recent years have introduced new hazards but also enhanced the scope for controlling existing hazards.

The trend for managing risks has been to merge and centralise industrial authorities through the establishment of regulatory regimes whereby broad general duties are explicitly put to those who are best placed to do something about preventing or controlling the risks. However, providing a clear explanation of the risk decision-making process is not an easy task. The process is inherently complex, with a variety of inputs. It has to be workable while allowing the use of judgement by the regulator (i.e. typically the mine action centre and/or national mine action authority) and flexibility for implementing companies or organisations. At the same time, it must reflect the values of society at large as to what risks are unacceptable, tolerable or broadly acceptable.

Any informed discussion quickly raises ethical, social, economic and scientific considerations. These include how to achieve the necessary trade-offs between benefits to society and ensuring that individuals are adequately protected.

The way we treat risks depends on our perception of how they relate to ourselves and the things we value. Particularly important for man-made hazards are "*how well* *the process (giving rise to the hazard) is understood, how equitably the danger is distributed and how well individuals can control their exposure and whether risk is assumed voluntarily"*.[2]

It is claimed that it may not be possible to derive a quantifiable physical reality that most people will agree represents the "true risk" from a hazard. Instead, the concept of risk is strongly shaped by human minds and culture, which is why a number of high quality risk assessments by leaders in the field have failed to reassure people.[3]

Other theories have been offered to explain why risks that are minor in quantitative terms produce massive reactions while major risks are often ignored. The "social amplification" model, for instance, suggests that the impact of a particular risk begins with the initial victims and diffuses outward to society at large. In this process, the public response to the risk can be amplified depending on how the reporting of the risk interacts with psychological, social, cultural and institutional processes.[4]

Measuring risk

Measuring risk is inherently complex. In the context of mine clearance for humanitarian purposes a major problem is already the lack of reliability, accuracy and quantity of data. The importance of operational record-keeping has only been considered since the development of mine action centres. Before this, records were only kept at the discretion of individual agencies and for their own purposes.

But, even if all available data and the best science and technology are used, measurement cannot be undertaken without making a number of assumptions such as relative values of risks and benefits or even the scope of study.

Depending on the issues, risks are measured either qualitatively or quantitatively or in combination.

Quantitative methods

The use of quantitative methods is reliant on the accuracy and appropriateness of the data that is available. Quite often, large amounts of data are required to provide any credible results. Quantitative data can be gathered from such sources as testing, accident reports, operational records, fault analysis and so on, and are particularly useful when the foreseeable severity and extent of harm are high.[5]

Qualitative methods

Qualitative methods are open to degrees of subjectivity and bias based on the experience, knowledge and interest of the individual. However, the process of risk assessment does provide a degree of accountability in information collection and analysis.

In mine clearance, methods of measuring reliability tend to be qualitative. For example, it is rare to know the exact number of mines that are in a minefield prior to clearance.

When measuring risk, care needs to be taken to avoid numerous pitfalls that can trap the unwary. These include accident or incident samples which are too small or have too narrow a scope, and which may therefore be misleading. Also, the time period may be too short, which may lead to the omission of representative accidents or incidents, and statistical data may not include the cause. Selective use of data can result in figures that do not accurately reflect history.

Achieving tolerable risk

A product, process or service is deemed to be "safe" when its users believe the risk associated with its usage is tolerable, even though some small risk may exist. As it may be unfeasible to provide absolute safety, tolerable risk takes into account factors such as the limitations of the product, process or service, the cost-effectiveness of reducing risk further and the conventions of the society concerned.

For example, in mine clearance a higher level of risk may have to be accepted if a demining tool is used that has low reliability, or if there is a requirement to reduce the cost of demining in an area. The tolerance of the local community may vary from place to place and people in one area may be prepared to accept a higher level of risk than people in another.

The level of tolerable risk needs to be continually reassessed, because, for example, an economically feasible improvement in technology or knowledge may be achievable, meaning that a higher level of safety can be achieved.[6] The tolerance levels of the affected community may also change. If, for instance, someone is injured due to a missed mine in a supposedly cleared area, the people in the area may call for a lower level of risk.

Risk assessment

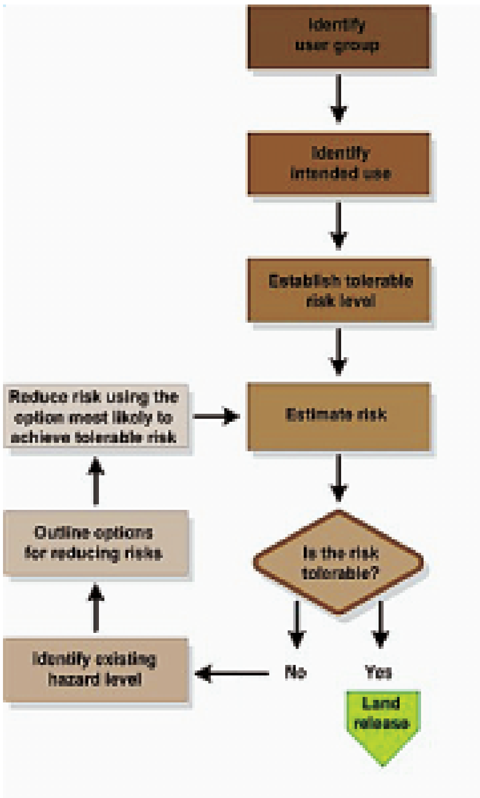
Risk assessment is a tool used to facilitate decisions about how to optimise the use of scarce resources. Risk assessment provides the basis for determining the risk involved in certain processes and justification for the actions that have been undertaken.

Properly used, a risk assessment often provides an essential ingredient in reaching decisions on the management of hazards. The results of a risk assessment are often used to inform rather than dictate decisions and are only one of many factors taken into account in reaching a decision.

However, the use of risk assessment practices is not without controversy. For example, an approach based on the assessment of risk could be seen to underestimate the true impact of a problem and could therefore undermine the adoption of precautionary approaches based on anticipating and averting harm.

In the context of mine clearance, tolerable risk is achieved by a process of risk assessment (risk analysis and risk evaluation) and risk reduction as illustrated in Figure 1 overleaf. The model presented describes several steps that, once completed, provide a basis for establishing and judging tolerable risk. These steps are discussed in greater detail in the remainder of this section. However, it is worth emphasising two points. First, the boundaries between stages are not clear cut. Information and perspectives are gathered while progressing from one stage to another, often requiring early stages of the process to be revisited. In short, the process is iterative. Second, stakeholders should be involved at all stages, although final decisions may not always be taken by consensus since the various stakeholders may hold different or even opposing views.

Fig. 1. Process of achieving tolerable risk



Adapted from ISO (1999a).

A fundamental principle underpinning Health and Safety Acts worldwide, covering almost all industries, is that those companies or organisations creating risks by nature of their work activity are responsible for protecting workers and the public from the consequences.

Where hazards entailing severe consequences are involved, the trend in recent years has been to amplify the duties for generic risk assessments to require the production of specific safety cases.

This requires implementing companies or organisations to write down and submit to regulatory bodies measures to ensure safe and healthy systems of work and proper management of heath and safety. This enables the companies or organisations to demonstrate that they understand the hazards associated with work activities and how to control them.

The responsibility to develop safety measures is with the company or organisation implementing the work activity. The regulation body clarifies the duties requiring, for example, employers to assess risks and base their control measures on the results of the assessment.

The model works by first identifying the user group for the product, process or service. The intended use for the product should be ascertained along with any foreseeable misuse. Once the user group and land use post-clearance have been defined, a tolerable risk level can be set. This tolerable risk level is a standard of “safety” that needs to be met before the people in the community use the land for its intended purpose.

The hazards in all stages of the process should be identified and the risk associated with each hazard estimated and evaluated. This involves gathering information about the area which enables a judgement of risk to be made. The risk can then be judged to be tolerable or intolerable to the user group. If the risk associated with the land prior to any clearance effort is tolerable, then no clearance is necessary. If the risk is not tolerable, options for reducing the risk should be outlined. Each option will come with its own limitations and estimates of reliability. The option which is likely to reduce the risk to the defined tolerable level should be implemented.

Step 1. Identify the likely user group(s)

The model is designed to identify the product or service that is provided to mine-affected communities. In the context of humanitarian demining the service is “mine and UXO clearance“ with the product being “safe land”. The main aim of the product and service is to remove all mines and UXO.

Thus, consideration should be given to the level of risk that the local community is prepared to accept. What may be an acceptable level of risk for one group of people may be unacceptable to another. To help determine what level of risk is appropriate for the user group, the survey team can analyse factors such as whether the affected land is currently being used, what level of risk may have been accepted in past clearance sites, and the views of the local government or residents. The process, however, is complex. Some of the main issues and constraints are set out in Table 1.

Table 1.

Issues	Constraints
Cleared land cannot be guaranteed as free from risk of mines and UXO.	Every clearance method used has limitations. Additionally, information regarding the exact number of mines in an area is vague. A demining organisation can not be sure all items have been removed based on the number located and cleared.
Mines and UXO may exist outside areas identified as requiring clearance.	The survey process is limited in its ability to locate all mines and UXO. It identifies areas of contamination and not individual items, which often exist randomly.

Step 2. Identify the intended use of the land

This stage of the model is designed to investigate what the local community intends to use the land for. If people intend to build houses and move onto the land with their families, the level of risk they will accept from injury by mines or UXO is likely to be lower than if the land is to be used for a more low-density purpose, such as grazing cattle. Moreover, building on cleared land, as opposed to farming it, means the risk of landmine or unexploded ordnance needs to be reduced to a greater depth so that building foundations can be safely established. Therefore the intended land use should be factored into the analysis of tolerable risk.

It is also possible that although a community may not originally have intended to live on the land, after passage of time they may still move onto it even though it has not been deemed tolerably safe to do so due to some pressing necessity. The potential for habitation is reduced if the land is mountainous, swampy or difficult to access, so these factors can be taken into account when considering possible future alternative use of the land, and thus the importance of conducting clearance in the right areas.

Determining the intended land use may also help in the division of land according to community priorities. For example, if the location of the suspected minefield impedes living conditions for the local people, then reducing the risk from mines and UXO in that area may be a higher priority than reducing the risk in an area the people do not need to put to immediate use. Some of the main issues and constraints are set out below.

Table 2.

Issues	Constraints
Clearance method is matched to intended use of the land.	Land use may change over time.
Land is not necessarily used after clearance.	Limited accountability or incentive for land to be used as intended.
An area may need urgent clearance but also be politically unstable. Future conflict may re-contaminate the area.	Difficult to predict future conflict.

Step 3. Establish the tolerable risk level

This is the most subjective phase of risk assessment because it is based on the perception of risk held by local people as well as the responsibility of the demining industry to ensure the relative safety of its product or service. So, even after a demining organisation has deemed an area to be tolerably free of landmines and UXO, if the people in the area refuse to use the land because of the perception of risk is still too high and the demining organisation may need to increase the perception of safety by implementing a further demining technique. Alternatively, the local people may be using an area that the demining industry cannot yet confirm to be tolerably free from mines and UXO.

In practice, risk tolerance criteria are being implemented poorly in a range of industries worldwide. This is due to risk measures being misunderstood. The major issues and roadblocks that need to be addressed before risk tolerance levels can be developed include:

- presentation of risk must be uniform and consistent;
- ethical assumptions must be consistent;
- terminology must be consistent;
- guidelines should be regularly reviewed; and
- organisations need to view risk reduction as an opportunity for improving their business instead of an imposed requirement.[7]

The general approach is to set out the objectives and to give considerable choice to duty holders as to the measures they should put in place to meet these objectives. The tolerable risk level may be affected by other factors, such as time constraints and cost-effectiveness. It may be suitable to accept a higher level of risk to release land for urgent activity, such as aid or road development, and an analysis may be required as to whether the land value is representative of the cost of clearance.

Establishing the tolerable risk level early is necessary because managing mine/UXO contamination is based on the optimum allocation of scarce resources. A programme must have a method of determining which areas will be cleared first and which areas will be cleared later. Again, some of the main issues and constraints are set out in Table 3.

Table 3.

Issues	Constraints
Time spent clearing in one area means people living in other areas are exposed to risk.	The more reliable the method of clearance, the more time is needed in each minefield.
Clearance conducted in large areas with few mines.	A lack of detailed and accurate minefield information.
The demining community is undecided on the most effective way to reduce mine/UXO casualty figures .	Different methods or approaches are often not comparable. These include mine risk education, full clearance or identification and marking.

It has been argued that rapid risk reduction with a high tolerance may result in a greater reduction in the number of victims than one with a low tolerance requiring an increased timeframe to achieve a higher level of risk reduction.[8]

One of the benefits of using machines to reduce risk is their potential daily output, which is superior to manual or dog techniques. If mine clearance machines were used in as many minefields as possible, prior to the deployment of any subsequent clearance activity, two things would happen. First, a larger percentage of mines would be cleared faster than if only manual teams were deployed. Second, the machine could act to allow any subsequent clearance teams to be deployed in a more focused manner, through an effective process of area reduction.

The hypothetical situation would be that all the minefields were first cleared by machines, where almost all mines would be detonated or broken up. Some items of UXO would also remain. As machines both clear mines and augment information about an area, this information would assist in prioritising clearance tasks as well as in identifying the real perimeters of mined areas.

The by-product of this approach is that many areas would not receive any follow-up clearance for a considerable period. The broken-up mines can be considered a tolerable risk, if only for a certain period, because the alternative is to do no clearance whatsoever for a relatively longer period.

The importance of establishing the tolerance level at this stage cannot be underestimated. This step is quite often overlooked but it did occur in Kosovo. The Kosovo example (*see Annex 4 at the end of this chapter*) discusses the implications of establishing a level of tolerance at the early stage of mine/UXO clearance action.

The same approach is also conducted by the TMAC through its "area and risk reduction" operations as opposed to mine clearance operations. Their tolerance levels were established after consulting local inhabitants and beneficiaries. This approach is detailed in Chapter 3.

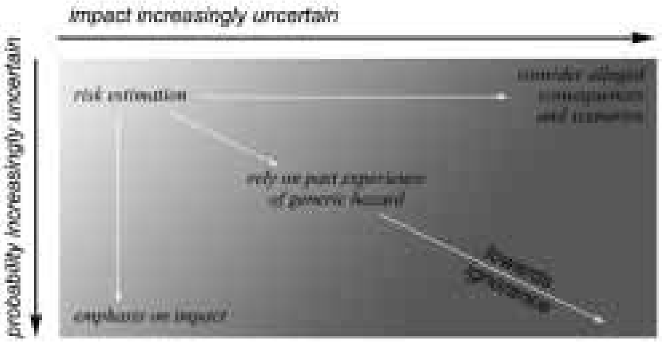
Step 4. Estimate the risk level

Estimating and evaluating the identified risks is a process of determining the probability and impact of the identified hazards, i.e. the likelihood that an incident with a mine or UXO will occur and the consequences of the incident. The impact of a mine and UXO detonation is difficult to predict as it depends on the type of device, how it was initiated and how many people were involved at the time.

Knowledge uncertainty

Estimating accurately the probability and impact depends on the reliability of the information. The process of uncertainty is illustrated in Figure 2.

Fig. 2. Process of uncertainty when estimating risks



HSE (2001).

The vertical axis represents increasing uncertainty about the probability of an incident occurring in a particular area. As less is known about the probability of an incident occurring, the more likely it is that decision-makers will focus on the possible impact.

The horizontal axis represents increasing uncertainty as to the nature of the impact. The less that is known about the possible impact of an incident, the greater the focus on hypothetical consequences.

When both the probability of an incident occurring and the impact of the incident are known (upper left hand corner), assessments of risk can be undertaken. However, the less that is known about the probability of events occurring and the impact of those events, the more decisions are likely to be based on generic hazards or past experiences. These decisions made in the face of uncertainty are likely to be precautionary in nature and incapable of being tested.

As more information is gathered, uncertainty is decreased. The example of Southern Lebanon (*see Annex 1 at the end of this chapter*) shows how machines can be used to gather information so that the impact and probability can be more accurately defined and the most effective clearance method applied. The scope of the task may be reduced in terms of area (area reduction) and methods used (less meticulous). Thus, machines may prove valuable not only in the sense that mines are detonated during their use, but also as a source of information about mine density and mine type in an area.

General probability levels

Table 1 overleaf shows that the probability of mine presence, when considered as a proportion of items per area suspected and cleared, is incredibly low. This reality is related to the inability of the technical survey (in its current form) to define the exact location of mines within a given area without conducting a physical search (high information uncertainty). Table 1 illustrates that most work is concerned with searching for mines (97.91 per cent) and very little work is concerned with actually clearing them (2.09 per cent).[9]

Additionally, Table 1 highlights the difference between perceived risk and actual risk. The total area perceived to be at risk is 292,080,515 square metres, however, the total area representing actual risk averaged out as 6,092,268 square metres.

Step 5. Decide whether the risk is tolerable

At this stage, it is important to determine whether the risks in an area are tolerable. Assuming that the risk is not tolerable regardless of the probability of mines or UXO existing in a suspected area will often result in a long and expensive risk reduction procedure. In the context of mine clearance, the mine/UXO hazard is generally regarded as significant unless past experience, or the probability of an occurrence, is low compared to the background level of risk to which people are exposed.

Table 4

Issues	Constraints
Confidence in the decision made.	Quality of the information cannot be accurately tested.
Freedom of organisations to make decisions.	Some regulations and laws dictate that the risk of mines/UXO is not tolerable regardless of probability or impact.
Organisations cannot immediately attend to mine/UXO problems although expectation to do so is high.	A lack of resources to satisfy needs; prioritising necessary.
Tolerance varies according to organisations' objectives and aims.	All mine/UXO risks tend to be categorised equally.

Table 5. Probability table[a)]

Programme	Reporting period	Area cleared (sq. m.)	Anti-personnel mines	Anti-tank mines	Mines unspecified	UXO	Submunition	Small arms	Total ordnance (mines & UXO)	% of area contaminated
Afghanistan	Jan-Mar 02	20,000,000	16,196	751	0	251,169	0	0	268,116	1.34
Albania	Year 2001	302,000	744	25	0	115	0	0	884	0.29
Azerbaijan	Year 2001	896,143	45	22	0	1,165	0	0	1,232	0.14
Cambodia (CMAC only)	March 92 - June 02	97,662,889	156,730	3,059	0	680,627	0	0	840,416	0.86
CROMAC	Year 2001	42,324,637	1,877	1,640	0	3,124	0	0	6,641	0.02
Guinea-Bissau	June 2001 - May 2002	136,477	976	30	0	6,277	0	0	7,283	5.34
Iran	20/03/01 - 20/03/02	70,000,000	3,200,000	914,000	0	4,236	0	0	4,118,236	5.88
Jordan	1993-Oct 01	8,000,000	0	0	84,157	0	0	0	84,157	1.05
Kosovo	June 99-01	32,224,107	19,457	5,515	0	13,896	15,940	0	54,808	0.17
Lebanon (Minetech only)	OES 1st 90 days June-Aug	1,000,000	8,000	7	0	600	0	0	8,607	0.86
Mozambique (incl. roads)	Sept 93 - Dec 94	4,239,652	1,168	16	0	10,764	0	67,287	79,235	1.87
North Iraq	1993 - 30/06/02	4,596,409	0	0	345,557	90,321	0	0	435,878	9.48
Peru	Jan-Mar 99	82,814	0	0	438	0	0	0	438	0.53
Thailand (TMAC)	July 00 - June 02	4,415,387	1,723	529	0	22,085	0	0	24,337	0.55
Zimbabwe (KochMinesafe)	1999 - 2001	6,200,000	0	0	162,000	0	0	0	162,000	2.61
TOTAL		**292,080,515**	**3,406,916**	**925,594**	**592,152**	**1,084,379**	**15,940**	**67,287**	**6,092,268**	**2.09**

a) Total ordnance divided into total area cleared includes small arms ammunition. Each item of ordnance is accorded an area coverage of one square metre.

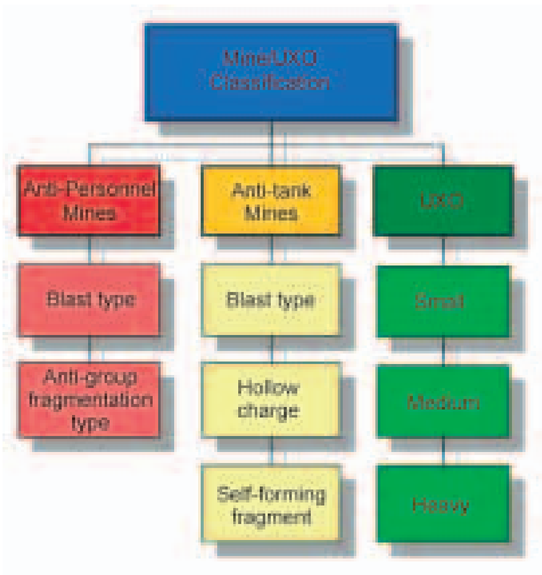
In Kosovo, the Mine Action Coordination Centre applied different clearance methods according to different explosive item risks. High-risk items included mines and cluster bombs. Clearance methods were used in areas known to contain these items. Other general munitions (mortars and artillery rounds, etc.) were believed to represent a lower risk and the primary means of dealing with them was through education and avoidance methods, implying that areas containing only general UXO could be deemed tolerable to clearance organisations, but intolerable to mine risk education organisations or programmes.

The use of machines is generally restricted to ground preparation work, after which other clearance techniques are employed, regardless of information obtainable from the mechanical process. The Southern Lebanon example (*see Annex 1*) highlights how tolerable risk levels were decided once a machine was applied. The information gained from applying machines often resulted in minimal follow-up clearance being required or, in some cases, no follow-up whatsoever.

Step 6. Identify the existing hazard

The next step in the risk assessment analysis is to identify the existing explosive hazards to the local people. Hazards can be categorised into mine and UXO types illustrated in Figure 3. The mine action survey team can gather information about the mine type and density of mines likely to be present in an area. Site maps of the minefield can be used, where available. Additionally, the history of the area should be studied to ascertain what the land was used for in the context of the conflict. Important information includes who was fighting, the length of the conflict, who was financing the conflict and where the weapons were coming from. The local residents can be asked about their knowledge of the land, whether any accidents have occurred in the region and what type of mines they have seen.

Fig. 3. Mine and unexploded ordnance classification



There are two aspects of landmine and UXO types to understand when identifying the different hazards:

- detectability of the mine/UXO, and
- design function of the mine/UXO.

Mine detection technology in manual demining is based on the detection of the metal content within the explosive item. Anti-personnel blast mines are generally plastic-cased mines with a small amount of metal in the internal workings of the mine. This means they can be relatively difficult to locate by a metal detector. Moreover, every piece of metal of similar size needs to be investigated in case it is a mine. This is a major inhibitor to clearance effectiveness, particularly in areas with high levels of extraneous metal.

By nature, anti-personnel fragmentation mines have much higher levels of metal content and are therefore much easier for metal detection technology to locate (smaller sized metal readings can be ignored). Additionally, UXO tend to have a similarly high metal content. Anti-tank mines can have either high or low levels of metal content but areas containing these mines can generally be differentiated from areas containing other mine types.

When using MDD techniques, explosive molecules are more efficiently released in mines with plastic casing than in mines with metal casing, although molecules in metal-cased mines may be released through built-in apertures.[10]

Additionally, the design function of an item influences the clearance options available. Different machine tools are capable of different effects on mines. A roller, for example, applies pressure to the ground, therefore only mines that are designed to function from direct downward pressure are affected. Tripwire-activated fragmentation mines become a less hazardous item to approach and destroy once the tripwire threat has been mechanically removed.

Machines will need to identify the types of mines and UXO that exist both before and after machine use in an area so that clearance can be tailored to the threat in the most efficient manner possible. The Thai Mine Action Centre example (*see the example in Chapter 3 on area reduction of non-patterned minefields*) shows how different mechanical tools can be applied to identify whether different hazard types exist in an area. Any areas that have been processed and where no evidence was found of the presence of any type of mine/UXO are cancelled out, and receive no clearance subsequent to mechanical action.

Step 7. Outline options for reducing risks

Although all the above six steps of the risk assessment process are important, getting Step 5 right — deciding whether the risk is tolerable — is crucial. Achieving this will not only help to reach decisions that are likely to be supported and implemented but, because of the iterative process inherent in risk assessment, it will help to get the other stages right as well. However, getting Step 5 right depends on the criteria adopted for deciding whether a risk is unacceptable or tolerable.

Research analysing the criteria used by regulators in the health, safety and environmental field has shown that, in general, the criteria can be classified according to three categories:[11]

- An **equity-based** criterion, which starts with the premise that all individuals have unconditional rights to certain levels of protection. If the risk estimate is above the limit and further control measures cannot be introduced then the risk is held as unacceptable whatever the benefits.
- A **utility-based** criterion, which applies to the comparison between the incremental benefits of the measures used to prevent the risk of injury and the cost of the measures (cost-benefit analysis). There is a requirement for a balance

to be struck between the cost of removing a risk and the benefit of removing it.

- A **technology-based** criterion, which reflects the idea that a satisfactory level of risk prevention or removal is attained when state-of-the-art control measures are employed to control risks whatever the circumstances.

Demining organisations and authorities tend to take a technology-based approach to determining tolerable risk with regard to how a hazard should be removed. Often equity-based and utility-based criteria are ignored.

Mine clearance operations are generally conducted using three different methods: manual demining, mine dog detection and machines. The technology-based criteria mean manual techniques are the preferred method of clearance as there is more confidence in the reliability of manual methods to clear all of the hazards, regardless of the overall effectiveness of the technique or the probability of mines being present in certain areas. But manual techniques are not infallible: according to Version 1 of the Database of Demining Accidents, around 18 per cent of manual demining accidents were due to missed mines. This information demonstrates that limitations exist with even the supposedly reliable methods.

The general limitations of the three main methods of clearance are summarised in Table 6 below.

Table 6. Limitations of the three main humanitarian clearance techniques presently in use

Technique	Limitations
Manual clearance	Reliant on the use of detectors to locate mines. Detectors have depth limitations and may miss what are known as minimum metal mines beyond a depth of 13 centimetres.[a)] Also, it is known that the sensitivity of detectors fluctuates throughout a working day. Human error is also involved, either with detectors or with manual excavation.
Dog detection	Dogs' ability to detect mines is influenced by environmental conditions, the migration of explosive molecules to the surface of the ground, training of the dog and the interaction between the dog and its handler. However, the parameters for these influences are not clearly understood.
Machines	Machines such as flails and tillers both detonate and break up mines. When mines are broken up they are not always completely neutralised and hazardous components can remain in their wake. Machine effectiveness is also influenced by ground conditions and environmental factors – machines are of limited use in rocky, damp soil or extreme terrain.

a) Minimum metal mines have been found deeper than 13 centimetres using manual excavation techniques. E.g. The HALO Trust, Cambodia 1996, Samaki minefield: in this incident an area was cleared by detectors first. The Location Manager then noticed a small area where it appeared earth had built up over time and ordered it to be manually excavated. Twelve MD82b anti-personnel mines were located.

Step 8. Reduce the risk using the option(s) likely to achieve tolerable risk

Selection and subsequent implementation of a demining technique (or combination of techniques) should be based in part on a consideration of the reliability of each method separately and in combination with other methods.

Method reliability

Obtaining information about the reliability of demining methods is difficult, because it is only possible to know the percentage of mines that have been removed from an area when the number present prior to clearance is known. The most accurate information on the reliability of clearance methods is gained in test situations where the number of mines and their location in an area is known. Alternatively, empirical evidence can be gained about the probable machine effectiveness if it is followed up by full clearance.

SWEDEC has conducted comprehensive testing on three different machine types, a summary of which follows. CROMAC has summarised the results of all mechanical actions in Croatia for 2002.

SWEDEC test results

SWEDEC did comparative testing on three machines in late 2002: the Scanjack twin flail (SJ), the Hydrema 910MCV (HD), and the Mine-Guzzler tiller (MG).[12]As part of the overall testing regime a probability test was conducted. Test objects similar to a PMA 2 anti-personnel blast mine and a TMM 1 anti-tank mine were used and fitted with live igniters only.

The test was carried out in the following soil types:

- *arable ground* degree of compaction: approx. 85 per cent of maximum;
- *sand* degree of compaction: approx. 90 per cent of maximum;
- *gravel* degree of compaction: approx. 94 per cent of maximum.

The test objects were laid with a metal plate so as to verify the status of the mine after clearing at one metre distances from each other at varying depths: 0, 10 and 20 centimetres. In each test bed and at each depth, 100 mines were used. The complete test schedule for each machine totalled 900 mines. The manufacturer selected both the speed and clearance depth of each machine.

Evaluation of the results was in accordance with:

- mines *destroyed* (only the plate was found or mine was broken up with less than 50 per cent of the explosive charge remaining);
- mines *separated* (more than 50 per cent of the explosive charge remaining, igniter detached);
- mines *damaged* (reduced functioning of mine or igniter); and
- mines *unaffected* (the mine still in working condition).

Figure 4 overleaf suggests that the choice of machine affects clearance performance. Each of the machines tested is quite different in its make-up and use (tool design and procedure). The Scanjack, a double flail machine, recorded the highest clearance performance results with one run. The other two machines had single system tools and also had one run at the test bed.

It could be that machine performance is also dependent on how many times it processes the ground. Further, when all three machines were tested on vegetated areas containing ten mines, the Mine-Guzzler out-performed the other two with a 100 per cent detonation rate, suggesting terrain conditions with vegetation can also have a significant influence.

Fig. 4. Percentage of anti-personnel and anti-tank mines destroyed, damaged and unaffected by each machine type across three soil types

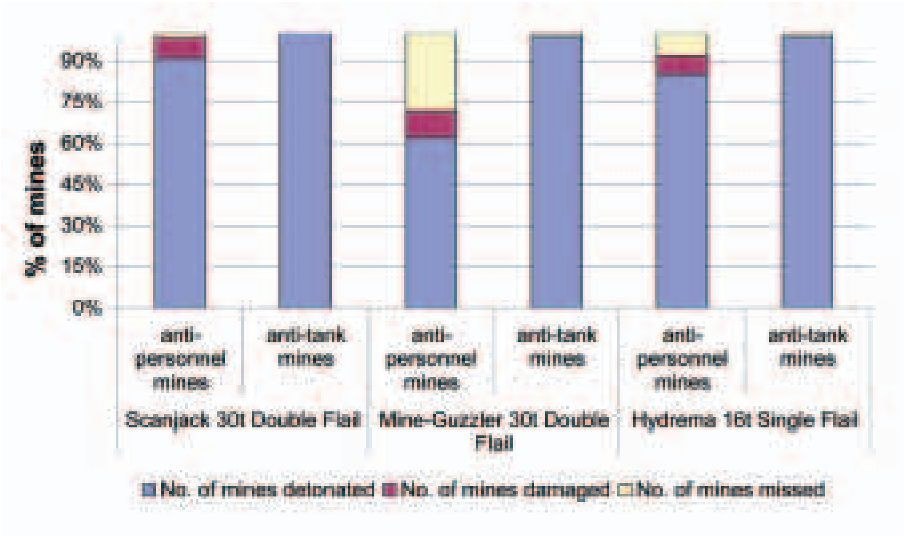


Figure 5 shows a significant effect of each machine type on detonation rates ($F_{(2, 17)} = 20.78$, $p < .001$), with the Mine-Guzzler detonating fewer mines overall than the other two machines. There was no effect of mine depth on detonation rate ($F_{(2, 17)} = 1.83$, $p > .05$) and no significant interaction between machine type and mine depth ($F_{(4, 17)} = 1.45$, $p > .05$). This means that while all three machines detonated mines with equal success at depths of 0, 10 and 20centimetres, the Hydrema and the Scanjack performed better overall than the Mine-Guzzler.

Fig. 5. Detonation percentages for each machine at mine depths of 0, 10 and 20 centimetres

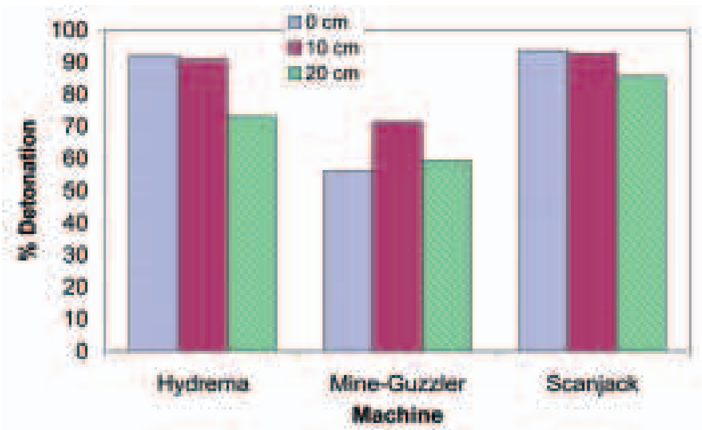


Figure 6 shows the results of operating the machines at different speeds. The Mine-Guzzler was operated at a much larger range of speeds than the other two machines and appeared to detonate a lower percentage of mines the faster it was used, although the negative trend was not significant ($r^s = -.17$, $p > .05$).

Fig. 6. Detonation percentages as a function of machine speed

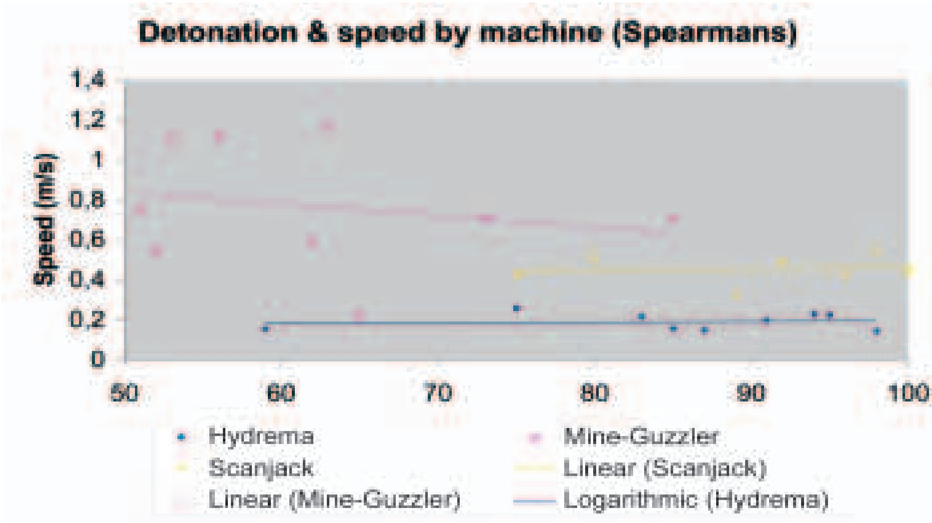
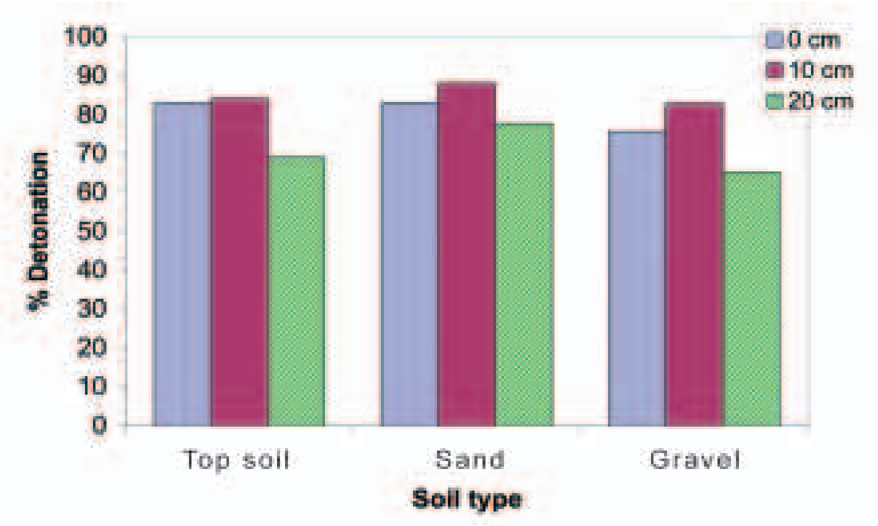


Figure 7 shows no significant effect of mine depth ($F_{(2, 17)} = 1.31$, $p > .05$) or soil type ($F_{(2, 17)} = 0.47$, $p > .05$) on the detonation rate. This means that the machines achieved similar detonation rates regardless of soil type and mine depth.

Fig. 7. Detonation percentages as a function of mine depth with three soil types



Using machines to reduce risk to a tolerable level requires that the performance of the machine is predictable. The results from the SWEDEC tests show little difference in detonation rate as a function of mine depth and soil type but some difference in detonation rate across machine type. However, many questions remain unanswered. There is very little knowledge about how a machine affects a mine. The use of a machine, therefore, should be based on its known capabilities and various features of the task site, such as terrain and parameters, which are reconciled with the ordnance and terrain threat at each task site.

CROMAC empirical data

The CROMAC data is a summary of all post-clearance project reports submitted to CROMAC in 2002.[13] When mine clearance machines are applied there are three different outcomes: mines are detonated, broken up or undamaged. Undamaged mines occurred only in areas where vegetation cutting machines were used. Figure 8 shows the effect of mechanical action on a range of mine types in Croatia. Table7 shows the number of mines found, detonated, damaged and unaffected by machines.

Fig. 8. Machine effect on mines encountered

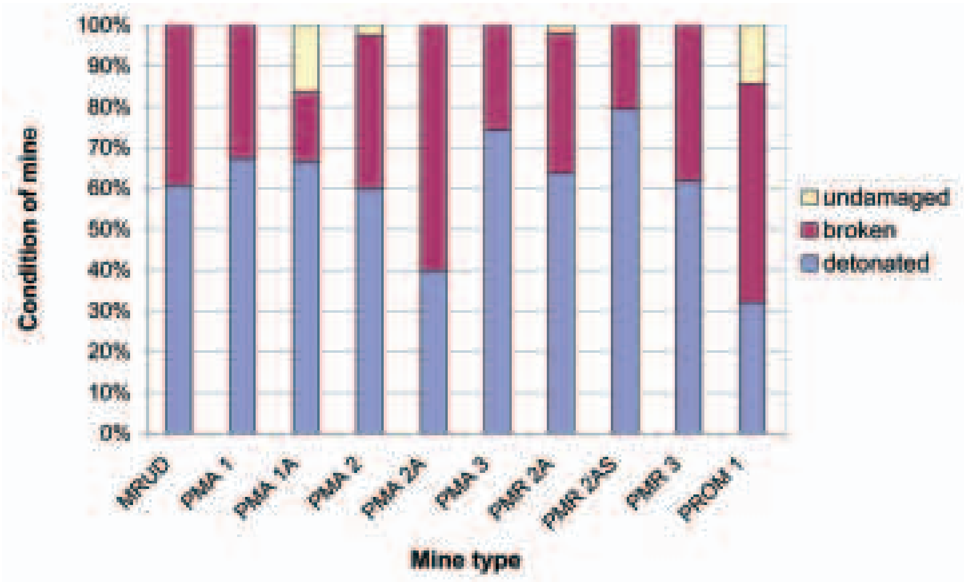


Table 7. Number of mines encountered, detonated, damaged and unaffected as a percentage of the total processed by machines

Mine condition	Total	Percentages
Number of mines encountered	2,004	100.00
Number of mines detonated	1,262	62.97
Number of mines damaged *(condition unspecified)*	669	33.38
Number of mines unaffected *(vegetation cutter only)*	73	3.65

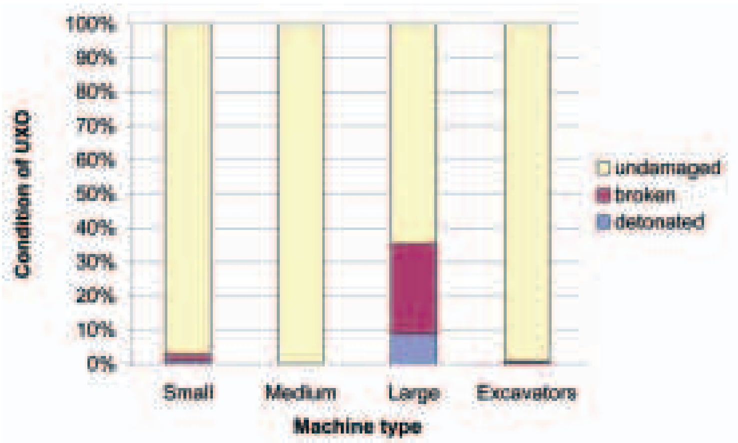
As Croatia legally requires an additional clearance method (a form of follow-up) when using a machine, information regarding each machine's effectiveness was obtained in the follow-up process. Sixty-three per cent of the mines were detonated by the machine. The 3.65 per cent which were undamaged are a result of the vegetation cutters not penetrating the ground. The condition of the mine may explain why some were not detonated. This information is not generally available to a demining organisation prior to conducting clearance operations. What the data does suggest is that the approximate number of remaining mines could be calculated, based on the number of mines detonated by the machine, as illustrated overleaf.

Table 8.

No. of mines in an area	Probable number of detonations
1	0
2	1
10	6
50	30
100	60

Additionally, an analysis of effects on UXO shows that machines are fairly ineffectual at detonating or breaking up all UXO (see Figure 9).

Fig. 9. Machine effect on UXO by machine type



The type and condition of the particular UXO would have an obvious influence on these results. As accurate knowledge regarding type and condition would also not be generally available to a demining organisation, UXO will remain a hazard after the use of a machine.

Machine follow-up

There are opportunities to tailor follow-up behind a machine. Full clearance applied behind a machine may not be justified in some scenarios. For example, if machines are deployed against a particular minefield and there are no detonations as a result, full clearance behind the machine may not be necessary. Based on the Croatian results, a very low number of mines may remain but be in a damaged state. An unknown number of UXO will also remain, but less intensive and more focused procedures can be applied to remove this threat, e.g. applying a battle area clearance (BAC) technique.

Broken-up mines — tolerable?

The CROMAC data also shows that mechanical violence results in either a detonation or a break-up (excluding vegetation cutters).[14] When a mine is broken up by a machine such as a flail or tiller, it is possible that a reasonably intact fuse remains with a portion of explosive attached to it (the explosive chain is still functional and therefore the item remains a threat). It is not known, however, whether a machine can further influence a change in mine condition if applied several times. Moreover, there is no clear definition between what constitutes a broken-up mine, which can be regarded as still operational (still a threat), from a mine which is broken up but considered non-operational (arguably no real threat).

Fig. 10. PROM 1 anti-personnel fragmentation mine after a flail had passed over it in Croatia. Note that the fuse is missing. What is required to initiate this mine now? Can it be left behind so that more dangerous items are dealt with in other areas first?

Fig. 11. M14 anti-personnel blast mine after a flail had passed over it in Lebanon. The firing pin is missing. What is required to initiate this mine now? What form of follow-up is now required to the area it was in; mechanical, manual or dogs?

Machine causing hazards to clearance teams?

In Southern Lebanon there is some concern that machines are leaving mines in a sensitive condition. The concern is that the fuse pin of the Israeli No 4 anti-personnel mine is being nudged further from its position, potentially making manual clearance of the mine after machine use more hazardous. Accidents have occurred in areas preceded by a flail and the machine has been identified as a possible contributor to the accident. However, accidents of a similar nature have also happened in areas not preceded by the machine. Nevertheless, the Mine Action Coordination Centre from Southern Lebanon is convinced that flails are contributing to the increased sensitivity of the mine.

The concern that flails are contributing to accidents has not been expressed in any other part of the world visited in this study. The effect of the machine could be particular to this mine, the terrain conditions, or both. This issue needs further investigation.

The HALO Trust Rock Crusher example (*see Annex 3*) highlights how the risk from mines broken up by machines is deemed tolerable. The mechanical process used has created high confidence that mine pieces exiting the machine do not pose a hazard.

The ability to predict whether a mechanical process will leave broken-up mines in a state that is generally accepted as non-operational could help tailor follow-up aimed at locating the type of explosive ordnance which remains operational. In some cases, no follow-up clearance may be required. In other cases, follow-up may involve the application of a machine several times or the application of different and mutually exclusive mechanical processes. There is little knowledge about, or investigation into, available options.

Conclusions, findings and recommendations

Conclusion 1.

How risk is measured and managed will be determined by tolerance to individual risk.

Findings

Risk-based approaches enable the development of appropriate procedures, protection and quality requirements and influence the clearance method to achieve the standard. In doing so, it is critical that both the probability and the impact of the risk are considered.

There needs to be a clear definition of what constitutes a mine that is still operational after machine violence from one that is not. Applying this definition of mine condition could have a dramatic effect on the levels of tolerable risk accepted in various countries, communities and circumstances. For example, pressure to release land may be so intense that non-operational mines could be left in an area until the clearance priority switches to clearing up this relatively limited residual risk.

Recommendation 1.

It should be accepted that the complete removal of risk cannot be assured in mine clearance (even though it is probably achieved in many cases) owing to the inaccuracy of information combined with the inherent limitations of clearance methods. This philosophy is standard among service-based industries worldwide and is reflected in the International Organization for Standardization (ISO) protocol. Furthermore, risk assessment methodologies, specific for mine clearance operations, need to be further developed and used at the field level.

Conclusion 2.

A detailed set of tolerable risk criteria established prior to clearance is a prerequisite for efficient humanitarian demining.

Findings

If every area of suspected land is treated similarly in terms of the level of risk that is tolerated, there is less room for tailor-made clearance operations to be selected. If the needs of the local people are understood prior to undertaking clearance, it may be possible to release land more efficiently using less intensive techniques, such as area reduction. Risk assessment is the tool used to make qualified decisions about how to optimise the use of scarce resources. It provides the basis for determining the risk involved in certain processes and justification for actions that have been undertaken.

Without a tolerable-risk criterion, the safest and the most easily defensible options for action are taken regardless of the circumstance and in many cases the cost. Establishing what is or is not tolerable before remedial action unleashes a range of possible actions that could prove more efficient and rational.

An international proscription against leaving components of broken-up mines *in situ* should not exist (currently one is recognised *de facto*). The IMAS stipulate that un-detonated mines must be removed in order to conform to international clearance standards. This reference does not appear to cover small mine fragments.[15] It is unlikely that mines/UXO broken-up sufficiently in the manner described above constitute a significant hazard. Saving time and therefore saving lives should not be limited by a hide-bound assertion that all fragments of explosive material must be removed.

Recommendation 2.

Leaving components of broken-up mines** in situ **should be considered as an option for clearance organisations, unless stipulated otherwise by the relevant mine action authority.

Conclusion 3.

The way to more effective and efficient demining is through acquiring more information about the hazards occupying an area rather than assuming a worst-case scenario.

Findings

Clearance techniques are applied once hazard information is obtained. However, a high degree of information uncertainty still exists on completion of a verbal-based assessment and as a result the worst-case scenario is assumed. This can result in unnecessarily time-consuming and expensive techniques being employed.

Machines are used as part of a risk-assessment process to acquire an additional layer of information of the actual risks in an area. This additional information can often result in the application of different and less intensive clearance techniques (as seen in Southern Lebanon example) or the elimination of areas requiring clearance (Thailand example — area reduction). In both these programmes, in specific circumstances an area does not receive subsequent follow-up clearance if the mechanical process has not indicated the presence of mines. Available information suggests that there is enormous scope for this approach.

It is well known that a reasonable proportion of the suspected mine/UXO contaminated areas have, through clearance, proven to contain no hazard whatsoever. It is important that these areas be identified through the use of a mechanical process so that expensive and time-consuming follow-up assets are set to work in areas "known" to contain mines.

Recommendation 3.

Machine development should focus on technology that is able to acquire as much information as possible about the minefield prior to clearance. These machines will probably need a variety of information-gathering tools to investigate a range of explosive-risk categories. There are numerous technological possibilities on the open market for this to happen in the field now. Furthermore, it should be recognised as an option for individual implementing agencies that, in areas where a machine has not indicated the presence of mines, no subsequent clearance method is required.

Conclusion 4.

Insufficient research has so far been conducted into the reliability and capability of mechanical clearance methods.

Findings

Studies by CROMAC and SWEDEC represent the first genuine attempt to quantify the capabilities and reliability of machines involved in the demining industry. The results of these studies, however, raise further questions.

Whenever machines are used in information-gathering or clearance-related activities, detailed records should be kept. The current standard of operational record-keeping is suppressing the growth of understanding in the use of machines.

Recommendation 4.

Records need to be far more thorough and should include:

a) details about the conditions in which mines were undamaged by machine use;

b) judgements of whether mines are still operational following machine use; and,

c) any trends or links between the machine type and its effect on various mine types, including variables like terrain and soil conditions.

Endnotes

1. Edmonson (2001:2).
2. ISO (1999a).
3. Health and Safety Executive (2001).
4. Pidgeon *et al.* (2003:33).
5. ISO (1999a).
6. ISO (1999b).
7. Health and Safety Executive (2001).
8. Brown (1999:2).
9. This corresponds to a GICHD study of operational needs identifying close-in detection and area reduction as the two activities that may have the greatest impact upon demining.
10. Phelan & Webb (2003).
11. Health and Safety Executive (2001).
12. Phelan & Webb (2003).
13. Reports are compiled by relevant demining organisations on the completion of each task. Reliability of data depends on how accurately this was done in each case.
14. In certain environments machines will miss some mines completely.
15. IMAS 09.10, Clearance Requirements, Edition 2, 2003.

Annex 1.

Southern Lebanon (Operation Emirates Solidarity)

This example shows how the probabilities of mines existing in an area affect follow-up clearance options.

Fig. 1. In Southern Lebanon, minefields are predominantly regular patterned minefields laid tactically or defensively by the Israeli Defence Force. There are a limited number of irregular minefields but some of these areas are suspected not to contain mines at all.

Both the Israeli Defence Force and local militia kept records of their mine-laying and this information was made available to the Mine Action Coordination Centre.

The approach adopted in Southern Lebanon replicates the Kosovo experience and approach in many ways. Manual teams are targeted in areas known to contain mines and not in areas where evidence of mines is not convincing. Machines are used in these areas.

In addition to ground preparation and area reduction, machines (usually small and medium-sized flails) are used to eliminate low probability areas and increase confidence that no hazardous items are present. Generally, where there is a reasonable degree of confidence that mines are not present in a given area, machines are deployed to confirm this or otherwise inform the MACC's Planning Officer. The machine *may or may not* be followed up by a clearance method, but this decision relies on discussions between the operator and the Planning Officer.

When a machine indicates the presence of a mine in areas of low probability (i.e. a mine detonates), an area of 100 square metres is then cleared from the seat of the detonation. The fact that follow-up is restricted to a specific area within the suspected area and not the entire area is significant. Information gained by the machine combined with existing information regarding the minefield affects the way the hazard is approached.

The general probability table strongly shows that the number of areas where area reduction following machine use can be applied is very high. Currently, this and similar approaches are rare.

Annex 2.

Mines Advisory Group (MAG) in Viet Nam

This example shows that there is doubt about a machine's vulnerability to a perceived risk. Information can be obtained to provide high confidence of the actual risks. The machines can then be used to expedite clearance.

In Viet Nam, MAG cleared a 120-hectare site in Dong Ha, Quang Tri Province. This site was an abandoned U.S. firebase in the former Demilitarised Zone. The site was known to be protected by a five-panel mine belt (25 rows) which surrounded the base.

After the war the Vietnamese Army undertook some limited clearance which was later abandoned. This complicated clearance because UXO, scrap and barbed wire were bulldozed into holes and buried. The initial approach was to clear this land using manual teams and standard detection methods (only 12 lanes were initially available). This method soon proved unproductive.

The initial concerns regarding the use of machines centred on the belief that the UXO to be cleared would be too sensitive to mechanical action.

Increased information was crucial to the implementation of a range of options and to investigate whether machines could be used. Information was gained by using the manual lanes around the site in a Technical Survey role (breaching lanes). After three months, sufficient information was gathered to build a picture of what risk types were evident on the ground. The site was then divided. Different clearance methods were designed according to the survey information, with each category of threat treated differently.

Mine clearance

Once identified, the mine panels were cleared using traditional manual clearance methods. Additionally, the safety distances were reduced from 25 to 15 metres between each man due to the low explosive content of the mines (M14 blast anti-personnel mines).

The entire area was searched using large loop detectors, often after the ground was initially cleared with conventional manual techniques and with machines (a Mk II screening unit).

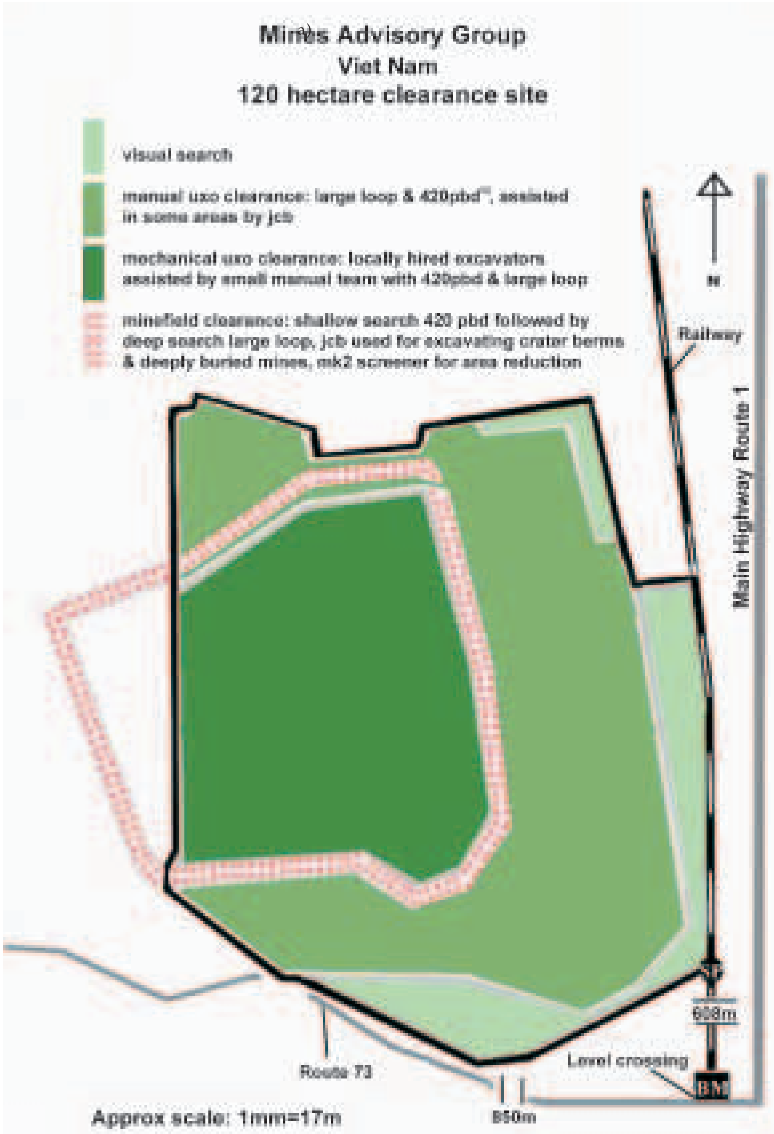
Fig. 1. Deep search

Information from the technical survey confirmed the location of the mines and that no mines were expected inside the firebase. Additionally, the condition and nature of the UXO meant mechanical excavation would be possible (abandoned UXO only, which had not been fired). Locally-hired excavators were used to dig trenches within the firebase. The spoil was searched with detectors before being replaced. The machines excavating for buried UXO were not armoured. The company the plant was hired from had many previous experiences of unearthing UXO on construction tasks and the risk was thus deemed normal and tolerable.

Fig. 2. Mk II screening unit.

On more static sites a large MkII screening unit was deployed to process the soil. The initial idea was to use the Screener as part of the trenching method. However, in this role it had to be moved an impractical number of times. It was then used on fixed locations in the minefield, clearance of pits and in areas of high metal contamination. This machine system is susceptible to UXO with centrifugal fusing. The technical survey established that this risk did not exist and the machine was used without incident. The figure below shows how the different areas were cleared.

Fig. 3. Illustration of the different methods used by MAG in Viet Nam



a) Ebinger EBEX® 420 pbd.

Some of the area only received a visual inspection as it was within the area requiring clearance but the probability of contamination was considered very low. A typical response to this type of task in humanitarian demining would be manual clearance over the entire site and an excavation process in selected areas where buried ordnance was known to be. This is often the case despite the time frame and costs involved. In fact, this was the initial response by MAG Viet Nam until the Senior Technical Adviser decided that clearance could be expedited if more information was gathered about the site and actually used.

Annex 3.

The rock crusher

This example shows how the risk from broken-up mines after machine use is deemed tolerable.

The HALO Trust operates rock crusher machines as full clearance tools in Afghanistan, Georgia (Abkhazia) and Sri Lanka. Mine-contaminated soil is fed into a hopper that transports the soil to a chamber containing hammers which break up all crushable objects to a uniform size (as used in quarries). The size of particles exiting the machine is adjustable.

When conducting mine clearance operations, the gap between the impact hammer and exit shaft is set so that the smallest mine cannot escape without being broken up. Once the soil has left the machine it is considered contamination free, as the machine both detonates and breaks up mines. The soil is then either left in a pile or it is replaced. No process is required to confirm that the mines that have been broken up still represent a hazard, because the machine has proven its ability to consistently break up mines to the degree that they do not represent an additional hazard.

Another interesting aspect of the rock crusher is that it distinguishes between hard metal-cased mines/UXO and plastic or blast mines. The latter are the only items that make it to the crushing chamber, the former are separated by a metal detector situated between the hopper and crushing chamber. When a large metal object passes over the detector the machine stops, and the conveyor belt is reversed so that the item spills out the other end of the machine to be destroyed *in situ*. The precedence here is that broken-up blast mines (usually plastic) can be considered a tolerable risk if the machine or process has proven to be capable of breaking them up to the degree that they pose no real hazard. The parameters for this, however, have not been established.

Annex 4.

Kosovo: establishing tolerable risk

This example highlights the implications of establishing tolerable risk early.

When the Mine Action Coordination Centre in Kosovo conducted the initial mission analysis, it was aware that the problem of dealing with mine/UXO contamination after a conflict in Europe was nothing new. The MACC therefore began to enquire about the current scale of the problem in other parts of Europe (e.g. the United Kingdom). This led to the Mine Action Coordination Centre's aim to "*replicate the situation in the rest of Europe*"[1] which still suffers from explosive contamination in various forms.

This approach is now commonly referred to as an "impact free" strategy as opposed to a "mine free" strategy. To manually clear the 360 square kilometres of suspected land in Kosovo would prolong the task by 30 to 50 years.[2]

The Kosovo approach resulted in manual assets being deployed only in areas known to contain mines. Machines were used in areas where more information about the existence of mines was needed: if there were no indications that mines were present, the area was considered clear without any further follow-up clearance methods (other programmes insist on follow-up in any scenario).

1. J. Flanagan, July 2003, personal communication.
2. J. Flanagan, 2000.

Chapter 3.

Mechanical application to area reduction

Summary

In patterned minefields (ones in which mines are laid in rows or clusters), machines are used to identify the presence of mines (i.e. the start of a row). In non-patterned mined areas, machines are used to identify areas containing mines. The potential for machines to reduce the amount of land considered contaminated with mines and UXO is enormous.
Indeed, productivity results in the two case studies in this chapter show that investment in an area reduction machine results in a high return when compared to the other clearance methods used (MDD and manual).
Eliminating non-hazardous areas where no evidence of a threat is found through systematic mechanical area reduction has clear advantages. It allows mine clearance resources to be deployed to where real threats are located, eliminating huge suspect areas that do not contain mines.
A more efficient approach to humanitarian demining would therefore be, where topography allows, to confirm the presence of mines through appropriate application of mechanical technology and then to reassess which areas actually need clearance.

Introduction

Background

In Chapter 2, we looked at the potential for mechanical systems to be employed for risk reduction. In this chapter, we look at the allied topic of area reduction as part of the technical survey process.[1] Area reduction is defined by the IMAS as "*the process through which the initial area indicated as contaminated is reduced to a smaller area*". Generally, the reduction is conducted on the basis of collecting more reliable information on the extent of the hazardous area.

Area reduction using machines is a relatively new concept with no formal or fully understood techniques or procedures yet established. Demining organisations find that the majority of land cleared does not actually contain mines. There is a strong need to identify actual contaminated areas quickly and accurately.

Minefields in general can be placed in two distinctive categories: patterned and non-patterned minefields. A patterned minefield is one in which mines are laid in rows or clusters: such minefields are also known as "defensive" minefields and are used to protect valuable resources and military positions. When one mine is detonated or otherwise located, it can indicate the location of the remaining mines. Thus, information gained about the presence of one or more mines can be used to determine the presence of other mines in the area. Usually, a high number of mines are laid in a patterned minefield.

A non-patterned minefield, however, can be offensive or defensive. Often these types of minefields (or mined areas) are a result of a low intensity conflict over a long period of time, where mines have been used as individual weapons. When one mine has been located in a non-patterned minefield its location cannot be used to determine the location of other mines in the area, although it is not unusual to find high concentrations of mines that are non-patterned.

Terms of reference

The sub-studies that form the basis of this chapter aimed to assess techniques used in area reduction operations by machine and to establish a framework for appropriate mechanical application to a minefield.

The chapter bases its conclusions on the use of machines in two minefield scenarios. The first case study is based on area reduction in Abkhazia by The HALO Trust in a patterned minefield scenario.

The second case study is based on area reduction techniques used in Thailand by the Thai Mine Action Centre (TMAC) in a non-patterned minefield scenario. The procedures used in the TMAC case study are defined as both risk reduction and area reduction, although the case study only focuses on area reduction.

Case study 1: Area reduction of patterned minefields in Abkhazia

Introduction

This case study is based on area reduction of patterned minefields in Abkhazia between 1999 and 2000 (area reduction has been undertaken there since 1998). It covers clearance operations along the banks of the Gumista river, which lies within the city limits of Sukhumi City.

Mine contamination in Abkhazia

There are basically three different minefield scenarios in Abkhazia. First, Georgian forces laid belts of mines at intervals along a seven-kilometre stretch of the southern banks of the Gumista river, when they occupied Sukhumi. The Georgians carefully mapped their minefields, laying dense mine belts of both PMN and PMN2 anti-personnel mines, no more than one metre apart, as well as the TM series of anti-tank mines (TM46, TM57) in specific places.

Second, Ochamchire province in central Abkhazia was the scene of the surprise attacks by the Abkhazians and as such no real frontline was established. The minefields in this area therefore were not mapped, are not well known and contain a non-patterned mix of Soviet-era anti-personnel and anti-tank mines and locally produced improvised mines and explosive devices.

Third, the Abkhazians laid minefields along its then newly established border with Georgia, notably along the northern banks of the Inguri river. The mines were generally laid in rows or patterns but the accuracy of these minefields is not as good as those laid along the Gumista river.

Fig. 1. Abkhazia, Republic of Georgia

Minefield conditions

Initially, mine clearance in Abkhazia was conducted along both the Gumista and Inguri rivers. The metal contamination in these areas was extremely high, particularly along the Gumista, as it was both a light industrial area and a frontline where frequent exchanges of small arms ammunition, light mortars and rocket-propelled grenades took place. Both rivers, however, are equally affected by the granite-like boulders (many ferrous) which dominate the sub-soil, so much so that the ground is best described as granite boulder with a thin layer of topsoil.

These two dominating factors — high metal contamination and rocky ground — make manual mine clearance techniques extremely slow. In fact, daily manual clearance rates along the Gumista river rarely exceeded five metres per lane and many lanes were manually excavated. In addition, mine clearance generally takes place during only ten months of the year as snow and frozen ground during the height of the winter season make many clearance options impractical.

Fig. 2. Ground conditions along the Gumista river.

Terrain that was being demined along the Gumista river is generally flat, even including an old football field that was mined. There are areas of overgrown grass, shrubs and blackberry bushes.

Area reduction in Abkhazia

The rationale

IMAS defines two types of surveys: the general mine action assessment and the technical survey. The purpose of the first is to assess the scale and impact of the landmine problem on a country and individual communities and is generally based on verbal and documented information. The technical survey is also based, among other things, on verbal and documented information but with the aim of collecting sufficient information to enable the clearance requirement to be more accurately defined by doing something physically to the area.

Fig. 3. A typical, obstacle-strewn manual demining lane on the southern bank of the Gumista river. Note the animal bones in foreground.

The process through which the land identified in the general mine action assessment — often referred to as a Suspected Hazardous Area (SHA) — is subsequently reduced to a smaller area is known as area reduction. Area reduction is an integral part of the technical survey process.

The use of machines to initiate some of the mines provides an organisation with a greater degree of information about where the mines exactly are and what areas need to be cancelled out.

At the time of initiating their operations, HALO was given the maps of the Georgian minefields along the Gumista river, which provided details of the location of mine belts in relation to each other and other key reference points, as well as the type and number of mines laid. But HALO did not know how accurate the information was, so it had to test it.

The clearance options

HALO conducted a risk assessment focusing on how they could use the information they had. Three options were apparent. The first was to deploy manual survey lanes to locate the mine belts and then subsequently clear the belts. This would mean the mine belt environs would receive limited verification. The risk of randomly laid mines was unknown and therefore needed investigation. The second option was to deploy a machine that would both identify the dense mine belts and provide a method of proving the ground in and around the mine belts (testing the information). The third was to simply manually clear the entire area initially identified (also thereby testing the information).

The decision

HALO chose the second option. The risk assessment recognised that the belts of mines represented the true minefield, but the environs needed a degree of verification. Manual clearance rates were extremely slow and a demining lane would not provide the coverage needed to make contact with the front row of mines in the belts. Mines were laid one to two metres apart and as the typical demining lane is only one metre across, it may clear land between mines and not locate the rows.

HALO chose to conduct area reduction operations (to indicate mine belts and verify areas) with a Pearson Engineering Area Reduction Roller[2] mounted on the front of an armoured Belarus 1507 Tractor or Volvo 4400 front-end loader. The roller is made up of heavy-segmented discs, each five centimetres wide. The discs float on a central axle and thus are able to contour the ground surface extending an even down-force of about 50 kilograms.

Area reduction procedure

The following four factors contributed to the decision to use the Pearson:

1. Even though the Pearson segmented roller is best used on reasonably flat ground or over features easily negotiated by the prime mover, it has a limited ability to overcome surface undulations.

2. In areas that have become overgrown a vegetation cutting attachment is used to reduce the vegetation back to ground level. If the vegetation were merely pushed over, there would be a buffering effect that could lead to some mines not detonating.

3. Area reduction does not take place in areas suspected of containing anti-tank mines. The primary threat in this case was limited to PMN and PMN-2 anti-personnel mines. HALO has found that the roller is at least 90 per cent effective against both these types of anti-personnel mine. The mines must, however, be in working order and have been laid properly (correct depth and position so as to be initiated).[3]

4. Moisture in the soil appears to influence the effectiveness of the roller. If the ground is too soft, a concern is that mines could be pushed further in the ground and, as a result, will not detonate. Although the legitimacy of this concern has not been confirmed in trials, the perception influences the areas in which the roller has been used.

Fig 4. Pearson

Fig. 5. Roller detonation

Method

The HALO Trust method of reducing areas is divided into three parts. First, the dimensions of the mine belts and the start-line for the manual clearance need to be established. Second, areas between the start-line (boundary of suspect area) and the newly established manual clearance start-line need to be verified to be confident that no mines are present. Third, after clearance of the mine rows are completed by manual teams, to a point 10 metres beyond the final row, rolling recommences to verify the remaining ground between the end of the manual clearance and the far end of the minefield.

The tractor/roller drives forward from the established start-line towards the suspected belt of mines. On detonating a mine, the roller reverses for 10 metres and the operator then lays a marker. It then moves further back to the start-line, then across about 25 metres (less if belts are not linear) and drives again until a mine is detonated. The operator then lays another marker and this continues until the roller has identified the entire mine belt front, plus indicating side dimensions.

The markers then form the starting point for the subsequent manual demining lanes that clear through and 10 metres past the mine belt. The area between the markers and initial start-line is then rolled four times in four different and opposing directions (*Fig. 1*). Provided there are no mine detonations, this area is cancelled out and receives no further clearance. If, however, a detonation has occurred the area concerned is then deemed to be part of the minefield and subsequently cleared.

Fig. 6. Phase one and two of the area reduction operation

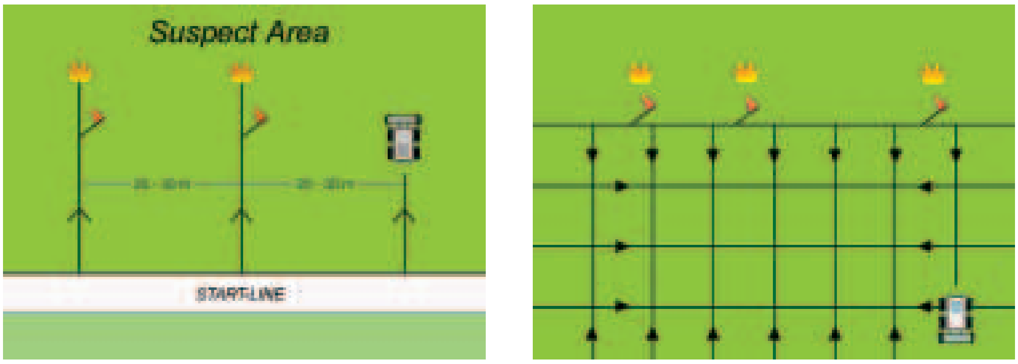
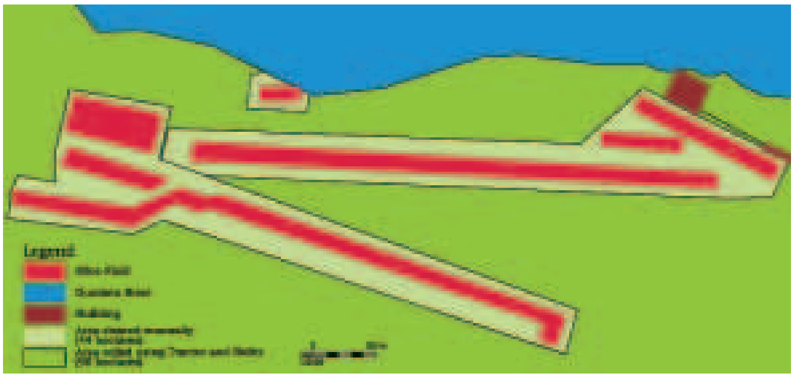


Fig. 7. Use of the roller on the banks of the Gumista river



Method effectiveness

How effective was the mechanical area reduction option?

Gumista river

Figure 7 illustrates the use of the roller on one task on the banks of the Gumista river. The threat was from PMN-2 and PMN anti-personnel mines only and no random mines were actually found in the areas reduced by the roller. On this particular task, 49,000 square metres were cleared manually and 95,000 square metres of land were cancelled out.

The project results were as follows:[4]

Table 1.

Project cost increase (12 month period)	Project productivity increase (12 month period)
39 per cent	323 per cent

These good results are a combination of low costs and high productivity. The mechanical area reduction costs were minimised by armouring a heavy tractor which could be purchased and maintained in the region. High productivity was achieved by the machine as the ground was open and flat, especially along the banks of the Gumista river.

Case study 2: Area reduction of non-patterned minefields in Thailand

Mine and UXO contamination in Thailand

Landmines have been used in Thailand over the past 40 years by conventional and guerrilla armies on all four of Thailand's borders. Understanding the need to quantify the mine problem, TMAC commissioned a landmine impact survey to determine the scope and impact of the mine problem in Thailand. The survey, which was completed in April 2001, identified a total of 933 contaminated areas covering an estimated landmass of 2,560 square kilometres. This was an area more than three times greater than that previously estimated by the Thai army.

Twenty-seven provinces on Thailand's borders are affected by landmines and UXO, impacting on some 530 communities. These are mostly poor rural villages surviving on agriculture and foraging amid contaminated border areas. More than 500,000 Thai people's daily lives are directly affected by landmines and UXO.

The challenges to demining

Unfortunately, it is not known how many mines were laid or where they were laid. Only information on general locations or approximate boundaries of contaminated areas is available. Further, since survey data was obtained from stand-off field observation without circumnavigation of suspected areas, spatial dimensions and densities of mine contamination are also not recorded. Therefore, given that large areas of suspected hazardous land endanger Thai citizens and deny productive use of land, area reduction is the primary focus of risk reduction efforts.

The difficulties inherent in manual area reduction, already relatively slow by its nature, are compounded by Thailand's terrain and environment along the border areas. Typically, all four border areas are primarily rough tropical terrain with seasonal weather extremes that complicate clearance efforts. Thick tree-canopy jungle, mountainous areas, laterite soils and tropical monsoons with their associated diseases, all contribute to the difficult challenges facing both deminers in the field and TMAC planners.

All categories of anti-personnel mines, anti-tank mines and booby-traps are present in Thailand. Particularly noteworthy are the low-metal-content mines

Figure 8.

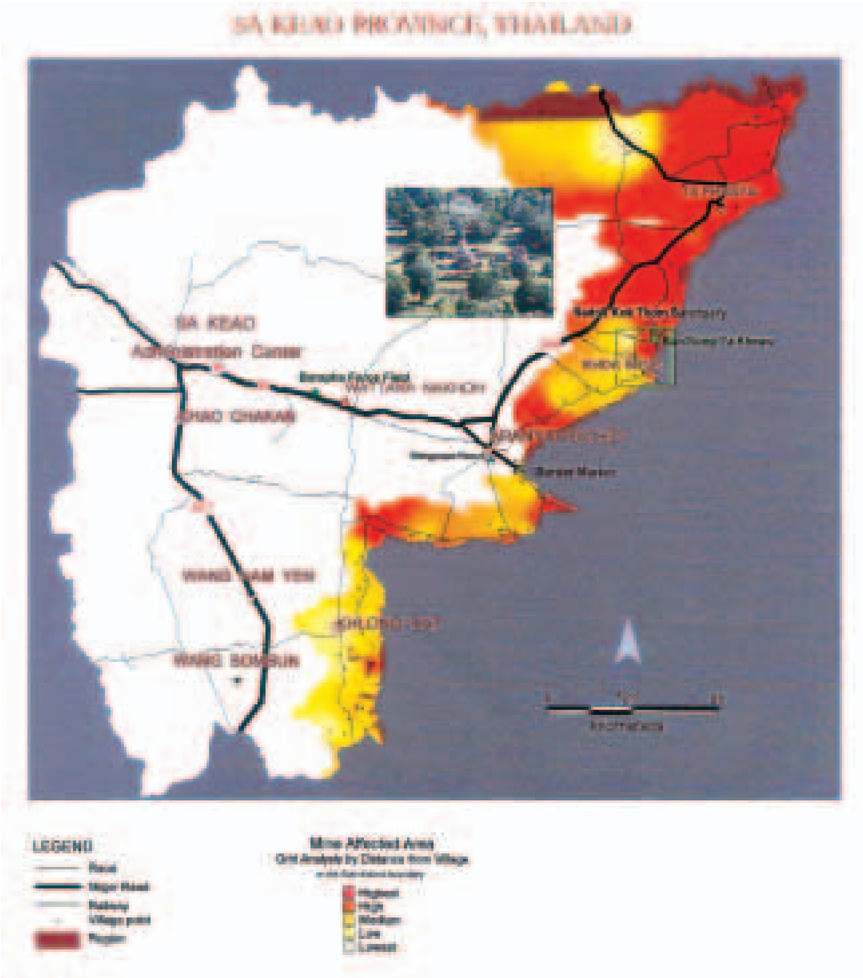
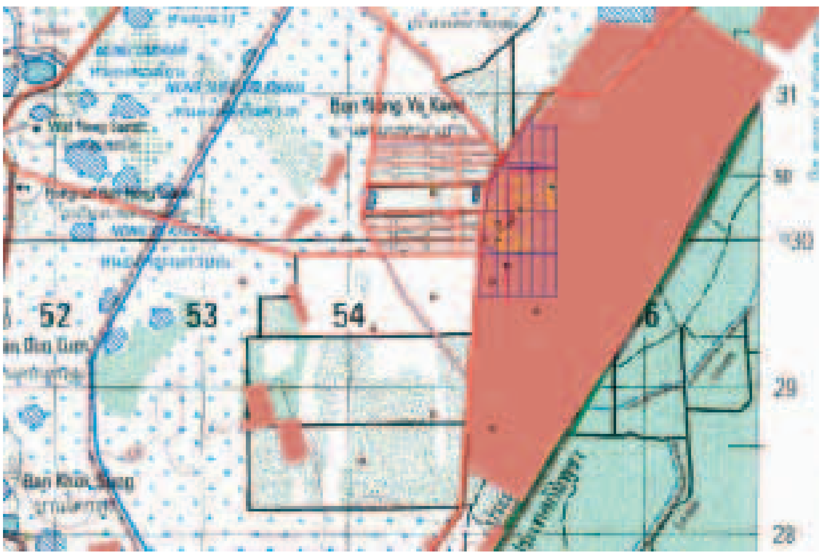


Figure 9. Nong Ya Khao village



which are difficult to detect with currently available metal detectors. In addition, as is typical of former battlefields, many items of UXO are regularly found during mine clearance operations — the UXO-to-mine ratio averages ten to one in Thailand.

Significantly, large portions of the border areas were under repeated artillery and mortar fire for some 20 years, contributing millions of pieces of metal fragmentation (shrapnel) in dense concentrations, further complicating clearance efforts. The lethal cocktail of low-metal-content landmines mixed with UXO is concealed in jungle conditions and buried in high ferrous content soil (laterite). Laterite masks or limits current metal detection technology's capability to locate these hazards.

Each report of a "hit" by either mine detection dog or mine detector must of course be investigated; in some areas, deminers have been getting up to 4-5 "hits" per square metre and each hit requires a slow, painstaking effort to determine the nature and lethality of the item that has caused it (almost all hits are false).

All of these conditions are, individually, difficult for demining; in combination, they make the job even more difficult and resource intensive. Thai deminers work to destroy mines and UXO all year round, in spite of monsoon conditions during nearly half the year and high temperatures almost the whole year. The aim of this effort is to provide land that meets the user requirements, primarily farmers.

In the face of these difficult conditions, TMAC took steps to introduce fully integrated mechanical, MDD and manual demining methods into its operations. The development of "Mined Area and Risk Reduction of Non-Patterned Mined Areas" operations using available technology is TMAC's operational strategy to address the huge mined areas on its borders. It is important to note that these integrated methods are still under development and there is a need to further improve area reduction methodologies and determine residual risks.

We will now look at the case of one village, Nong Ya Khao, along the border with Cambodia, to see how TMAC's operational methodology works in practice.

A long history of contamination

The village is on the site of a former refugee camp which housed Khmers from Cambodia escaping both the Vietnamese invasion and Khmer Rouge.

Resistance groups and the Thai Army used landmines to protect the area, adding to the lethal mixture of the nearby K-5 border mine belt. Frequent incursions by Vietnamese and Cambodian troops laying mines and clashing with the resistance forces have made the location of landmines extremely difficult at best. The net result is a very contaminated mined area without identifiable boundaries, generating fear and causing mine accidents among the returning Thai population.

Prior to the Landmine Impact Survey, information on the mined areas around the village was sketchy at best. Six villagers fell victim to mines attempting to clear land for agriculture inside the former refugee camp area. The village is bounded on the east side by "Siphen Road" an asphalt road built in 1996 without mine clearance. The east side of this road is considered mined by the villagers. Engineers who constructed the road claimed that mines were encountered but believe that most of the mines were pushed into the verges by bulldozers.

Vegetation includes both hard and soft wood up to 50 centimetres in diameter with the majority of trees less than 10 centimetres in diameter and up to 10 metres in height. Impenetrable bamboo thickets of all types dot the terrain. The area contains old termite mounds — steep, hard soil, honeycombed with tunnels, averaging three to five metres in base diameter with heights of up to three metres and covered in thick vegetation. These formidable obstacles are found in densities of up to 10 per hectare. The significance of these hills is their inherent tactical value. Mines are placed to deny cover to combatants. Mines were laid amidst termite hills which subsequently grew over them.

This site was used for 16 years by approximately 40,000 refugees who left a significant amount of metal contamination, making the area virtually one big rubbish dump. Heavy shelling in the area added metal fragments impregnated with explosive traces, introducing additional difficulties for using MDDs.

The explosive threat

A broad range of known anti-personnel mines contaminate the border areas. Local mine victims are primarily lower-limb amputees, suggesting a preponderance of pressure-activated anti-personnel blast mines. Villagers have identified Type 72 blast mines and Type 69 bounding fragmentation mines from identification charts they were shown. Mines laid and cleared by the Royal Thai Army included M14 and M16 anti-personnel mines and, to the west of the refugee camp along a former anti-tank ditch, M15 anti-tank mines. These mines were all expected to be encountered.

In addition, since Vietnamese and Cambodian forces in the area employed a full arsenal of conventional weapons during combat, small arms munitions, grenades, rockets, mortars and artillery munitions of all calibres were also expected.

Available information suggested a significant anti-tank mine threat on the periphery of the suspect area, with anti-personnel mines and large UXO within the affected mined areas.

Operational methodology

TMAC determined a need to address area and risk reduction actions through an integrated approach using manual deminers, MDDs and mechanical assistance in combined team efforts. Incremental introduction of trained teams and resources took several months to complete, allowing valuable experience for the teams in both the terrain and threat environments.

Manual teams were trained for clearance operations in dense jungle conditions using standard manual clearance equipment and methods. The teams were withdrawn from operations and integrated with MDD teams to operate under similar conditions.

Hampered by the thick vegetation and the severe nature of the metal contamination, operations were grindingly slow. MDD teams required continuous retraining to operate in the highly contaminated areas which confused both the dogs and handlers. Eventually, mechanical assistance was introduced, enhancing performance dramatically by removing vegetation, metal fragments and preparing the ground for MDD teams and manual deminers.

Demining by "rai" blocks

Land measurement in Thailand is based on an ancient system. The "rai" is a standard measurement for land, measuring 40 by 40 metres, a total of 1,600 square metres. The rai represents the amount of land needed for a family to build a house and garden to sustain a living; additional land is needed to produce surplus or cash crops.

Each farmer living in Nong Ya Khao village is allotted a 14-rai plot to cultivate crops supporting their families. This block of land measures 80 by 280 metres (or 22,400 square metres) a convenient size dividing the suspect area into manageable parcels. Unfortunately, these blocks of land were allocated in a mined area where a number of villagers lost their legs. Based on the village system of 14-rai blocks an operational plan was developed to clear priority blocks in an orderly process.

Manual effort

Initially, manual deminers were deployed to develop basic skills and create team cohesion. Using the asphalt road as a safe baseline, clearance lanes were laid out 25 metres apart along the road penetrating into the heavily vegetated mined area. With thick vegetation pressing on to the road verges and heavy concentrations of metal scrap mixed with mines, progress was slow.

Employing one-man drills using standard hand vegetation cutting tools, probing and excavation tools and a metal detector, proved adequate for basic operations. Heavy vegetation and high metal contamination in the suspected mined area reduced manual demining progress considerably.

Manual vegetation clearance per square metre averaged between five and 10 minutes of effort. Sweeping and surface identification using metal detectors took a similar amount of time. Metal detectors were locating metal fragments up to 15 centimetres in depth owing to the high ferrous content of the soil. Individual metal hits ranged from four to 10 hits per square metre. Averaging five hits per square metre made manual clearance and excavation work very laborious and time consuming.

Probing and excavation of targets down to a maximum depth of approximately 15 centimetres in dry season conditions with hard-baked soil is back-breaking work. Excavations as a response to signals from the metal detector take up to and beyond 30 minutes for each target to be located and removed. Locating mines or UXO under these conditions negatively affected progress.

For example, a single 30-man platoon[5] employing 12 working lanes for eight hours a day was able to produce a maximum of 120 cleared square metres a day, although average progress was normally only 80 square metres. Over a 20-working-day period (one month's operations) 1,600 square metres were cleared.

Manual demining with MDD teams in support

Following the training and integration of MDD teams to support the manual deminers the production of cleared areas increased. The full use of MDD teams is not possible in heavy vegetation. Manually cleared lanes were therefore used as a baseline to remove vegetation in the adjacent lanes allowing the deployment of MDD teams. MDDs indications were followed up by manual deminers operating from the flank of the cleared lanes.

The use of MDD teams negated the requirement to investigate every metal indication in the lanes. This dramatically reduced the areas to be swept and excavated manually.

MDD teams increased productivity by reducing the number of metal fragments to investigate. However, MDD teams are not productive while waiting for manual deminers to clear vegetation with hand-held cutting tools.

MDD teams still indicated a high number of shell and mortar fragments in the suspect area. Additional training was required to condition animal behaviour where heavy concentrations of metal fragments were mixed with mines. MDD teams can be conditioned to react to mines while passing over metal fragments, although dog interest in metal fragments could not be totally eradicated. Locating metal fragments that indicate high concentrations of explosive residue is a positive MDD team reaction but is not ideal for productivity.

During this operation, three MDD teams (each with two dogs, two handlers and one superviser) were deployed to support half a platoon (18 people, including 12 deminers) or 12 working lanes.[6]

Productivity after MDD team corrective training cleared 300 square metres a day. Over a 20-day cycle, clearance of 3,000 square metres was typically achieved. Clearance results are best when MDD teams identify explosive-trace metal fragmentation no more than once every three to five metres.

This operation therefore doubled production using half the number of deminers.

Mechanical area reduction

The mechanical system employed in these operations was again based on the Pearson Survivable Demining Tractor and Tools (SDTT).[7] Introduction of mechanical assistance to area reduction changed the deployment capabilities of both manual and MDD teams. Full use of the SDTT system allowed complete coverage of the block area in a series of mechanical applications identifying the presence or absence of mines and preparing the terrain for further investigation.

After repeated trials to maximise area reduction capacity, a simple system was developed to provide maximum assurance that all the ground had been covered. It combined mine clearance (the physical destruction of the mines as opposed to their detection) and area reduction operations.

The SDTT tractor chassis, with seven tool attachments, began by making a series of 16 passes to ensure that any landmines present were initiated or identified. The attachments included a tree extractor, a vegetation slasher, a vegetation mower, a light and heavy cultivator, a grabber, a segmented roller and a tow-behind magnet. The process of applying these tools is described in detail below.

Difficult terrain conditions with heavy vegetation cover, high-metal-content contamination and hard ground matched with the SDTT system capacity, resulted in a process where 20 working days of operations by the combined team produced the first area-reduced block. In reality, machines do not work a full eight-hour day, rather three to four hours each day.

During the dry season, five to 10 working days were needed for the mechanical operation due to vegetation thickness and soil hardness. A further 10 days are necessary for the MDD teams and manual deminers to follow up with 100 per cent coverage of the block area, when evidence of mines or UXO was confirmed by the machines.

If a block area had no evidence of mines then the block was 10 per cent checked by MDD teams and manual deminers using standard clearance methods. This took only two or three days. During a 10 per cent check, areas are selected where machines or attachments did not perform well or other areas where mines are likely to be found.

Once the process started, moving in sequence an average of 20 working days was required to area-reduce one block. The workforce for these operations was considerably smaller, totalling 23 personnel as follows:

Table 2.

Integrated mechanical/mine dog/manual team		
	Team commander	
	Team deputy	
Mechanical assistance section:		
	Mechanical unit commander	
	2 SDTT x 2	
	2 SDTT operators	
MDD section:		
	4 MDD teams	
	2 MDD supervisors	
	8 mine dogs	
	8 dog handlers	
Manual demining team		
	Supervisor	
	6 deminers	
Medical		
	One medic	**Total: 23 people**

The emphasis of this operation was "horsepower" over "manpower", capitalising on the advantage of mechanised systems for removing obstacles and preparing the way for MDD teams and manual deminers.

Summary of performance[8]

Manual mine clearance operations and operations supported by MDD teams

Manual demining was conducted at a base rate of 1,600 square metres in a 20-day period or a slow clearance rate of 80 square metres per day in very high metal contamination and heavy vegetation conditions. These operations are clearance tasks, which only manual deminers can perform due to inherent limited technical performance of metal detectors and hand-tools used to locate mines or UXO.

Adding MDD teams to the procedure increases performance. However the process is still basic clearance operations. Area reduction is enhanced by the mine dog capability to focus on explosive vapours instead of non-hazardous metal scrap as located by metal detectors.

MDD teams supporting manual clearance where deminers remove vegetation manually allows limited deployment of the MDD team. However, clearance capacity increased to 3,000 square metres per 20-day period. This represents an 87.5 per cent increase in productivity over standard manual methods.

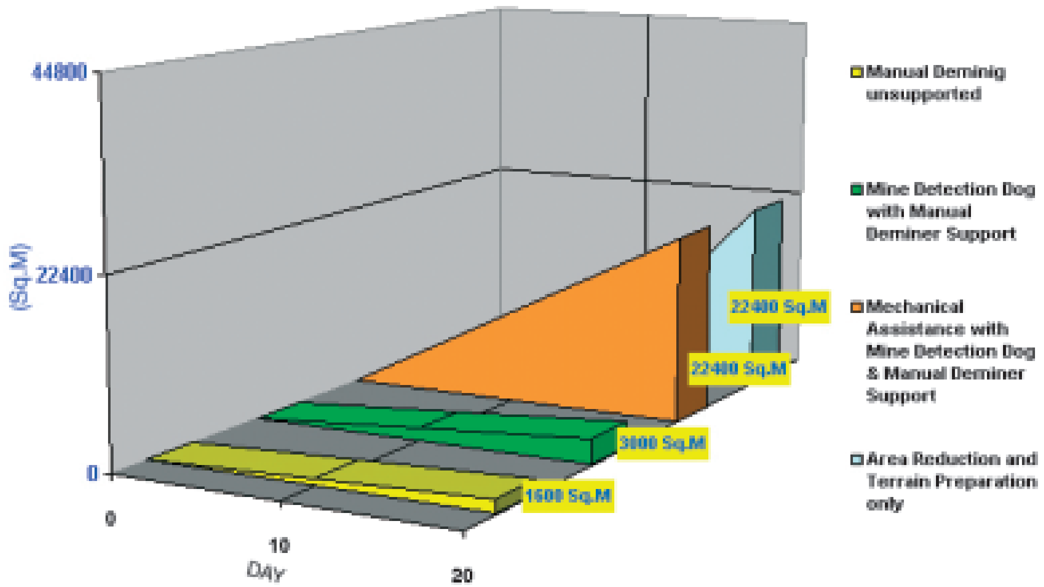
Area reduction with mechanical assistance followed by mine clearance operations

During 20-day periods the SDTT system was deployed to remove vegetation, break up ground to activate landmines and conduct multi-level investigation. These activities prepare terrain for MDD and manual deminer team deployment to maximum effectiveness, reducing threat and encumbrance from tripwires, vegetation, metal contamination and hard soil.

Mechanical assistance supporting MDD and manual demining teams can reduce as much as 22,400 square metres in 20 days, equalling a 1,400 per cent increase over manual or a 746.6 per cent increase over MDD teams with manual deminers in support. In addition, another 22,400 square metre area was mechanically reduced during the same period, although a MDD team was not available to complete the 10 per cent check during the same timeframe.

This totalled a 2,100 per cent increase in productivity over manual methods or a 1,120 per cent increase over MDD with manual deminer teams. These results are summarised in Figure 10 below.

Fig. 10. The increasing productivity of integrated area reduction operations



Methods of area reduction (dry and wet season)

Dry season operations

Step 1. Establish area boundaries

Arbitrary boundaries defining the area where operations will be conducted are based on the capability of the mechanical system and the terrain features. The SDTT mounted on steel wheels is driven into the area outlining the perimeter and marking the four corners with flags to guide operations. The SDTT is equipped with the heavy slasher mounted on the front and grabber mounted on the rear of the tractor chassis.

The commander directs the operator by radio on a bearing and distance using the heavy slasher to cut lanes forming a block. Yellow flags are erected at each corner of the inner box visually identifying the boundaries to both the operator and commander. The lane established by the first pass of the SDTT around the box is now considered a turn-around area and overlap zone for subsequent blocks. During these operations the 14-rai block (80 x 280 metres) is used, corresponding with the needs of the beneficiaries and the technical capabilities of the systems and operators.

Fig. 11. Oblique view of suspected mined area.

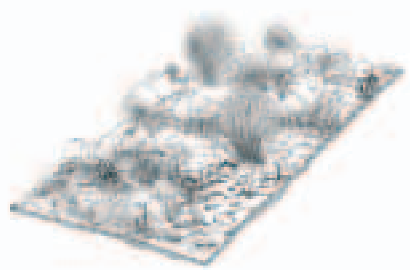
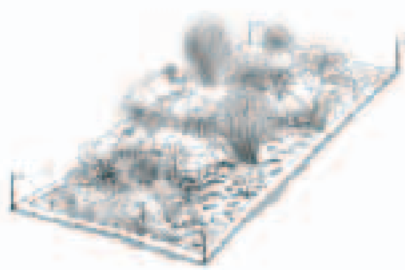


Fig. 12. Block area showing lane cut by SDTT and slasher with flags marking boundaries.

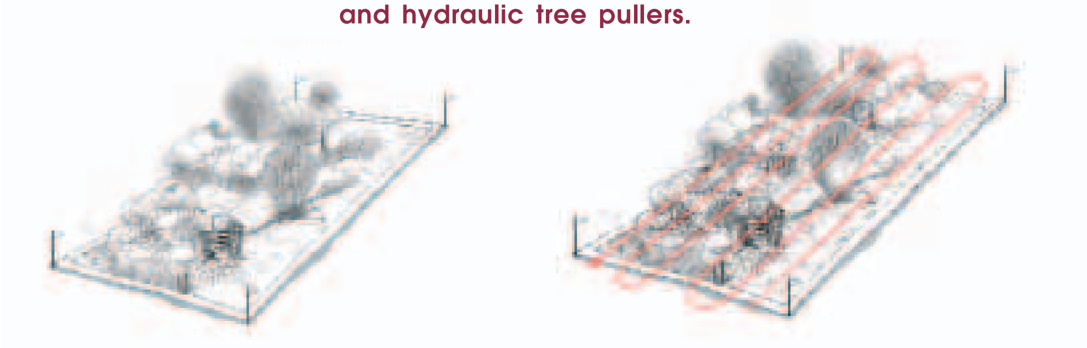


Step 2. Remove heavy vegetation (one pass)

The SDTT is now directed by the commander in a series of passes to cut down all heavy vegetation of up to 10 centimetres in diameter within the block area. Both the operator and commander observe the progress of the operations.

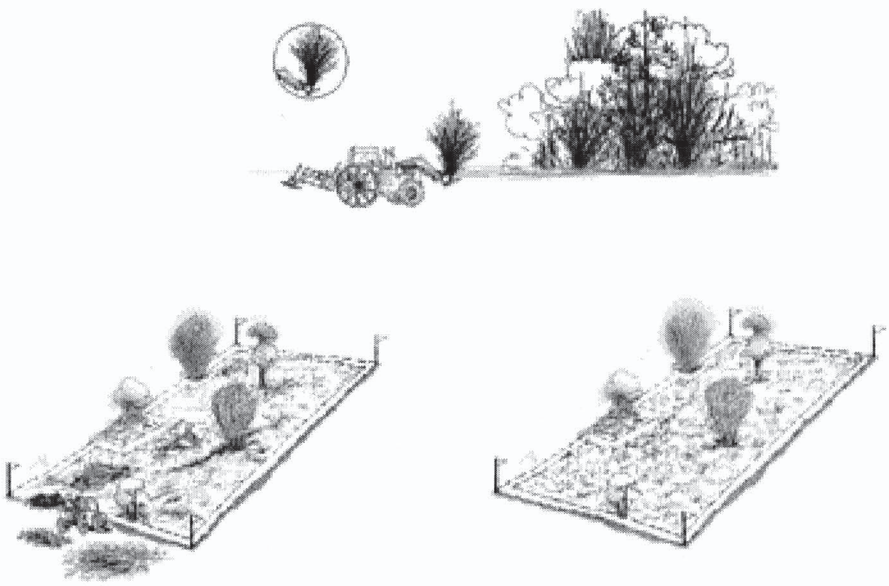
Fig. 13. Slasher is capable of cutting down large trees and vegetation.

Fig. 14. All heavy vegetation is cut down using both the slasher and hydraulic tree pullers.



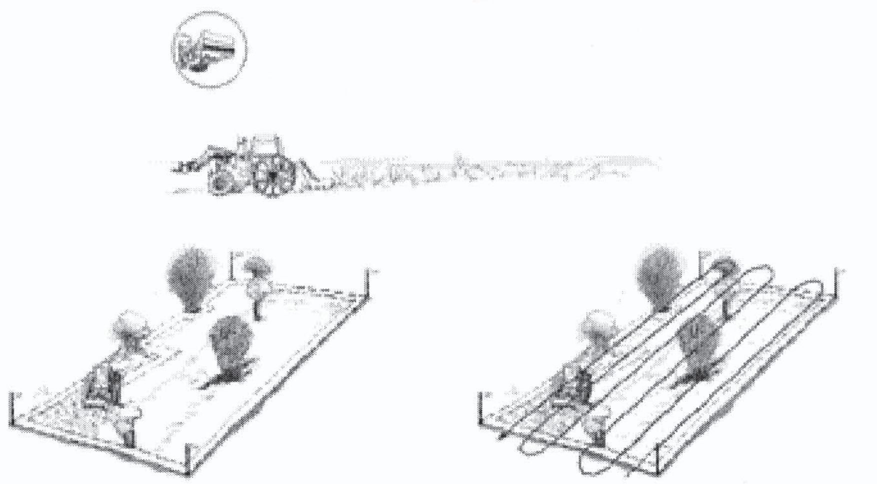
Grabber (one pass): The heavy slasher leaves a considerable amount of debris in its wake. Broken vegetation stems litter the area and are picked up in batches by the grabber. Piles of debris are established outside the suspect area in safe areas. Mounted on the tractor is the light or heavy tree extractor which can be used to pull trees out of the ground and remove them from the area as necessary. Normally, trees over 10 centimetres in diameter are left in place, as mines are not likely to have been laid underneath them.

Fig. 15. Combined usage of the grabber and tree pullers to remove the debris and place batches into safe areas for deminers to check.



Light Vegetation Removal (one pass): The SDTT is now mounted with the push/ pull mower. The purpose of the mower is to reduce remaining vegetation stubble and debris to ground level. Cutting down the stubble allows the effective deployment of the roller and magnet. The mower is deployed in an overlapping pattern ensuring consistent cutting of remaining vegetation.

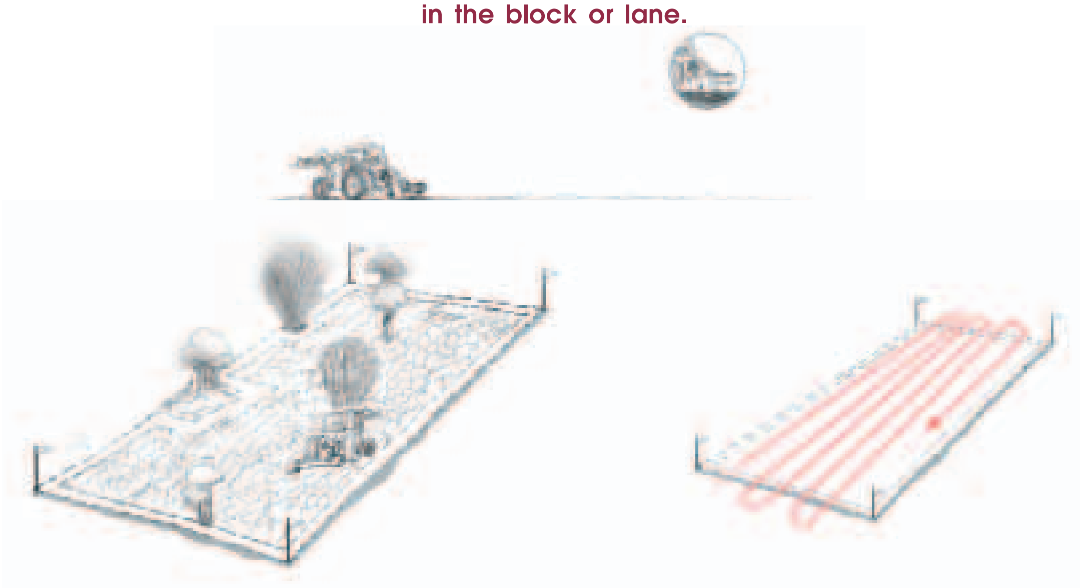
Fig. 16. Mowing the stubble allows the effective deployment of the articulating roller and magnet.



Step 3. Investigate the threat and remove surface metal with a magnet (one pass)

The heavy magnet is mounted on the rear of the SDTT and pulled in overlapping sweeps along the length of the block. In the turnaround areas at the end of the block, the magnet plate is released dropping collected metal fragments onto a tarpaulin. Deminers are employed to observe, identify and dispose of hazardous material, which also identifies further potential threats in the lane and other areas of the block.

Fig. 17. Passing the magnet in overlapping sweeps and checking the results at the end of each lane is an efficient method to remove metal and identify threats in the block or lane.



Step 4. Investigate the threat with segmented roller (four passes)

The segmented articulating roller is mounted on the front of the vehicle. Systematic rolling in overlapping passes at 50 per cent of roller width is conducted over the full area of the block. Three additional passes are made over the area until all four cardinal directions are completed by rolling vertically, horizontally and both diagonals. Theoretically, each area of ground will be impacted by the mechanical pressure from a 50 kilogram roller up to eight times.

Fig. 18. Complete coverage of the block is achieved by overlapping passes.

Step 5. Investigate the threat at depth with light cultivator (one pass)

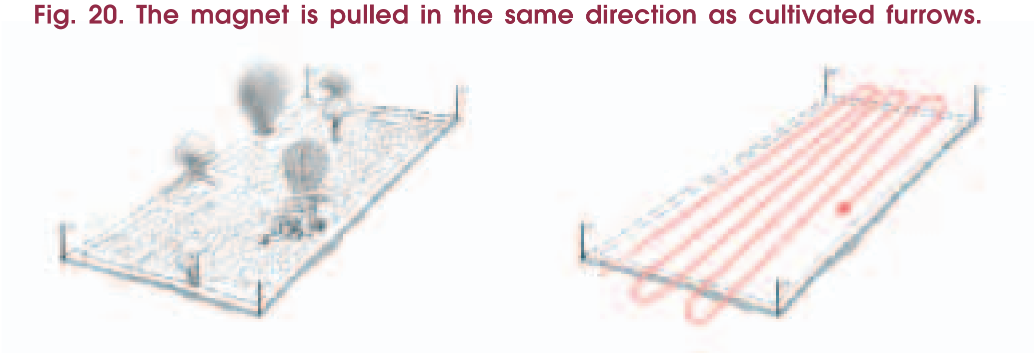
Light cultivator is adjusted to 10 centimetre digging depth and mounted on the rear of the SDTT. The light cultivator is pulled in overlapping sweeps over the entire block. This action disrupts hard soil creating access for additional applications of the magnet and roller at greater depths.

Fig. 19. Light cultivator is the first step in sub-surface investigation for evidence of mines.

Step 6. Investigate the threat at depth with magnet (one pass)

In line with cultivated furrows the heavy magnet is pulled in overlapping sweeps along the length of the block, picking up sub-surface exposed metal or mines and components.

Fig. 20. The magnet is pulled in the same direction as cultivated furrows.



Step 7. Conduct deeper threat investigation with heavy cultivator (one pass)

The heavy cultivator is adjusted to 20 centimetre digging depth and pulled over the block area in a different direction to the light cultivator. Again, overlapping passes are used to ensure total coverage. The direction is determined by terrain features on the ground.

Fig. 21. The heavy cultivator is pulled in a different direction to the light cultivator.

Step 8. Conduct deeper threat investigation with magnet (one pass)

The heavy magnet is mounted on the rear of the SDTT again and pulled in overlapping sweeps along the full length of the block.

Fig. 22. The magnet follows the same pattern as the heavy cultivator collecting metal fragments or mines.

Step 9. Conduct deeper threat investigation with segmented roller (four passes)

Four additional passes are made over the area until all four cardinal directions are completed, attempting to detonate mines that may have been brought to the surface by the light and heavy cultivator.

Fig. 23. Final passage of the roller is intended to ensure no further evidence of threat is present.

Total passes – 16: This repetitive system starting at the surface and processing the ground to find evidence of mines is an area reduction process and is not considered mine clearance by TMAC.[9] After conducting this process without finding evidence of mines, the reduced area is then released.

Wet season operations

Increased moisture content in the soil reduces the effectiveness and mobility of mechanical systems. The process must therefore be modified during the wet season. The same activities are conducted with fewer passes based on how the soil responds to the machine and its attachments. The passes used are as follows:

- establish area boundaries,
- heavy vegetation removal (one pass),
- grabber (one pass),
- light vegetation removal (one pass),
- magnet (one pass),

- articulating roller (four passes).

Total Passes: 8.

Depending on the soil moisture and how the soil reacts to the machine and its attachments, additional passes are attempted increasingly until the full 16 passes can be implemented without turning the field into a morass.

Action taken on evidence of hazardous threat

Carefully controlling all activities through visual observation and gathering information is obtained by the following three methods:

- visual identification of mines/UXO,
- detonation of mines/UXO through activation by roller or cultivator, or
- magnetic collection of mines/UXO or components.

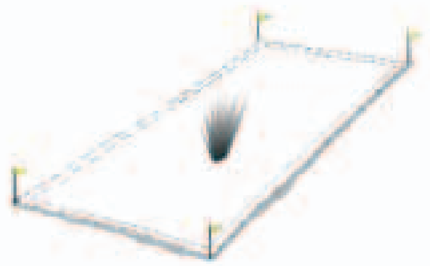
Visual identification

Equipment operators, commanders and deminers can observe the presence of exposed mines or components throughout the process. Once a suspected mine is identified it will be located through triangulation and recorded for further clearance action.

Detonation of mines/UXO through mechanical activation

Multiple passes of the mechanical equipment and tools provide the opportunity for mines to detonate as designed. Observing detonations and recording the location through triangulation identifies primary threat areas for clearance action.

Fig. 24. Mine strike using mechanical equipment immediately identifies the threat area.



If a detonation is consistent with a landmine the entire box is considered mined. Depending on the nature of the detonation (for example an explosion consistent with an anti-personnel mine) mechanical operations may continue in the block, further identifying other areas or reducing risk and ultimately preparing the terrain for manual and MDD teams.

Magnetic collection

Passing the magnet over the ground after vegetation clearance offers the opportunity to collect surface-laid or exposed mines and their components. Magnet strength does not allow mines to be "sucked"out of the ground although considerable metal debris can be collected. The debris tell a story, showing contamination levels and types of munitions expected.

The magnet's removal of metal fragmentation increases the effectiveness of manual deminers, and removal of explosive-encrusted metal amplifies the efficiency of MDD teams. Positive identification of hazardous material narrows the search to the lane where the hazard was picked up.

No evidence of mines or other hazard

If, after repeated passes of the SDTT tractor and mechanical application of a full range of attachments no evidence of mines is produced or witnessed, the assumption is that mines are unlikely to be present. Knowing that no system is infallible, confirmatory checks are necessary.

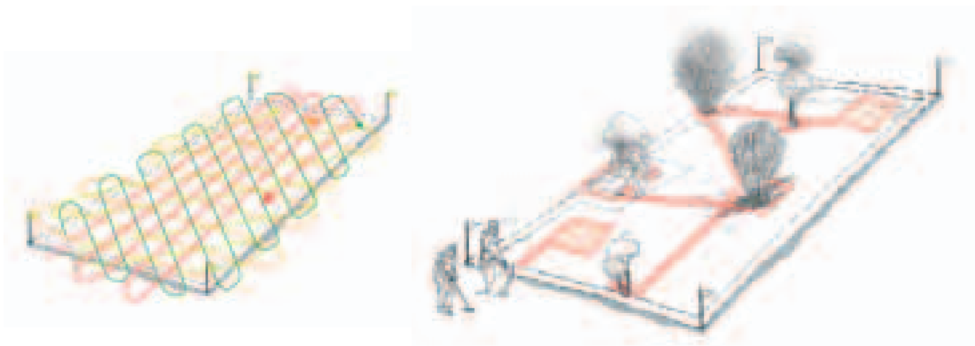
Checking areas where mechanical application is weak or ineffective (such as steep slopes) is therefore obligatory. Areas where mines are known to be frequently located (e.g. around water sources and field fortifications) are also checked using alternative methods. Following up with MDD teams and manual deminers ensures the mechanical process is reinforced. Using dogs and metal detectors brings two separate sensory methods of checking or quality assurance to the mechanical area and risk reduction process.

Confirmatory checks with alternate sensory method

Follow up of systematic mechanical area and risk reduction operations should employ a different methodology than the primary methods employed. MDD and manual teams are ideal to confirm the effectiveness of mechanical systems.

Fig. 25. Following thorough mechanical application, MDD teams and manual deminers perform quality assurance checks and investigate areas where mechanical systems perform poorly.

MDD | Manual



Once the mechanical system has moved to another block, MDD and manual teams can check the block. Arbitrarily, 10 per cent of the block is the recommended level of checking until quantifiable tests can be conducted on the mechanical system. Should the teams find any evidence of mines the entire block must be cleared by both MDD and manual teams, or just manually. However, if no mines are found during this confirmatory check then the area is declared released.

Evidence of mines

At any stage in the TMAC process the first indication of mines initiates a "100 per cent clearance of area" response. The block becomes the arbitrary area where the full measure of MDD and manual clearance effort will be deployed in standard clearance operations.

Systematic area reduction operations

These procedures are repeated over the entire suspected mined area, block by block, until all mined areas are identified or shown to contain no evidence of mines. Understanding the difference between blocks that are "reduced" and blocks that are "mine cleared" is important. Considerable time was invested educating farmers and other beneficiaries receiving the cleared or area reduced land. The local perspective is quite practical in that, following the repeated processes of the mechanical equipment, farmers are satisfied to take over the land.

Additional checks with MDD and manual teams provide marginal increases in farmer confidence after witnessing the effects of mechanical methods that produce no mine evidence. Greatest confidence is achieved when MDD and manual teams deploy to fully clear areas identified containing mines.

During these operations two types of mines were located: Chinese Type 72A pressure-activated anti-personnel mine and the Chinese Type 69 bounding fragmentation mine. Type 69 mines were found by visual observation, magnet and MDD teams with manual deminers. In all cases these mines were missing the plastic fuse, which had deteriorated as a result of the forces of nature, and the tripwires had long since disappeared.

During clearance operations, in the vicinity of the Type 69 mines, additional Type 72A mines were located by MDD teams and uncovered by manual deminers. The mines appeared to be in generally good condition although weathered with possible water intrusion into the mechanism and firing chain. No mines were detonated during area reduction operations, indicating either the depth of the mines did not allow them to detonate as intended or their firing mechanisms had deteriorated.

Figure 26. Top view showing reduced areas in a block system.

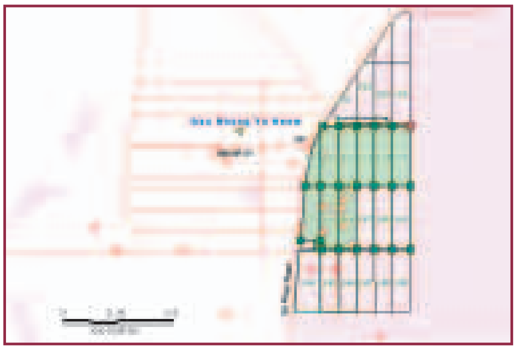


Fig. 27. Typical ground after area reduction process

Quality control process

Defining adequate quality control (QC) procedures to follow up repetitive mechanical processes with a 10 per cent MDD and manual check requires either new technologies or a sensor system that adds value to the described area reduction methodology.

However, during these operations in Thailand a final QC process was implemented, witnessed and directed by third party stakeholders, e.g. members of non-governmental organisations and military engineering technical staff. The roller system was directed at random by QC participants in blocks. Also, MDD and manual teams were directed to conduct random checks of areas until the QC monitors were satisfied with the results. During these random checks and QC operations, no mines were either detonated or discovered.

Conclusions, findings and recommendations

Conclusion 1.

In patterned mined areas machines are used to identify the exact presence of mines. In non-patterned mined areas machines are used to identify the areas containing mines. The potential for machines to reduce the amount of land deemed contaminated with mines and UXO is significant.

Findings

In a *patterned* mined area, demining organisations work with available information, which is often comprehensive. Mines are generally found in a deliberate formation. A machine can identify patterned minefield perimeters so that clearance assets can deploy to the affected area quickly.

In patterned minefields, information is often extensive but its reliability may require confirmation. Machines can be used to effectively verify this. If the information proves reliable, it may impact on future clearance techniques used in the area. If the information proves unreliable then greater caution is required in its use.

In *non-patterned* mined areas, a process to obtain greater information is required. Typically, available information is vague. A machine process is a good way to provide information to a level that suspect areas can be cancelled out. Various threat possibilities can be categorised, with each being targeted successively. For example, the presence of metal-cased mines, UXO and metal mine components can be identified by the use of a magnet whereas pressure-activated plastic anti-personnel mines might be identified with the use of a roller. Other technologies could assist with other mine threats. The basic requirement would be to identify the likely threat types using the most appropriate technology to identify a presence.

In *non-patterned* mined areas, land can be divided into workable sections. The size of each section might depend on the mine history of the area as well as terrain. Sectioning allows for areas to be separated into two categories; those which have been shown to contain a mine threat, and those which have not.

Recommendation 1.

Demining organisations need to invest in technology that will deliver more information about a minefield prior to clearance operations. This information can save both time and money and, as a result, more minefields can be cleared in a given time. Machines can apply a series of confirmation tools including those designed to detonate mines, electronically indicate and map the location of mines and UXO, pick up or retrieve metal-cased mines and UXO, and collect explosive vapour.

Conclusion 2.

Technical survey involving area reduction with machines has the potential to rapidly release large suspected hazardous areas.

Findings

Applying the world's limited mine clearance resources to actually clearing all suspected land, rather than identifying areas that do not contain mines is wasteful. Changing focus to "area reduction operations" followed up by "mine clearance operations" of identified threats will have a greater and quicker impact on the mine and UXO threat.

Eliminating suspected hazardous areas where no evidence of a threat is found through a systematic mechanical area reduction process has clear advantages. This process allows mine clearance resources to be deployed where real threats are located, as opposed to huge suspect areas subsequently shown not to contain mines.

Areas deemed as requiring clearance are typically identified in a general mine action assessment. Information is gained via a variety of means — e.g. verbal interaction or mined area documentation such as sketch maps. Information gained in the general assessment should be proven and confirmed by physically "doing something", i.e. conduct a technical survey. The use of machines to provide on-the-ground confirmation in technical survey is not a standard approach among most demining organisations.

If most of the work in demining is searching for mines rather than clearing them, more effort is required during the technical survey phase of an operation. Immediately switching to clearance operations after the conduct of a verbally based technical survey is arguably not the best use of clearance resources.

In both case studies in this chapter, productivity results show that investment in an area reduction machine results in a high return when compared to the other technical survey or clearance methods used (MDD and manual). Moreover, there are probably more efficient methods of conducting full clearance than those used in the case studies and therefore the results are only an indication of potential productivity increases. In any case, using a method that more accurately locates mines and thereby reduces the size of the area to be cleared will almost always produce a positive cost-effective result.

Recommendation 2.

Machines can be effective tools to hasten the technical survey process, quickly revealing the true areas containing mines and requiring full clearance. The use of mechanical systems during technical survey should be standard where physical conditions allow.

Conclusion 3.

The effect of mechanical action upon mines is not 100 per cent predictable. Machines vary in their ability to destroy ordnance and the physical conditions in which they work will have a bearing on the outcome. However, machines are effective enough that they can be expected to at least indicate the presence of mines and can therefore be used for area reduction. This is borne out by tests and empirical clearance data.

Findings

The reliability of the machine tool is more of a general concern, as reliability will differ from machine to machine, and will depend on how each machine is applied and the mine type it is up against. In addition, a machine's reliability should be compared to the ability of other methods to do the same job (e.g. REST and MDD techniques or manual survey lanes). Despite certain grey areas as to a machine's effectiveness against ordnance, consideration should be given to how much slower area reduction will be if means other than mechanical must be relied upon.

Recommendation 3.

Since an objective comparison between clearance methods is unlikely to be available in the short term, demining organisations should be encouraged to exchange machine

reliability data and knowledge while continuing to work with the degree of confidence each has in the respective methods deployed.

Endnotes

1. A risk assessment is a key ingredient in a mechanical area reduction operation. It involves a closer look at the information obtained about a minefield with the aim of cancelling out areas requiring clearance in an informed and transparent way.
2. See GICHD (2003:100-105).
3. In other trials HALO has conducted, the roller has proved less effective against PMA-2 anti-personnel mines (50-60 per cent success rate) as the fuses tend to be broken off from the initial side-forces of the roller effect. Also the PMD-6 mine is not easily initiated (40-50 per cent effective) as the wooden construction of the mine crumbles at the joints thereby not applying sufficient downward force on the fuse.
4. The HALO Trust (1999b) and (2000a).
5. The platoon configuration was one commander, one second-in-command, three section commanders, 24 deminers and one medic.
6. MDD teams only work four hours a day due to temperatures and the ability of manual deminers to clear enough vegetation allowing the MDD teams to deploy.
7. See GICHD (2003:100-105).
8. Neither the manual nor the MDD procedures were fully optimised. For example, machines were not used to prepare the ground for manual clearance or MDDs to increase their productivity. Clearance performance is therefore an extreme comparison and only indicative of the options used.
9. Since this case study was written the dry season procedure has been refined and the total number of passes has been reduced.

Chapter 4.

The application of machines to ground preparation

Summary

Ground preparation machines are typically underused in mine clearance operations. They can contribute significantly to the performance of a manual or MDD clearance programme, especially if machine use is tailored to the area. In order to quantify the productivity improvements that result, more demining organisations need to separate the recording of land cleared manually behind a machine from the land cleared manually without machine assistance.

Machines conducting ***surface ground preparation*** *are limited by the degree of preparation they provide for follow-up clearance teams. The maximum productivity increase is restricted to areas with low levels of metal contamination. Machines conducting* ***sub-surface ground preparation*** *are also limited by the degree of preparation they perform for follow-up clearance teams, but do hasten the excavation process perfomed by manual deminers and have the potential to extend dog working-day periods into the cooler months of the year. Machines conducting* ***sub-surface with metal removal ground preparation*** *offer the most advantages as they remove all common obstacles for follow-up clearance. Such machines remove the threat of tripwires, so that the deminer is no longer required to perform a tripwire-detection drill. They remove vegetation so that the deminer no longer spends time cutting away vegetation down to ground level, and they remove the majority of metal contamination.*

Introduction

Background

In Chapter 3, we looked at the potential for mechanical systems to be employed for area reduction to enable land to be returned to the civilian population more quickly and efficiently. In this chapter, we look at the topic of ground preparation.

Many different types of machines were deployed in demining operations with the intent of completely clearing minefields. In the early days, the machines used then generally demonstrated that complete clearance could not be achieved with a high degree of confidence. However, demining organisations quickly saw the potential for machines to be used to prepare ground for subsequent clearance methods. Currently, clearance after the use of machines is conducted by both manual and MDD techniques.

In general, machines such as flails and tillers are used in a ground-preparation role and focus on removing tripwires (used to initiate some mine types) and vegetation. Tripwires are difficult, hazardous and time consuming to deal with. If the machine removes the tripwire and vegetation, both manual deminers and MDD teams can then concentrate on searching for mines.

A large variety of machines are used in other forms of ground preparation. Examples include excavators used to scoop up and lay out debris in built-up areas. Without a machine to do this, a deminer would have to laboriously excavate through piles of debris by hand, making the task very slow. Rollers or steel wheels have also been used to prepare minefields to reduce the workload of follow-up clearance. This detonates a large percentage of the mines so less time is spent excavating for mines and destroying every one uncovered.

There are three general deployment methods for ground preparation machines: machines that are driven by an operator into a minefield, machines that are controlled remotely and used inside the minefield (both types known as intrusive machines), and machines that are only operated from established safe or previously cleared land (known as non-intrusive machines).

When machines are used in a ground-preparation role, it is now assumed that some mines might be missed. The emphasis today is on improving the productivity of follow-up clearance.

Study aims

The aims of this sub-study were to:

- identify the advantages of mechanically preparing the ground;
- document the results of ground-preparation experiences;
- recommend an optimised ground-preparation methodology; and
- discuss issues related to optimising machine use

Categories of ground preparation

The following are the three different categories of ground preparation:

Surface ground preparation: the removal of vegetation and the tripwire threat. This category generally involves two types of machines. One operates and travels along cleared areas with commercial cutters attached to hydraulic arms that reach out and cut in the un-cleared areas. The other involves small remotely-controlled specialised vegetation cutters.

Sub-surface ground preparation: the removal of vegetation and the tripwire threat with the tool penetrating the ground to a certain depth. This method usually involves flails or tiller-type tools attached to armoured machines that operate in un-cleared areas.

Sub-surface with metal removal ground preparation: the removal of vegetation, the tripwire threat, penetration of the ground and the removal of metal contamination. This currently involves the same type of machine as for sub-surface ground preparation with the addition of a magnet towed behind or on board the machine, collecting metal.

Surface ground preparation: case study HALO Cambodia

Introduction

Vegetation cutting was one of the first mechanical ground-preparation methods applied in humanitarian demining. The HALO Trust in Cambodia, for instance, has been using specialised machines to cut vegetation since 1995.

The main type of vegetation cutter used by The HALO Trust is a non-intrusive commercial agricultural tractor, which has been armoured and fitted with a commercial vegetation cutter. The initial concept was to attach a commercial vegetation cutter to a standard piece of agricultural machinery that could be purchased and maintained locally.

The machine first chosen was a Belarus MTZ 82R tractor, which was purchased in Phnom Penh. While this machine could do the job, it proved too light to carry both the cutter and armour and to be reasonably manoeuvrable. The best choice of tractor is now considered to be the Ford New Holland 8340. At around eight tonnes in weight and with more than 160hp it is big enough to take the extra weight and be reasonably manoeuvrable (crucial with this type of machine). It is, however, still restricted to working on reasonably flat ground.

Fig. 1. The armouring consists of a simple three-sided eight-millimetre-thick armoured cab. The far side or the left-hand side is left open for ventilation as cutting can only be performed on the right-hand side.
Additionally, an armoured plate covers both the right-hand side of the engine and the fuel tank.

The vegetation cutter chosen was a B80XM from Bomford Turner. The extendable cutting arm has an 8 metre reach from the centre of the tractor. The cutting head is 1.25 metres wide and rotates at about 2,300rpm. The only modification to this cutting arm is that two wooden skids are fitted to each side of the cutting head. These act as the main contact between the cutting head and the ground. If they initiate a pressure anti-personnel mine, they are “sacrificed”, leaving the cutting head damage-free.

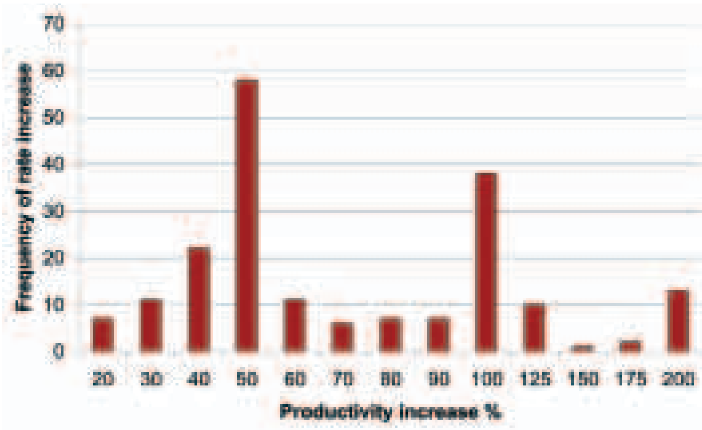
Methods

Productivity in 190 individual manual demining lanes was estimated over a 12-month period by the HALO Mechanical Supervisor. The data was taken in 43 minefields with vegetation cutting by 11 different machines. Productivity was compared to that achieved by a manual deminer in the absence of a cutting machine (the deminer was required to cut the vegetation).

Results

Productivity improved in all 191 instances in which the deminer followed a cutting machine (*Fig. 2*). The average increase was 73.8 per cent (±s.e. 3.3, range 7-200 per cent) with more than 100 per cent achieved in 26 instances; the median increase was 50 per cent. In general terms, productivity increased by about 50 per cent when manual deminers followed a machine, but considerably greater increases were possible under some circumstances.

Fig. 2. Increase rate (IR) as a result of surface ground preparation with HALO Tractor.[a]



a. The report is a yearly summary of all monthly mechanical results for 2001.

Figure 2 shows that the productivity increase is difficult to predict as the range is quite large. The lowest productivity increase of 20 per cent was recorded six times and the highest productivity increase was recorded 13 times.

What influences the IR and the range of results?

The productivity of a manual deminer working on areas cut by the HALO tractor is influenced by two main factors: the amount of metal contamination in the ground and the type of vegetation being cut.

a) After vegetation is removed, the subsequent progress made by the deminer depends primarily on the amount of metal contamination. Areas where the machines recorded a 100 per cent IR or less were considered to contain a high level of metal contamination and areas where the machine recorded an IR higher than 100 per cent were areas considered to have relatively low metal contamination .[1]

b) Improvements in efficiency of manual demining were smaller in areas containing high elephant-type grass than in areas containing thick underbrush. Although the latter is often categorised as thicker vegetation, bushes are often easier for the deminer to remove because a much larger area of vegetation is removed when one main base trunk or stem is cut. The time costs of removing high grass are more substantial because of the small net clearance gained on each cut.

How the machine affects overall productivity

The HALO tractor is a non-intrusive machine. It therefore works concurrently with the follow-up clearance teams. Coordinating this cooperation to optimise the machine's effect includes the following considerations:

Reliance on demining follow-up

The machine is capable of cutting up to 3,400 square metres of land per day, depending on the vegetation and terrain type.[2] The average area cut daily by 11 machines over a 12-month period was 560 square metres with an average working time of three hours per day.[3] Deployment of the machine is limited by the progress made by the deminers and the availability of breaching lanes. Therefore the cutting rate of 500-600 square metres per day reflects the rate of manual demining in the minefield, a limitation likely to apply to all types of non-intrusive vegetation cutters.

Over use of breaching lanes

The manual teams have to prepare four-metre wide breaching lanes before the machine is used in the minefield. When the aim is to provide enough breaching lanes to enable the machine to cut all day, a dilemma is created: breaching lanes can represent a significant portion of the minefield area, thereby reducing the increase in productivity which is the main benefit of using the machine. For example, if the breaching lanes represented 25 per cent of the total area being demined and the effect of mechanically cutting vegetation was a 50 per cent productivity increase, then the net effect would be a 37.5 per cent increase in productivity. Requirements for breaching lanes need to be calculated for each individual site, as the size of the minefield and the ease of access for the machine will differ for each task.

Using breaching lanes has an obvious advantage: they can be used to target obstacles (tree stumps, ditches, etc.) which could limit deployment of the machine. These obstacles can be removed or otherwise negated during the demining of the breaching lane.

Informative reporting

The machine needs to be used to target as many demining lanes as possible. However, simply recording the area cut per day by the machine and the area cleared manually by the deminers gives a false representation of what is happening. One could be fooled into thinking there is a balance between what is being cut and what is being subsequently cleared. For example if 500 square metres per day were cut by the machine and 500 square metres per day were cleared by follow-up clearance, this could mean that half of the deminers are working on cut land and clearing at twice the rate. Different sites can more easily support different percentages of demining lanes (not all lanes can be supported). It is very difficult to template or pre-plan the work of the machine. It is again a case of making day-to-day decisions as the demining operation progresses.

Summary/conclusions

The large range for the individual-lane productivity increase is explained by the varying degrees of metal contamination in the ground and the types of vegetation being cut. Best use of the machine to maximise overall productivity increase is achieved by minimising breaching lanes which should be ideally as far apart as practical so as to support as many demining lanes as possible. Additionally, deploying the machine a few days before follow-up clearance is more productive, provided initial breaching lanes have first been established.

It seems apparent that because this type of machine cannot support all demining lanes (breaching lanes are a necessity) an intrusive machine could prove more beneficial if deployed to cut all the vegetation before clearance began.

Small intrusive vegetation cutters

The HALO Trust in Cambodia also operates a small vegetation cutter known as the Tempest.[4] The Tempest is a low cost unit that is simple to operate and is constructed using materials and manufacturing techniques that are available in mine-affected countries. The Tempest is remotely controlled, therefore forward vision of the unit is compromised. As a result its vegetation-clearance capacity is slowed by time spent manoeuvring the machine away from and around obstacles (tree stumps, dead-fall, etc.).

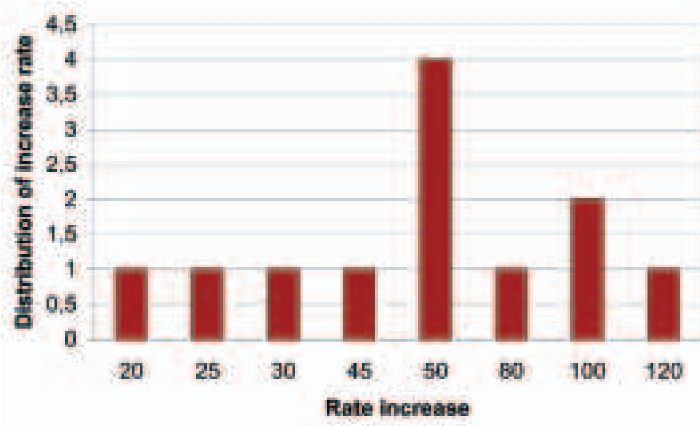
Fig. 3. Tempest operating in Thailand.

Intrusive vegetation-cutting machines were designed because of their potential to clear vegetation in areas which larger non-intrusive machines could not access (e.g. between closely-located large trees and over undulating ground). An original objective for this machine was for it to work with non-intrusive machines, so that a greater percentage of vegetation could be cut. This, however, seldom happened.

Methods

Clearance data was taken over a 12-month period. Twelve different minefield results were recorded in total as the monthly average productivity increase taken from an analysis of the daily reports. Figure 4 shows that the average recorded increased rate (IR) was 60 per cent. The range was from a 20 per cent IR to a 120 per cent IR.

Fig. 4. IR as a result of surface ground preparation with Tempest



Source: HALO Trust (2001b).

Results

All monthly measures of adjusted productivity were positive, indicating that using vegetation cutters always improved productivity. Productivity increased by 60%±s.e.9.4 (range 20-120%, N=12). The median was 50 per cent.

What influences the IR and the range of results?

Similar productivity increases would be expected from any type of vegetation cutter as the productivity increase of the deminer is a result of the areas to which they are deployed and not the type of vegetation cutter. However, different machine types have a different effect on the overall minefield productivity. The main factor influencing the Tempest's ability to maximise overall minefield productivity is its daily productivity.

The Tempest weighs 2.7 tonnes and is driven by a single 70hp diesel engine. The fact that it is remotely controlled means forward vision is non-existent. This combination of a small, lightweight machine with limited horsepower and no forward vision results in a very low rate of productivity. The average clearance rate to be expected from the Tempest in both Bosnia and Cambodia was 800m^2 per six hour working day.[5]

Low productivity can occur when the machine is working concurrently with manual deminers because of safety distance requirements. The minefield size decreases over time, further increasing the machine-deminer space restriction. This often limits the amount of vegetation that is cut each day as the work of the deminer takes priority. Sometimes the amount of area cut by the unit in a day is less than that cleared by the deminers, who then catch up to the machine.[6]

Catch-up is most likely to occur when the minefield is small and the metal contamination level is low. These two circumstances represent an ideal deployment situation for a vegetation-cutting machine as the conditions can potentially optimise the overall productivity increase.

Deminers tend not to catch up to machines deployed on large minefields where the metal contamination is high. This circumstance is not an ideal deployment situation for a vegetation-cutting machine, as the productivity increase of the deminer is restricted by the level of metal contamination. With high levels of metal contamination, the presence of vegetation does not slow the progress of manual demining.

If the unit is used to cut the entire minefield in front of follow-up teams, there is a limit as to what size the minefield can be. Deploying more than four weeks in advance in places like Cambodia (high vegetation growth rate) could mean having to contend with vegetation re-growth and therefore time spent re-cutting some areas. Deploying four weeks in advance (20 working days as a maximum) would mean deploying the Tempest in minefields no larger than 20,000 square metres to ensure the entire area is prepared.

In a situation where the unit is not deployed to clear the entire minefield, the pattern the unit cuts can determine the minefield IR (*see Figs. 5 and 6*).

Fig. 5. Cutting at right angles to baseline

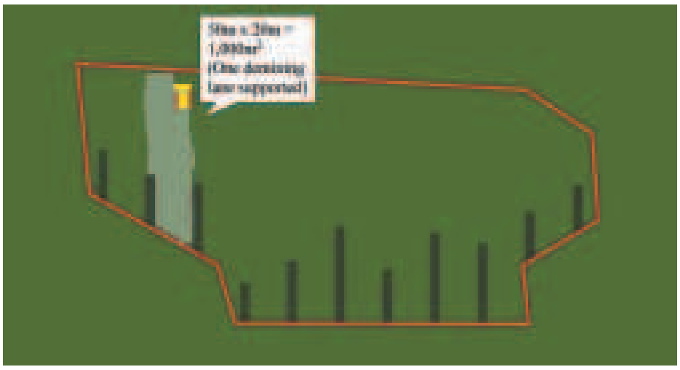
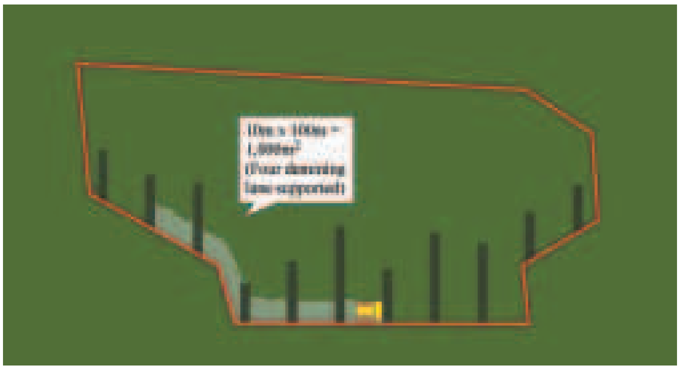


Fig. 6. Cutting along baseline



The distance between each manual lane influences the minefield IR. The farther away the deminers are from each other, the more vegetation the unit has to cut per day to support a given number of lanes (cutting in front of each lane is not viewed as practical). For example, when lanes are 25 metres apart and each demining team clears 50 metres per day, the required length of the baseline is 500 metres and contains 20 lanes. However, when demining lanes are 15 metres apart, the 500-metre baseline will contain 33 lanes. The distance between working lanes is a risk management issue, which depends on the severity of the mine threat. Organisations tend to increase the distance between deminers when the severity of the mine threat increases, but the reverse is rare.

Summary

The advantage of small remote machines is their ability to get into smaller and more difficult places than larger machines. Small vegetation cutters are inexpensive but productivity is low. The remote-control nature of this type of machine is necessary because of its size but contributes to its low productivity rate.

Small, remote machines are optimised when they are cutting along the front of demining lanes, ensuring as many lanes as possible are supported. When not operating concurrently with manual teams, best use could be expected in small minefields (< 20,000 square metres). To be fully independent (no area size restriction) this type of machine would probably need a daily productivity rate of about 2,000 square metres per day.

In small minefields with low metal contamination, a normal-sized demining team working about 20 lanes is likely to clear more land than can be cut by a small vegetation cutter.

Sub-surface ground preparation

Introduction

Sub-surface ground preparation machines are generally intrusive machines (able to enter a mined area to operate). Machines that can break up the surface of the ground are usually more powerful than machines that only remove vegetation. They therefore generally have higher daily productivity rates than vegetation cutters, as they are able to work independently of subsequent clearance methods.

Advantages of sub-surface ground preparation

Sub-surface ground preparation combines the advantages of surface ground preparation with the additional ability to break up the ground. This gives at least two potential advantages over surface ground preparation:

1. facilitating the use of MDDs; and
2. reducing the time spent investigating signals registered by the metal detector.

In temperate climates, the layer of soil between the mine and the ground surface is normally quite moist for most of the year, influencing the ability of explosive molecules to reach the surface.[7] Dogs may find it easier to locate scent of explosive behind machines that break up the earth's surface. A greater explosive plume is produced by exposing the sub-soil to the atmosphere. The advantage is short-term only and depends on the amount of rain after sub-surface ground preparation and air temperatures at the time dogs are searching.

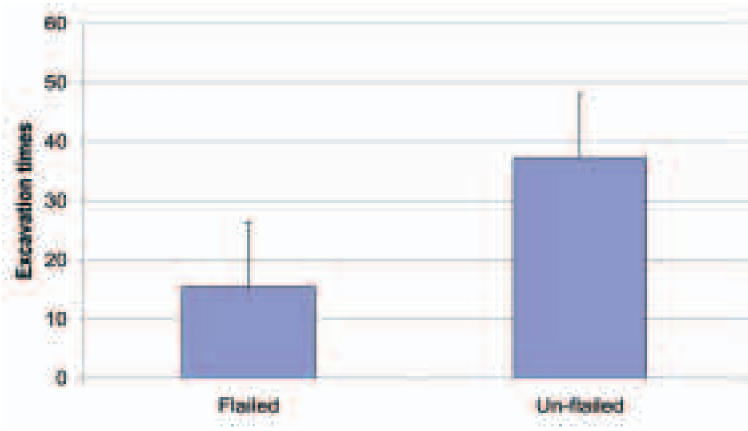
However, there is potential to extend the working-day period of dogs into the cooler months if the machines were used to churn up the moist soil thereby exposing it to the sun to dry which, in turn, releases explosive molecules.

In September 2002, the GICHD study team conducted an experiment in Croatia. The area chosen was flat grass land (no vegetation) and the soil was soft as it had been raining for about eight days prior to the experiment. Two deminers were each given 10 metal pieces to investigate (nails at 10 centimetres) along separate 20-metre paths.

One path had been flailed by a machine to a depth of 10cm; the other had not. The time taken to excavate each signal was recorded. The times recorded for each of the excavations do not represent excavation times in a real minefield as the deminers were excavating for nails not mines. Instead, the experiment was concerned with the relative efficiency of each type of excavation (flailed ground vs. un-flailed ground).

It took significantly longer to locate each target in unflailed ground than in flailed ground ($t\ (_{18}) = 4.24$, $p = .0005$, Fig. 7).

Fig. 7. Time costs of excavating for metal pieces in flailed and unflailed ground (blue represents average, "T" represents standard deviation)



Experiment observations

Excavating in ground that had been broken up was more efficient because a sharp tool (bayonet) was not necessary to penetrate the ground and remove or cut through the root systems present. The tool was necessary in un-flailed ground. A small hand spade was used in flailed ground and therefore digging was more efficient for removing loose soil surrounding the item being investigated.

Assistance to manual excavation techniques

Some organisations use manual excavation techniques as a full clearance method when the metal contamination in an area is too high for the use of a metal detectors. NPA has conducted two tests to gauge the effect of breaking up the ground prior to manual excavation.[8]

In the first test, one 10 x 10 metre box was flailed and one 10 x 10 metre box was left un-flailed. Ten deminers took 130 minutes to excavate the flailed box, and 190 minutes to excavate the un-flailed box, representing a productivity increase of 46 per cent in the flailed box.

In the second test, two groups of five deminers excavated for four hours each, one group in flailed ground and one group in un-flailed ground. In flailed ground, 47.2 metres were completed. In un-flailed ground, 36 metres were completed. This represents a productivity increase of 31 per cent in the flailed ground.

Effects of metal contamination in sub-surface ground preparation

In the surface ground preparation section it was argued that higher productivity increases occur after vegetation cutting in areas where there is less metal contamination, because the vegetation represents the major obstacle to manual demining. However, breaking up the soil provides added value after sub-surface ground preparation in high metal-contaminated areas because the excavation process is hastened. This advantage is not obtained after surface ground preparation.

Sub-surface with metal removal ground preparation

Introduction

Sub-surface with metal removal ground preparation incorporates all aspects of surface and sub-surface ground preparation with the additional benefit of removing metal contamination. This technique is seldom used and is a relatively new approach to mechanical ground preparation.

Mine clearance organisations often disapprove of the use of machines which cause mines to detonate and spread numerous metal fragments into the area to be cleared, because it exacerbates clearance productivity. The use of magnets could remove the added contamination thereby expanding the potential use of machines to detonate mines in more situations.

There are two general types of magnets: the permanent (or earth magnet) and the electro-magnet. Magnets are used in industry to clear away ferrous debris at airport runways, driveways, parking lots, etc.; to reduce vehicle and aircraft maintenance and reduce occurrence of flat tyres. In these roles, permanent magnets seem to be preferred over electromagnets as there is no need to provide an electrical power source. Fragments are removed from the magnet by either collecting them on a non-ferrous separator plate or by inverting the magnets. Suitable commercial tow-behind magnet systems sell for about US$6,000 and weigh approximately 400kg. Magnet strength is categorised in grades, with Grade 8 being the strongest available.

Sub-surface with metal removal ground preparation was observed only in Thailand. TMAC uses a Pearson magnet as part of the ground preparation process to remove the majority of metal pieces found at sites along the Thai/Cambodian border (*see case study Area reduction of non-patterned minefields in Thailand*). The magnet is fitted to a prime mover with a hydraulic lift and external service. In use, the magnet is either pushed or pulled over the minefield with the depth wheels set to position the magnet 50 to 100millimetres clear of the ground.

Fig. 8. Pearson magnet as used by TMAC.

Advantages of sub-surface with metal removal ground preparation

The obstacle which most hampers the progress of the manual deminer is metal contamination. Some areas can be so highly contaminated that the metal detector will continually signal the presence of metal and consequently require full manual excavation. This can result in daily clearance figures lower than five square metres per six-hour working day. Sub-surface with metal removal ground preparation incorporates the advantages of both surface and sub-surface methods with the added advantage of removing a significant portion of the metal contamination.

This section focuses on the metal-removal effects of sub-surface with metal removal ground preparation and is based on the results of a trial conducted by the HALO Trust in Cambodia, and The Japanese Alliance for Humanitarian Demining Support (JAHDS) in Thailand, using the Pearson magnet.[9]

Methods

The trial was conducted between 25 March and 10 April 2001 in Thmar Pouk district, Banteay Meanchey Province, Cambodia (internal trial report dated March 2001).

Six closely-located 200 square metre boxes were marked out. Box 1 was cleared using normal manual techniques to gauge the amount of metal contamination in the area. A Pearson magnet was passed over the surface of Box 2 and the number of metal pieces counted.

In Boxes 3 and 4, a cultivator working to a depth of five-six centimetres was used to expose the metal contamination below the surface. The magnet was then passed over the area and the number of metal items collected was counted.

In Boxes 5 and 6, the magnet was passed over the box and the items counted before cultivation to assess the surface metal contamination. After cultivation, the magnet was passed over the boxes again and the items counted.

After processing, all boxes were cleared by a manual deminer, and the number of metal items found recorded. The daily clearance rate by the manual deminer was recorded.

Results

Similar amounts of metal were found in all of the boxes (*see Table 1 overleaf*). The magnet reduced the amount of metal to be found by the deminer under both removal conditions. Passing the magnet over the ground both before and after cultivation removed more metal than passing it only after cultivation, as the amount of metal found by the manual deminer in Boxes 3 and 4 (52 of 149 pieces) was significantly higher than in Boxes 5 and 6 (27 of 160 pieces) ($X^2 = 13.2$, $P=0.003$).

Removing surface metal contamination resulted in an IR of 21 per cent (Box 2). Removing sub-surface metal contamination resulted in an IR of between 93 per cent (Box 3) and 101 per cent (Box 4). Removing surface then sub-surface metal contamination resulted in an IR of between 127 per cent (Box 5) and 200 per cent (Box 6).

Box 1 was cleared completely by one deminer who found 76 metal pieces in total with a clearance rate of 66 square metres per six-hour working day.

In Box 6, the magnet was passed over the area to collect surface metal. The area was then cultivated to expose sub-surface metal and the magnet passed over the box. The number of metal pieces in Box 6, coincidently, was the same as the number in Box 1 but the clearance rate increased to 200 square metres per six-hour workday. This represents a 200 per cent increase in the manual demining rate.

An indication of metal contamination levels was obtained at the Nong Yakeao minefield (ref No. 005) in Thailand, which was cleared by JAHDS. At this site the

Table 1. Number of metal items collected by magnet and deminer after different cultivation treatments (cultiv.=cultivation)

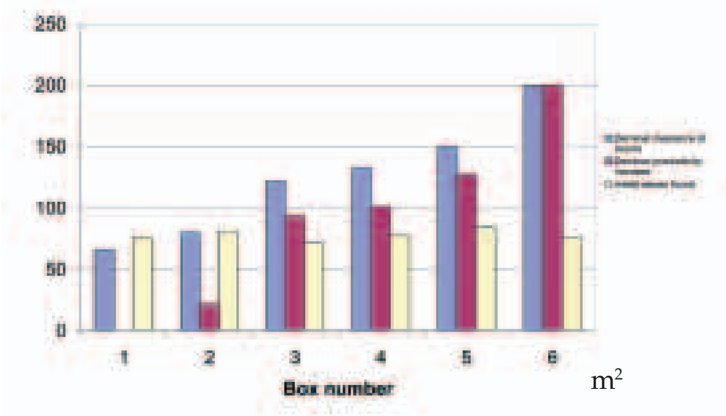
	Metal items collected before cultivation	Metal items collected after cultivation	Metal items found by deminer	Total items found	Percentage of items removed by magnet
Box 1	No collection	No cultivation	76	76	
Box 2	28	No cultivation	56	84	**33**
Box 3	No collection	41	Surface: 2 Sub-surface: 28	71	**58**
Box 4	No collection	56	Surface: 2 Sub-surface: 20	78	**72**
Box 5	29	37	Surface: 2 Sub-surface: 16	84	35 before cultiv. 45 after cultiv. **Total: 80**
Box 6	27	40	Surface: 1 Sub-surface: 8	76	36 before cultiv. 53 after cultiv. **Total: 89**

The different treatment conditions influenced the subsequent rate of manual demining, with Boxes 5 and 6 (magnet, followed by cultivation, followed by magnet) giving the most productive return (Table 2).

Table 2. Manual demining rates for clearance of boxes under different treatment conditions after magnet and cultivator (cultiv.=cultivation)

	Manual demining rate per 6-hour day	Area cleared	Total metal items found
Box 1	No metal removal	66 m^2	76
Box 2	Metal removal without cultivation	80 m^2	84
Box 3	Metal removal after cultivation	122 m^2	71
Box 4	Metal removal after cultivation	133 m^2	78
Box 5	Metal removal before and after cultiv.	150 m^2	84
Box 6	Metal removal before and after cultiv.	200 m^2	76

Fig. 9. Effects of magnet of use on deminer productivity



number of metal pieces of different size and configuration within a 11,241 square metre block was 36,119 (averaging 3.2 pieces per square metre).[10]

If deminers were spending, on average, 15 minutes to excavate each and every metal signal and the magnet removed 70 per cent of the metal contamination, and this was being done in a six-hour working day, 1,053.5 working days would be saved by using a magnet in this block. If 30 demining lanes were deployed on site then the saving would be 35 operational days (1,053.5/30).

Use of magnets in operations

It is necessary to remove any vegetation prior to deployment of the magnet. Additionally, in this example, rollers were used on land before the magnet was towed behind to limit the chance of mine damage. Future magnet use may involve a flail with a commercially-available tow-behind magnet. In this way, vegetation is removed, the chance of mine damage to the magnet is limited, and the ground is broken up to make metal fragments more accessible to the magnet.

Summary

Removing the vegetation and breaking up the ground significantly improves the productivity of manual demining. However, the result of these techniques depends on the amount of metal contamination in the ground. Therefore, removing metal contamination prior to the deployment of manual deminers potentially offers the most effective time saving method of ground preparation.

There are two categories of metal contamination — surface and sub-surface. Removing sub-surface metal contamination would have a greater effect than removing surface contamination as the deminer will spend more time investigating the former than the latter.

Removing surface then sub-surface metal contamination is the most effective use of a magnet in the metal-removing process. Neglecting the surface metal contamination and immediately breaking up the ground to expose the sub-surface metal contamination will result in some of the surface-metal items being buried and therefore becoming less accessible to the magnet.

Fig. 10. Metal collected by the Pearson Magnet on TMAC operations.

Removing metal contamination has major potential benefits in terms of clearance efficiency. The HALO Trust test results showed that as much as 89 per cent of metal contamination can be removed under some conditions leading to a 200 per cent increase in the manual-demining rate.

Evidence of the operational effectiveness of a magnet was seen in operations conducted by TMAC which initially conducted mine clearance along the Cambodian border manually. Each deminer was averaging four to five false metal investigations for each square metre cleared.

After the deployment of the Pearson Magnet, manual deminers were averaging one false metal investigation every four to five metres.[11]

Conclusions, findings and recommendations

Conclusion 1.

Ground preparation machines are generally underused.

Findings

Within some mine action programmes, machines still play only a small role in the mine clearance process. For example, the Cambodian Mine Action Centre's manual demining platoons cleared a total of 6,921,372 square metres in the first six months of 2002 but only 640,252 square metres (10.3 per cent) were prepared by machine.[12] In Angola, NPA mechanically prepared 23 per cent of the total area they cleared in 2001.[13] Manual teams in the Mine Action Programme for Afghanistan cleared a total of 15,645,634 square metres in 2001 but only 288,998 square metres (1.8 per cent) was prepared mechanically.[14]

However, in Thailand, the Humanitarian Mine Action Unit One mechanically prepares 100 per cent of all the land it clears.[15] In Croatia, of the 13,640,000 square metres demined in 2001, approximately 75 per cent (10,230,000 square metres) were prepared mechanically and followed up with either manual demining or MDD techniques.[16]

The GICHD *Study of Global Operational Needs* found that "*In the great majority of demining scenarios, mined areas contain very few mines, and time spent dealing with these individual mines is insignificant in relation to the time spent carrying out other activities such as vegetation clearance and the detection or removal of scrap metal.*"

Also, the risk assessment sub-study report (*see Chapter 2, Table 1*) explained that, on average, mines occupy a very small part of a suspect area. This indicates the need for ground preparation machines to contribute more, particularly if such large percentages of suspect areas do not contain mines. Moreover, ground preparation machines can contribute significantly to a manual or MDD clearance programme's performance if machine use is tailored to the area.

The lack of detailed comparative data collected by demining organisations may be the reason that ground preparation machines are not being used to a greater degree. Most organisations do not have effective recording procedures and therefore do not know what quantitative benefits their machines are producing. We should assume that if organisations knew the quantitative benefits, they would then capitalise on them by maximising their mechanical ground preparation capacity.

The normal demining organisation's operational reporting format is seldom detailed beyond the amount of land processed by machine. However, measures of productivity alone do not lead to improvements in productivity, or a greater understanding of the usefulness of a machine.

Recommendation 1.

Mine clearance operations should make significantly greater use of machines for ground preparation. In order to quantify the productivity improvements that result, more demining organisations need to separate the recording of land cleared manually behind a machine from the land cleared manually without machine assistance as a basic requirement.

Conclusion 2.

Machines conducting sub-surface with metal removal ground preparation offer the best quality of ground preparation as they remove all practical obstacles for follow-up clearance.

Findings

Machines capable only of surface ground preparation are limited in the assistance they can provide to manual deminers and MDD teams. They merely remove vegetation and, on occasion, tripwires. Productivity is increased when they are deployed to areas with minimal metal contamination, where vegetation is the main obstacle facing subsequent deminers. Optimising the productivity of intrusive and non-intrusive vegetation cutters involves considering:

- how the greatest number of demining lanes can be supported;
- the most effective use of breaching lanes for non-intrusive machines; and
- the metal contamination levels in each minefield.

Machines conducting sub-surface ground preparation are limited by the degree of preparation they perform for follow-up clearance teams, but offer a higher degree than surface ground preparation as benefits are cumulative. Additional advantages include:

- speeding up the excavation process the manual deminers perform;
- enabling dog working-day periods to extend into the cooler months of the year; and
- speeding up the excavation process undertaken by a deminer investigating each metal signal from a metal detector.

Ground preparation machines are probably more productive if they are driven into the minefield containing invisible obstacles (dead-fall, tree stumps, wire fencing and ditches, etc.) as opposed to being remotely controlled.

Productivity would be maximised by the increased ability of the driver to see and avoid obstacles. By including a driver, the cost of a machine will increase because of the operator protection needed. However, this extra expense would probably be more than compensated for by the extra productivity.

Machines conducting sub-surface with metal removal ground preparation offer the best quality of ground preparation as they remove all common obstacles for follow-up clearance. These obstacles can be grouped in a hierarchal order as described in Figure 11.

As the machine or mechanical process removes each level of obstacle, follow-up clearance productivity is increased depending on the degree that each obstacle poses to the subsequent clearance technique.

Sub-surface with metal removal ground preparation machines remove the threat of tripwires, so that the deminer is no longer required to perform a tripwire-detection drill. They remove vegetation so that the deminer no longer spends time cutting away all vegetation down to ground level and they remove a high degree of metal contamination. A magnet is best used to remove metal contamination on the surface then reused after exposing the sub-surface. This technique requires multiple passes and the use of several tools, and as such, may negate the advantage of using a magnet twice. The better ground preparation machine is, therefore, one which performs these tasks in as few passes as possible.

Recommendation 2.

Demining organisations and mine action centres should give particular consideration to the use of machines that perform sub-surface with metal removal ground preparation, especially where a machine can achieve all three categories of preparation in as few passes as possible.

Fig. 11. Hierarchical order of obstacles (bottom to top)

Endnotes

1. The HALO Trust (2001b).
2. *Ibid.* 3,400 square metres was the highest recorded area cut by the machine in 2001.
3. The machines actually cut intermittently throughout the day, this is the average aggregate time.
4. See the GICHD *Mechanical Demining Equipment Catalogue 2004*.
5. This average is consistent with MAG Cambodia, NPA Bosnia as well as HALO in Cambodia.
6. Records in 2001 show that more land was being cleared manually than was being cut by the machine in all the sites it operated.
7. Phelan and Webb, in press.
8. Information provided by Aksel Steen-Nilsen, Programme Manager, NPA Angola.
9. Saratha (2001). This report is just one section of a larger trial report on the range of Pearson tools which were attached to a Volvo 4400 front-end loader.
10. Information provided by J Van Zyl, JAHDS, Thailand.
11. Information provided by D. McCracken, Technical Advisor to TMAC.
12. CMAC (2002). CMAC annual reports can be downloaded from their website *www.camnet.com.kh/cmac*.
13. Internal report provided to GICHD, summarising operational results of 2001.
14. Results of all operational activities for 2001, provided to the GICHD by the MAPA operations office.
15. This is limited to Humanitarian Mine Action Unit 1 working on the Thai/Cambodian border.
16. Results for 2001 provided by Nicola Pavkovic, Assistant Director, Centre for Testing Development and Training, CROMAC.

Chapter 5.

The protection of vehicles and plant equipment against mines and UXO

Summary

Three principles can be incorporated into the design of vehicles and equipment to render protection against the blast effect of mines: absorption of energy, deflection of blast effect away from the hull and the distance from detonation point.

A simple and cost-effective manner to absorb energy is to fill the tyres of wheeled vehicles with water. This increases considerably the protection of light and medium vehicles against the threat of blast anti-tank mine detonating underneath a wheel.

The effect of blast against the hull of a vehicle can be reduced considerably by incorporating steel plates at an angle to the direction of blast. Reflected pressures are generated when the blast direction is at a 90° angle to the plate. This approach has lead to the introduction of V-hulls, which have been successfully used in the protection of light- and medium-sized vehicles against mines.

The protection level of all vehicles can be further increased by use of four-point safety belts, good seating design and footrests (not attached to the floor), and "good housekeeping" (not having loose items in the car).

Introduction

This chapter discusses the threat posed by landmines and UXO to vehicles and plant equipment operating in the field and offers guidance on appropriate ways to minimise the damage to vehicles and injuries to their occupants in the event of an explosion.

The design, construction and testing of mine-protected vehicles and systems are conducted within a framework of military standards and specifications. Most of the design and testing detail is considered confidential information. Some military standards and specifications have, however, been de-classified for use by commercial and humanitarian deminers; where this has occurred, they have been included.

Similarly, construction methods are regarded as intellectual property by the various companies and entities involved within the industry. It has therefore not been possible to include exact detailed mechanical design and manufacturing criteria as well as test data.

This chapter does not provide the last word in the protection of vehicles in demining. It represents sensible principles, distilled over years of practical field experience. The information provided is especially useful for organisations intending to adapt commercial vehicles for demining purposes.

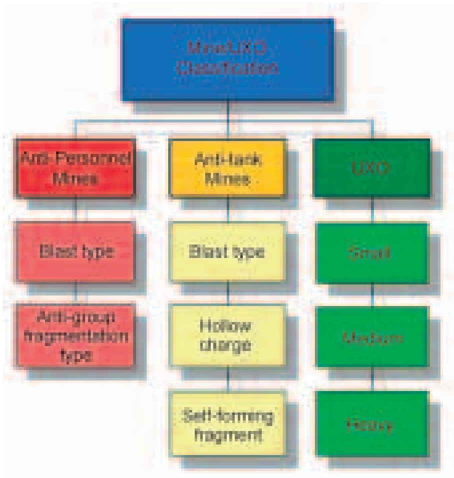
Assessing the mine and UXO threat

Classification of mines and UXO

It is assumed that the majority of humanitarian and commercial demining operations are conducted in a stable or semi-stable political environment. Hostilities have ceased and deminers, vehicles and equipment are not exposed to direct or indirect fire or the threat of command detonations. The threat of hostile fire (direct or indirect) as well as that of command-detonated mines or devices are therefore excluded from the study underpinning this chapter.

It is common to classify mines according to their intended use and purpose. This classification is used throughout the demining world today and will be used here to provide a framework for further discussion. While clearing mines dominates the overall demining effort, items of UXO also need to be located and rendered safe. UXO poses a threat to operators, vehicles and plant equipment during clearance operations and items of UXO are therefore included in this classification.

Fig. 1. Classification of mines and UXO



Anti-personnel mines

Anti-personnel mines are designed to incapacitate or kill personnel on foot through blast or fragmentation effect.

Blast mines

As their name suggests, anti-personnel blast mines rely primarily on the blast effect from the explosive charge to incapacitate personnel. Such mines are usually initiated by direct pressure on top of the device, i.e. by stepping on them. Detonation results in a combination of shock and blast effects that destroy human tissue with severe localised maiming of flesh and limbs in the lower body region. If the victim is not killed outright, amputation of the lower limbs — feet or legs — is usually required.

Secondary blast effects can also include severe damage to the lungs in the upper torso, depending on the size of the explosive charge and the position of the victim's body relative to the mine. The detonation and resulting blast effect also creates secondary fragmentation in the form of soil particles, stones and mine debris that can cause wounds and lacerations to the lower limb region as well as the upper torso and arms. Eyes are particularly vulnerable to the secondary fragmentation effect. Hearing is normally impaired as a result of the blast.

Smaller blast mines contain less than 100 grams of high explosive as their main charge. Their primary objective is to incapacitate the victim by causing severe localised damage to the feet and lower limbs. Secondary effects, aside from the threat of fragmentation to eyesight, are usually less severe than those encountered with larger blast mines.

Larger blast mines contain between 100 and 250 grams of high explosive. These mines not only cause severe damage to lower limbs and tissue, they also have greater and more severe secondary effects on the upper torso, which include severe lung damage and secondary fragmentation effects. The loss of upper torso limbs, such as fingers and hands, is not uncommon when victims encounter these larger anti-personnel blast mines.

Fragmentation mines

Omni-directional mines

These mines rely on the fragmentation effect to incapacitate personnel. This type of mine usually consists of a cylindrical metal sleeve that surrounds an explosive charge. The metal sleeve produces fragmentation with velocities up to 1,500 metres per second when the explosive charge is detonated and is lethal to people up to 50 metres.

Two types are encountered: the first is stake-mounted on the surface and activated by pull-switch and tripwire; the other is referred to as the "bounding mine". Bounding mines are buried underneath the surface and activated by either pressure or tripwire. Activation of the fuse initiates a black powder charge that expels the mine from the ground to detonate at a height of approximately 1.5 metres to optimise the fragmentation effect against personnel.

Directional mines

These mines restrict the projection of fragmentation within a 40° to 60° arc in front of the mine. They are commonly used to initiate ambushes where they are command detonated (usually electrically) or for perimeter protection and early warning. In the last instance they are initiated by tripwire.

Anti-tank mines

These mines rely on blast effect to incapacitate vehicles. Self forming fragment (SFF) and hollow charge (HC) mines (discussed below) use the "platter charge" effect or the "Munroe" or "hollow charge" effect to penetrate steel in order to incapacitate vehicles, especially heavy armour.

Blast mines

These mines rely on the blast effect from the main explosive charge (normally 5-7 kilograms) to incapacitate vehicles. The charge is usually initiated by a pressure mechanism that activates the mine. While the blast effect is devastating to light, soft-skinned vehicles, damage to medium-size armoured vehicles is usually contained to the wheel stations or tracks. The shock effect transferred to the hull can cause injury to occupants, especially if the hull is penetrated.

Fig. 2. Double mine located in Angola. The bottom mine is a metallic TM46 anti-tank mine with a low-metal-content Type 72 anti-tank mine on top.

Anti-tank blast mines can either be boosted with additional explosives placed underneath the mine or by more than one mine being stacked on top of the other, as depicted in Figure 2. This results in a main explosive charge of 15-20 kilograms that enhances the blast effect. (So-called triple mines are not uncommon in certain regions). This configuration is usually used against armoured personnel-carriers, mine-protected vehicles and medium to heavy tanks.

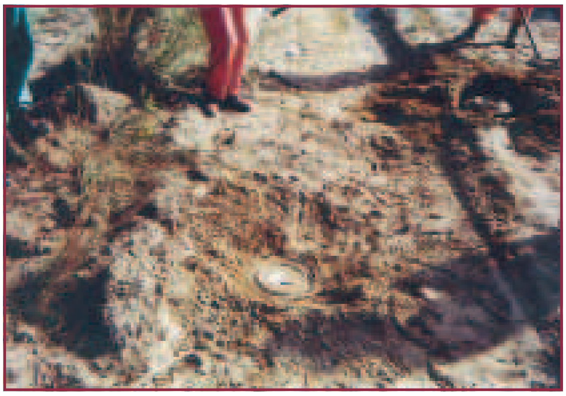


Fig. 3. Two linked mines located in Angola. The TM57 anti-tank mine in the centre is linked by a detonating cord to a low-metal-content PTMI BA3 anti-tank mine in the track on the right of the picture.

Another tactic is to position the mine to allow for a centre blast underneath the vehicle's hull. The blast is contained underneath the hull and causes greater damage to the vehicle. The mine is positioned in the middle of the road with a second mine located in the wheel track. These mines are linked with detonating cord as depicted in Figure 3. This configuration is known as the "goggle mine".

Hollow charge mines

These mines use the "Munroe" or "hollow charge" effect to penetrate armour and allow the blast and shock effect of the accompanying explosion to incapacitate the vehicle and occupants. The explosive charge is cone-shaped and provided with a metallic liner (usually copper) with the open end of the cone pointed upwards towards the target. Upon detonation, the Munroe effect causes a focused blast effect that turns the metallic liner into a high-speed copper slug capable of penetrating the steel due to its very high kinetic energy. Once the steel has been penetrated, the blast effect enters the vehicle interior and incapacitates the occupants. These mines are used against armoured and mine-protected vehicles.

A number of mines are included in this category because they create more damage to vehicles than the conventional anti-tank mine relying on blast alone, even though they are not, strictly speaking, HC mines. For example, although the South African

No. 8 anti-tank mine does not use the Munroe effect optimally (as it does not have a metallic liner), the focusing effect of the explosive charge causes the resultant blast effect to be more effective than some other conventional blast anti-tank mines. Similarly, the British MK 7 anti-tank mine is fitted with a heavy metal fuse array on top of it. This fuse forms a high-speed metal slug that penetrates steel up to a certain thickness. This mine is also more effective than some other conventional blast anti-tank mines.

Self forming fragment (SFF) mines

SFF-type mines rely on the "Miznay Shardin" or "platter" effect to incapacitate vehicles and its occupants. The mine contains a hollow dish-shaped metal liner facing towards the target. Upon detonation, this dish (with a mass of 0.73 kilograms) forms a high-speed metal slug that is projected towards the target at velocities up to 2,500 metres per second. This slug is capable of penetrating armoured steel, allowing the ensuing blast effect to enter the target vehicle and incapacitate the occupants and cause damage to the vehicle.

The Miznay Shardin effect causes greater damage to vehicles than the Munroe effect. The formed slug is bigger and thus causes greater damage to the vehicle's hull. The ensuing hole in the hull is larger, with the result that the blast effect that enters the hull is considerably larger, causing more damage to occupants and the interior of the vehicle. These mines are usually used against medium and heavy armour and mine-protected vehicles.

Less effective SFF mines can be improvised by positioning a circular metal plate (10-20 millimetres in thickness) on top of a conventional blast anti-tank mine. While detection of the mine is easier, the resulting effect is far more devastating than that of a conventional blast mine alone.

Unexploded ordnance

UXO can be classified as small, medium and heavy according to their explosive content. While most items of UXO rely on a combination of blast and fragmentation effect to incapacitate personnel and vehicles, more sophisticated devices include HC effects, thereby posing a greater threat.

Small-size UXO

Small-size items of UXO contain an explosive charge of less than 500 grams and rely on a combination of blast and fragmentation effect to incapacitate personnel and vehicles. Examples include the following:

- hand grenades,
- rifle grenades,
- 40-millimetre aircraft rounds, and
- submunitions.

Medium-size UXO

So-called "medium-size" items of UXO contain an explosive charge of between one and 20 kilograms and rely on a combination of fragmentation and blast effect to incapacitate vehicles and personnel.

Large UXO

These items of UXO consist mostly of aircraft bombs with explosive charges of up to 500 kilograms. They rely mostly on their blast effect to incapacitate vehicles, equipment and personnel.

Definition of mine threat levels

The threat that mines and UXO pose to vehicles, plant equipment and their occupants is defined according to severity in Table 1 below. These levels will be used to determine required protection levels to counter this threat.

Table 1. Definition of mine threat levels (MTL)

MTL	Description	Typical examples
MTL-01	anti-personnel mine blast type	PMN, PMD-6, Type 72
MTL-02	anti-personnel mine fragmentation type small-size UXO	POM-Z, OZM-4, OZM-72, PROM-1 Hand grenades, rifle grenades, submunitions
MTL-03	anti-tank blast type	TM46, TM57, TMA-3
MTL-03A	anti-tank blast under wheel	TM46, TM57, TMA-3
MTL-03B	anti-tank blast under hull	TM46, TM57, TMA-3
MTL-04	medium-size UXO (mortars and artillery rounds)	60-120 millimetre mortars. Artillery rounds up to 155 millimetres
MTL-05	anti-tank HC	AT-4
MTL-06	anti-tank SFF	TMRP-6, TMRP-7, TMK-2
MTL-07	heavy-size UXO	250-500 kilogram aircraft bombs

Effect of mines and UXO on unprotected vehicles, plant equipment and occupants

While the protection of personnel working in mine-affected areas is of paramount importance, the effects of mines and UXO on personnel "in the open" fall outside the scope of this study. This section concentrates on the effects on unprotected vehicles and plant equipment, with particular emphasis on the safety of the occupants and crew inside.

The mass of the vehicle or equipment plays an important role in determining the effects of mines and UXO on them. The heavier a vehicle, the less damage is caused by the mine or UXO. Vehicles and equipment are therefore classified by mass in order to facilitate this discussion, although hull shape and materials used are also of importance.

Table 2. Classification of vehicles and plant equipment

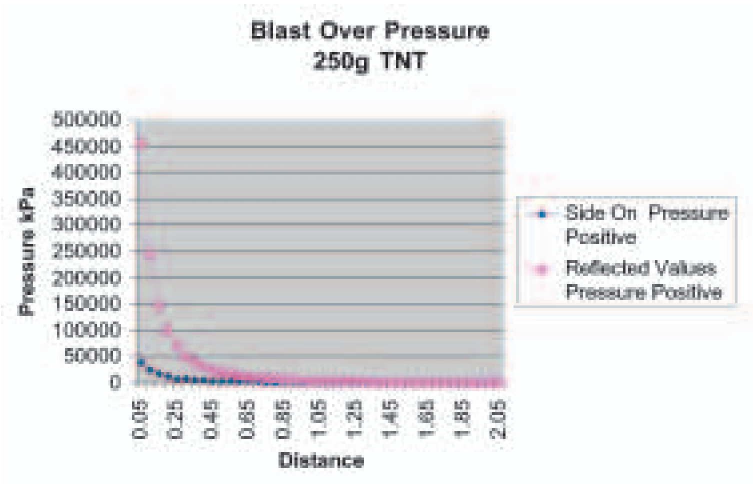
Classification	Mass (metric tonnes)	Examples (unprotected non-military vehicles)
Light	< 3	Sedan vehicle, light pick-up, lorry, light back-actor
Medium	3-15	Medium lorry, bus, D-4 bulldozer, excavator
Heavy	15-30	Heavy lorry, D-8 bulldozer, heavy excavator
Extra heavy	> 30	Low-bed with freight

Anti-personnel blast type (MTL-01)

Light vehicles

The blast effect associated with the detonation of high explosive manifests itself in the form of a high-speed shock wave with very high overpressure being emitted from the charge. This overpressure decays very rapidly with distance due to expansion into the surrounding air as depicted graphically in Figure 4 below. The graph depicts the decay of reflected overpressure with distance for the detonation of 250 grams of trinitrotoluene (TNT) on the surface. The overpressures were calculated from the Rankine-Hugoniot equation, which enables the overpressure to be calculated at given distances for a TNT charge detonated on the surface. The overpressure can be calculated and presented in two ways, either as reflected pressure or “side-on” pressure. The difference is the way in which the blast wave is viewed.

Fig. 4. Blast overpressures against distance in metres for 250 grams of TNT charge



Reflected pressures are obtained when the blast wave is viewed directly from the front, i.e. the measuring probe is positioned directly in front of the approaching wave. The wave hits the surface of the probe directly and reflects back towards the point of its origin. The direction of measurement is in the same direction as that of the blast wave.

“Side-on” pressures are obtained when the blast wave is viewed from the side, thus the direction of measurement is 90° perpendicular to the direction in which the blast wave is travelling. "Side-on" pressures are much lower than reflected pressures, depending on conditions. Reflected pressures are more useful in engineering applications because they give an approximation of what pressure and associated impulses are exerted on materials and structures when subjected to explosives blast waves. Care should be taken when using quoted or calculated pressures to always establish how the blast wave was viewed when pressures are quoted or calculated.

While the Rankine-Hugoniot equation is useful to estimate the resulting overpressure for a given explosive charge size, it is only valid for ideal conditions for the explosive charge suspended in free air. It further assumes that the shock front and blast wave develop and expand evenly away from the point of detonation. It does not take soil effects into account. When explosive charges are detonated under the surface of the soil, factors such as soil type, moisture content and depth have a profound effect on the development of the blast wave. The wave will develop in the direction of least resistance and will project the soil on top of the charge in these directions, causing zones of pressures much higher than calculated. In spite of this, the Rankine-Hugoniot equation is handy to establish the order of magnitude of overpressures expected at certain distances from a given explosive charge size.

From Figure 4 above it is evident that the blast effect is limited to less than one metre from the detonation point. Thus, the effect of anti-personnel blast type mines on light vehicles is restricted to local damage in the wheel area. The tyre is punctured and the tyre rim and wheel studs may be damaged by the bigger type anti-personnel mines, such as the PMN or PMD-6. Hydraulic brake lines may also be damaged.

The threat to occupants caused by the blast effect is minimal. The biggest threat to occupants is the ensuing accident resulting from the sudden puncture of the tyre, similar to a tyre blow-out in normal vehicle accidents. Occupants are shielded from the blast effect by the vehicle body and are usually more than two metres removed from the detonation point. The resulting blast from the detonation of this class of mines is insufficient to rupture body panels and thus prevents the blast and associated shock wave from entering the vehicle compartment.

Medium, heavy and extra heavy vehicles

The effects are similar to those on light vehicles, but with less damage to the wheel station. There is no damage to tracked vehicles, especially with heavier vehicles and plant equipment.

Anti-personnel fragmentation mine and small UXO (MTL-02)

All vehicle classes

The detonation velocity in cast explosives such as TNT is approximately 7,600 metres per second. When a column of explosives is encased in steel, the velocity of the ensuing shock wave (approx. 7,600 metres per second upon detonation) exceeds the velocity of sound in steel (approx. 6,000 metres per second). Energy is pumped into the steel at rates higher than those with which the steel can conduct this energy. This leads to the build-up of very high, localised stresses within the material along the molecular grain boundaries. This results in the fracture of the material along the grain boundaries. These fractured pieces are referred to as fragments and are propelled away from the detonating explosive charge at velocities in the order of 1,000 to 1,800 metres per second. The size and shape of these irregular fragments depend very much on the material properties of the steel.

The fragmentation emitted by this class of mine and small UXO is capable of penetrating the body, windshield and windows of the vehicle at distances of up to 30 metres causing a serious threat to occupants or operators. Shrapnel can also cause severe localised damage to vehicle systems such as brakes, cooling, hydraulic and fuel lines.

Tripwire-operated mines pose a serious threat to plant equipment working in mine-infested areas. The equipment can activate the mine by disturbing the tripwire up to 10 metres in front of the machine, but the mine may be positioned right next to the machine, resulting in a detonation very close to it. Shrapnel velocities in such close proximity average between 800 to 1,000 metres per second that can easily penetrate 10 millimetres of mild steel.

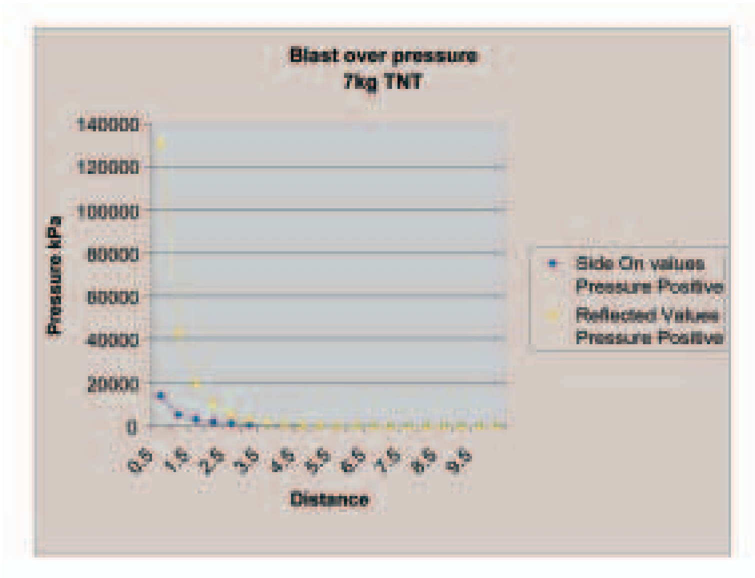
Bounding mines pose an additional danger. They are expelled from the ground with considerable force when activated. The mine itself can easily penetrate the soft belly of an unprotected vehicle. In one instance, a Casspir MPV was hit by an OZM-72 bounding mine which detonated just behind the rear door. The mine hit the side of the three-millimetre-thick "checker plate" step with sufficient force to bend the plate out of the way before detonating.

Blast of anti-tank mines under a wheel (MTL-03A)

General considerations

When anti-tank blast mines are initiated, the blast and shock front is formed exactly in the same manner as that for the initiation of anti-personnel blast mines. The difference is that the ensuing blast wave generates overpressures much higher than that of anti-personnel mines. Anti-tank blast mines are thus capable of causing damage at much further distances from the detonation point. The relation between blast overpressures and distance for a seven kilogram TNT charge is depicted in Figure 5.

Fig. 5. Blast overpressure *v.* distance in metres for 7 kilograms of TNT



The high-pressure zone associated with the extremely high associated reflected pressure (3,300 kiloPascals) is now extended to three metres.

The initial shape of the blast wave as it emerges from the ground depends on the depth of the charge as well as soil conditions (moisture, soil type and hardness), but is generally cone-shaped with an angle between 45 and 60 degrees. This wave flattens out to an inclusive angle of 100 to 120 degrees in the final development of the blast wave due to the sideways expansion parallel to the soil surface as indicated in Figure 6. This picture was captured on film approximately five milliseconds after initiation.

Fig. 6. Final development of explosive shock wave approximately 5 milliseconds after initiation of a 7 kilogram TNT test charge buried 100 millimetres under the surface.

The position of the shock wave edge is clearly visible along the surface by the dust kicked up as the shock wave passes over the ground. The dotted red line depicts the theoretical position of the shock wave at this stage, had the shock wave formed symmetrically upon emerging from the soil. This edge is further away from the detonation point than the following plume that contains smoke (detonation products), sand and dust particles. These particles, and thus the plume, travel at the so-called particle velocity which is less than the shock wave velocity. The black objects emerging above the plume are solid debris (e.g. stones), which were initially projected upwards through the impulse caused by the blast wave.

At this point their velocity is greater than that of the shock wave and they are in front of the shock wave. The velocity decay of the shock wave in air is greater that that of solid objects with a certain level of kinetic energy. This is due to the expansion in air.

While the reflective pressures generated by the horizontal development of the blast wave is of the same magnitude as the vertical development, the reflected pressures associated with the vertical development are of greater importance where the blast effect on vehicles is concerned. This is the area included within the 100º cone above the detonation point (depicted in Figure 6), also referred to as the "cone of destruction". Local overpressures within this cone are normally of such a magnitude that they lead to the complete destruction of vehicle chassis parts, panels and even the engines of unprotected vehicles.

The size of this cone of destruction as well as associated reflected pressures, particle velocity (plume velocity) and time of arrival of the shock wave against the vertical distance from the detonation point are given in Table 3. The values were calculated from the Rankine-Huguniot equation and can therefore only be regarded as indicative of the order of magnitude. The calculations to establish the cone diameter are contained in Annex 1 to this chapter.

Table 3. Shock wave characteristics *v.* distance for a 7kg TNT test charge

Distance above detonation point (metres)	Cone diameter (metres)	Reflected pressure (kPa)	Shock velocity (m/s)	Particle velocity (m/s)	Arrival time of shock wave (millisecs)
0.5	1.2	131,000	3,610	3,290	0.08
1.0	2.4	43,500	2,440	2,020	0.24
1.5	3.6	19,800	1,840	1,430	0.49
2.0	4.8	10,400	1,440	1,060	0.81
2.5	6.0	5,720	1,160	815	1.22
3.0	7.2	3,300	936	637	1.72
3.5	8.4	1,950	812	507	2.33
4.0	9.6	1,250	714	412	3.01
4.5	10.8	838	642	340	3.79
5.0	12.0	583	588	284	4.65

Blast effect on light unprotected vehicles

Based on an “average” light vehicle five metres long and two metres wide and with a ground clearance of 50 centimetres, the cone of destruction will encompass roughly one quarter of the vehicle when an anti-tank blast mine is detonated under a wheel. Three quarters of the blast effect is dissipated into the surrounding air, but the blast wave generates extremely high reflected pressures on the chassis and hull of the vehicle close to the ground. These high reflected pressures simply destroy and remove everything in its path. The vehicle itself is flung into the air, and pending on its initial velocity, normally lands five to 10 metres away from the detonation point.

The effect of the cone of destruction resulting from a wheel blast underneath a light unprotected vehicle is depicted schematically in Figure 7. The part of the vehicle coloured in red is usually completely destroyed and the likelihood of occupants within this area surviving is slim.

Fig. 7. Illustration of the “cone of destruction” in wheel blasts on light unprotected vehicles

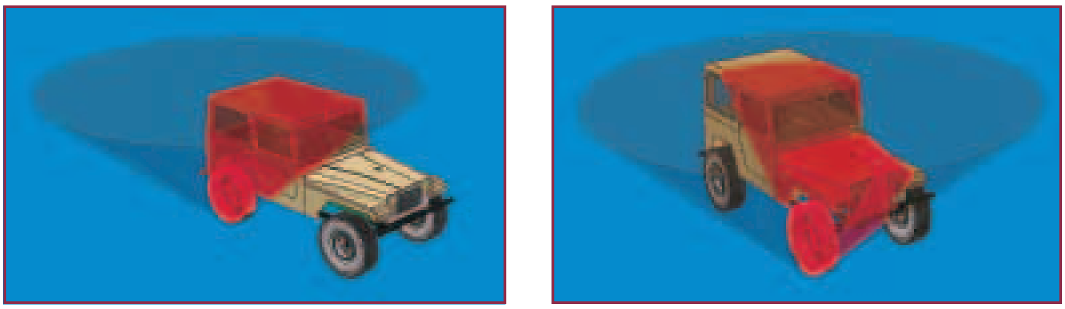


Figure 8 depicts a light unprotected pick-up that detonated a single TM 46 anti-tank blast mine under the left front wheel. The entire cab and engine compartment have been destroyed (the areas within the cone of destruction). Note that no damage occurred to the left rear wheel and wheel-base as well as the rear area outside the cone of destruction.

Fig. 8. Light unprotected pick-up destroyed by the blast from a single TM 46 anti-tank mine under the left front wheel

The effect on the occupants depends on their position relative to the detonation point. If an occupant is positioned within the cone of destruction, death is almost certain.

Statistics of the effect on the occupants of the explosion of single anti-tank mines under the wheels of light unprotected vehicles in the former Rhodesia (1972-1978) are summarised in Table 4. They indicate that in recorded incidents 28 per cent of the occupants were killed outright and a further 36 per cent sustained severe injuries. Injuries included severe tissue damage and lacerations (some leading to amputation of limbs) sustained by secondary fragmentation generated by the blast wave. Further injuries included impaired hearing, damage to eyesight and, though to a lesser extent, lung damage.

Table 4. Mine incidents recorded in Rhodesia (1970-1978)
Blast effect on medium and heavy unprotected vehicles

Vehicle	Detonations	People involved	Deaths	Injuries
Unprotected Land Rovers	22	88	81 (20%)	52 (59%)
Unprotected Land Rovers, front wheel only	7	24	2 (8%)	15 (60%)
Protected Land Rovers, steel plates next to wheels	118	397	25 (6%)	185 (47%)
Protected Land Rovers, front wheel only	81	249	3 (1.2%)	120 (48%)
Leopard	37	139	0	18 (13%)
Rhino	12	45	1 (2%)	15 (33%)
Hyena (SA)	99	407	1 (0.2%)	82 (20%)
Kudu	14	70	7 (10%)	39 (56%)
Puma (heavy vehicle)	82	715	2 (0.2%)	106 (15%)
Unprotected light vehicles (cars, etc.)	95	498	139 (28%)	181 (36%)
Unprotected heavy vehicles	173	1949	103 (5%)	397 (20%)

The blast effect and associated damage caused by single anti-tank mines exploding underneath medium or heavy unprotected vehicles tend to be more localised. This is due to the bigger size and mass of the vehicle as well as the higher ground clearance. The cone of destruction associated with the blast effect covers a proportionally smaller area of the vehicle than that for light vehicles. In spite of this, local damage is just as severe as in light vehicles and leads to the complete destruction of a segment of the vehicle as depicted in Figure 9. This 10-tonne truck detonated a single anti-tank mine under the right front wheel.

Fig. 9. Unprotected medium-sized vehicle that detonated a single anti-tank mine under the right front wheel

The cab was destroyed with little or no damage towards the rear of the vehicle or the lower left hand side in front. The driver of the truck was killed instantly.

Statistics in Table 4 indicate that five per cent of occupants were killed and 20 per cent injured during incidents involving the detonation of single anti-tank blast type mines underneath medium to heavy unprotected vehicles. These figures are much less than those for light unprotected vehicles due to the fact that occupants are further removed from the detonation point in these bigger and heavier vehicles than in the smaller light vehicles.

Fig. 10. Bulldozer after detonating a single TMA 3 mine in Mozambique

After some of the roads were cleared by manual teams in Mozambique this was the fate of road-building equipment following them up. Hand-held metal detectors and prodding sticks were cleaning to a depth of some 100mm. The TMA-2 mine detonated after the blade had removed enough cover. The mine was too deep for other vehicle traffic to detonate it.

Figure 10 depicts a bulldozer that detonated a single TMA-3 anti-tank blast mine underneath the right hand track. The blast effect shattered the track and damage was limited to the right hand side alone. The blast effect was insufficient to throw the vehicle out of the crater created by the blast. The driver survived and sustained severe lacerations due to the secondary fragmentation effects.

Blast effect on extra heavy size unprotected vehicles

The blast effect of anti-tank blast type mines detonating under the wheels of extra heavy unprotected vehicles is similar to the effect on heavy vehicles. The difference is that the effect is more localised due to the bigger size and mass of the vehicle. However, the localised effect when detonating an anti-tank blast mine under a front wheel is sufficient to cause extensive damage to the cab of the vehicle and can cause death or serious injuries to the occupants.

Detonation of anti-tank blast mine underneath hull (MTL-03B)

General considerations

Double anti-tank blast mines became common during the middle of 1978 in the former South West Africa with the advent of the first generation mine-protected vehicles (MPVs). These mines appeared in both the linked or "goggle" configuration causing blast effect directly under the vehicle hull or, in the stacked configuration (triple mines were not uncommon), detonating underneath the wheel.

The number of mines involved in incidents in South West Africa (now Namibia) during July/August 1978 is reflected in Table 5.

Table 5. Number of mines detected and involved in incidents in South West Africa in July-August 1978

Type	Mines located		Detonations	Total
	Visual	Detected		
Single mines				
TMA-3	0	1	0	1
Total	**0**	**1**	**0**	**1**
Double mines				
Stacked TMA-3	0	2	3	5
Linked TMA-3/ TM 46/57	0	3	1	4
Linked others	0	2	0	2
Total	**0**	**7**	**4**	**11**

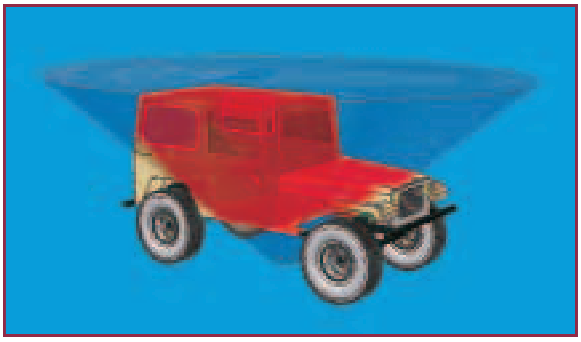
The blast effect of these multiple mines was much more devastating on unprotected vehicles than when single mines were detonated underneath the wheels: more occupants were killed and injured. This is depicted in Table 6.

Table 6. Number of people killed and injured in vehicle mine incidents in South West Africa: January-July 1978

Vehicles	Incidents	People involved	Killed	Injured
Unprotected	22	117	43 (37%)	61 (52%)
Protected	48	356	5 (1.4%)	32 (9%)
Total	**70**	**473**	**48 (10%)**	**93 (20%)**

Blast effect on light and medium unprotected vehicles

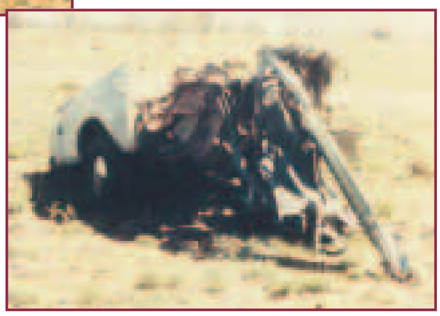
Fig. 11. The effect of the cone of destruction on a light, unprotected vehicle from a centre blast underneath the hull



The blast effect of multiple mines on unprotected light- and medium-sized vehicles is much more severe than that of single mines. If multiple mines are detonated in the linked configuration, the mine initiates underneath the hull of the vehicle. Blast damage is not localised to the wheel area, as in the case of single mines detonating under the wheel. The full force of the mine causes much more damage to the vehicle as depicted schematically in Figure 11.

The effect of a centre blast underneath the hull of a light unprotected pick-up is depicted in Figure 12. While the front of the vehicle, engine compartment and cab have been destroyed and removed, the rear area suffered relatively little damage. Note that the one rear hubcap remained fixed to the wheel: this area was obviously outside the cone of destruction.

Fig. 12. The effect of a single TM-46 anti-tank blast mine detonated underneath the centre of an unprotected light vehicle



When multiple mines are stacked (either double or triple), the ensuing blast effect on the vehicle, even for a detonation under a wheel, is much bigger due to the increase of explosive charge. Figure 13 depicts a light unprotected vehicle almost completely destroyed by a double mine. The mine detonated underneath the right front wheel. All five occupants were killed instantly.

Fig. 13. Damage to a light unprotected vehicle from a double mine detonating under the right front wheel

Blast effect on heavy and extra heavy unprotected vehicles.

The blast effect of multiple mines on heavy and extra heavy vehicles is just as severe as that on light and medium vehicles, especially for detonations underneath the hull. Overall damage, though, tends to be less severe due to the bigger size and mass of these vehicles.

Medium-size UXO (MTL-04)

The biggest danger from medium-size UXO is when they are used as booster charges in conjunction with anti-personnel or anti-tank blast mines. The effect is similar to that of multiple anti-tank blast mines, but with an added fragmentation effect.

When used as booby-traps and initiated above the surface with the aid of tripwires, the fragmentation from this class of UXO poses a threat to unprotected vehicles up to 100 metres away. It also poses a threat to plant equipment engaged in excavation or bush clearing activities. Figure 14 shows artillery shells and 122 millimetre rocket warheads (BM-21) used as booster charges in the road. These warheads were connected to anti-personnel blast mines in the road with detonating cord.

Fig. 14. Rocket warheads shells used as booster charges located in a road in Angola

Anti-tank HC Mines (MTL-05)

Although anti-tank HC mines are mostly "scatterable mines", which lie on the surface after being deployed against armoured vehicles from the air, the hollow charge effect can penetrate armoured steel up to 40 millimetres in thickness at five metres. This allows the blast effect to enter into the vehicle and cause extensive damage. These types of mines will cause severe localised damage to all classes of unprotected vehicles and occupants will similarly be exposed to the blast effects, resulting in deaths and injuries. The effect of a Soviet TMK-2 HC mine on a Casspir MPV is depicted in Figure 15.

Fig. 15. The effect of a TMK-2 HC mine on a Casspir MPV

However, when these mines are detonated under the wheel, the hollow charge effect is neutralised if the hull of the vehicle does not extend over the wheel and the effect is similar to that of a single anti-tank blast mine detonating under the vehicle's wheel.

Anti-tank SFF Mines (MTL-06)

The SFF type of anti-tank mines is designed to incapacitate heavy armoured vehicles so they have a devastating effect when detonated under unprotected vehicles. Such SFF mines will completely destroy light unprotected vehicles and cause severe localised damage to the heavier classes of vehicles. The chances of occupants surviving the blast are slim.

A black powder charge explodes and dispels soil from the top of the mine upon initiation. This is required to allow for the optimal formation of the "platter slug" in air during the detonation of the main charge. This molten slug (approximately 0.74 grams of steel) is projected towards the target with a high velocity. Velocities of up to 2,500 metres per second have been measured and the associated kinetic energy is sufficient for the slug to penetrate up to 80 millimetres of armour plate at distances of four metres.

The most damaging effects are obtained when the mine is detonated under the hull of a vehicle, which is why tilt rods are the preferred way of initiating these mines, allowing for the full width of the vehicle as the attack area. The penetration of the armour plate allows the blast effect to enter the vehicle and cause further damage.

When these mines are detonated underneath the wheel of a vehicle, the "platter slug" is not formed optimally, however the resultant blast effect on the vehicle is similar to that of a double mine. Figure 16 depicts the effects of a TMRP-6 SFF mine detonated underneath the wheel of a Casspir MPV during a test. The wheel was filled with a liquid rubber compound that solidifies after a short period to minimise the effect of smaller anti-personnel type mines as well as to reduce punctures.

Fig. 16. Effects of a TMRP-6 SFF mine exploding under the wheel of a Casspir MPV

UXO Heavy (MTL-07)

The use of 250-500 kilogram aircraft bombs as mines or booby-traps is not uncommon in certain regions. These bombs are buried in the road and linked with detonating cord to either anti-tank or anti-personnel mines, which are used to trigger the devices. The resulting blast effect from these devices will destroy all types of vehicle classes (from light to heavy) with virtually no chance of survival for the occupants. Figure 17 depicts a 500 kilogram aircraft bomb connected with detonating cord to several anti-personnel mines.

Fig. 17. A 500kg aircraft bomb rigged as a mine

This type of UXO also poses a serious threat on its own to unprotected plant equipment used for bush clearing or excavation.

Mine/UXO protection levels

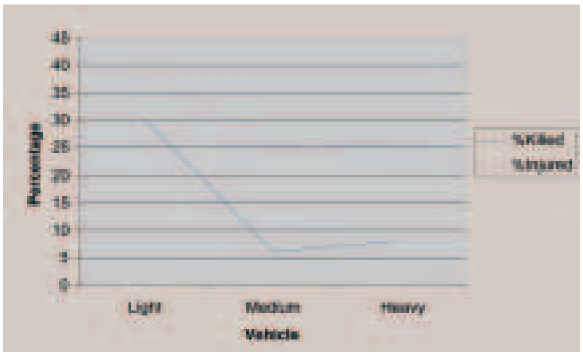
The mine or UXO protection levels for vehicles are generally defined in terms of the likelihood of the occupants surviving the effects of the explosion as well as the possibility of the vehicle being able to be repaired.

The likelihood of occupant survival

It is difficult to categorise the survivability of occupants of vehicles involved in mine blasts. This is because the position of a particular occupant relative to the detonation point as well as the cone of destruction created by the blast effect will be determinant factors.

Nonetheless, statistics recorded during the Rhodesian War (1972-1978) indicate that the size and mass of the unprotected vehicle plays an important role in determining whether the occupants survive a blast or not. The analysis of these statistics, which are related to the detonation of a single blast mine underneath one of the wheels (MTL-03A), is depicted graphically in Figure 18.

Fig. 18. Percentage of occupants killed and injured against vehicle size



The percentage of occupants killed in light vehicles differed slightly when compared with those injured (30 per cent killed and 38 per cent injured). For medium and heavy vehicles the difference increased considerably (less than 10 per cent killed and 25 per cent injured). Occupant survivability and associated medical care required are defined in Table 7.

Table 7. Definition of survivability levels for vehicle occupants

Survivability level (OSL)	Immediate condition	Medical care required	Estimated time to full recovery
OSL-04	No incapacitation	Nil	N/A
OSL-03	Temporary loss of hearing Light lacerations Minor fractures of limbs Not life threatening	First aid	Hours
OSL-02	Temporary loss of hearing Severe multiple lacerations Severe multiple fractures Not life threatening	First aid and stabilisation Casualty evacuation to clinic	Days
OSL-01	Partial/complete loss of hearing permanent Temporary/permanent loss of sight Severe multiple lacerations Blast lung Limbs completely torn off Multiple fractures Life threatening	Stabilisation and immediate casualty evacuation Trauma surgery and amputations	Months
OSL-00	Instant death	N/A	N/A

Vehicle repairability

Vehicle repairability levels are defined in terms of the skills levels, required capabilities and time required to carry out repairs after a mine or UXO explosion. The vehicle repairability levels are defined in Table 8.

Table 8. Definition of vehicle repairability levels (VRL)

VRL	Immediate condition	Repair capability and action	Duration
VRL-04	No incapacitation	Nil	NA
VRL-03	Temporary incapacitated	Effect repairs on site	Hours
VRL-02	Temporary incapacitation No structural damage	Recovery to field workshop Requires general components	Days
VRL-01	Semi permanent incapacitation Light to medium structural damage	Recovery to field workshop Requires factory supplied subsystems	Weeks
VRL-00	Destroyed beyond economic repair	Recover to workshop Salvage usable parts and systems	NA

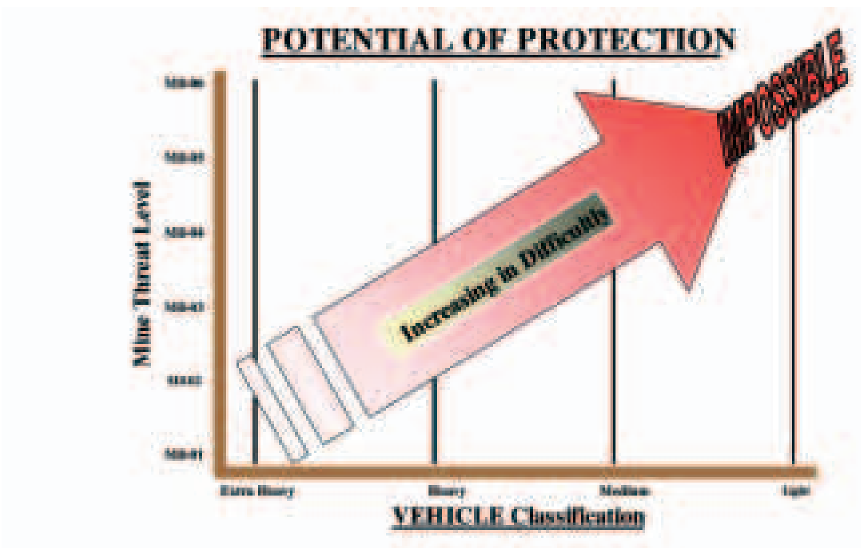
Principles for the protection of vehicles and plant equipment against the threat of mines and UXO

General considerations

Steel plating (usually armour plate) is used to neutralise the blast and fragmentation effect of mines and UXO in order to render protection to vehicles, plant equipment and their occupants. However, any design incorporating the use of steel plating adds considerable mass to the vehicle.

Automotive engineers usually accept a power-to-mass ratio of 27kw per metric tonne to ensure vehicle mobility that also caters for off-route conditions. Another aspect that needs to be considered is axle loadings. In general, it is more difficult to protect the light to medium range of vehicles than the heavier classes, as depicted in Fig. 19.

Fig. 19. Difficulty of protecting vehicles against mine threat



Principles for the protection against blast effect

The following principles can be incorporated into the design of vehicles and equipment to render protection against the blast effect of mines:

- absorption of energy,
- deflection of blast effect away from the hull, and
- distance from detonation point.

Absorption of energy

A simple and cost-effective manner to incorporate this principle has been found to fill the tyres of wheeled vehicles with water. This concept increases the protection level of light and medium vehicles considerably against the threat of single blast anti-tank type mines detonating underneath a wheel. Figure 20 depicts a three-ton Bedford truck that detonated a single TM46 anti-tank mine under the left front wheel.

Fig. 20. Bedford truck with water in the wheels that detonated TM 46 anti-tank mine

It was previously thought that the water absorbed energy by being converted into spray and vapour, but recent studies suggest that the water, being much heavier than the air in the tyre, deflects the shock wave sideways thereby flattening the cone of destruction.

This concept can be enhanced by adding protection plates to shield the vehicle occupants from the blast effect. However, these plates must be able to withstand the blast effect (although considerably less) within the cone of destruction. Otherwise, they could form deadly secondary fragmentation when shattering or shearing off during the blast. The general positions for inserting protection plates on a light vehicle are indicated in green in Figure 21. The windscreen and side windows should be replaced by reinforced, laminated glass to withstand the blast effect of the mine and render protection against fragmentation.

Fig. 21. Schematic layout for insertion of protection plates in light vehicles

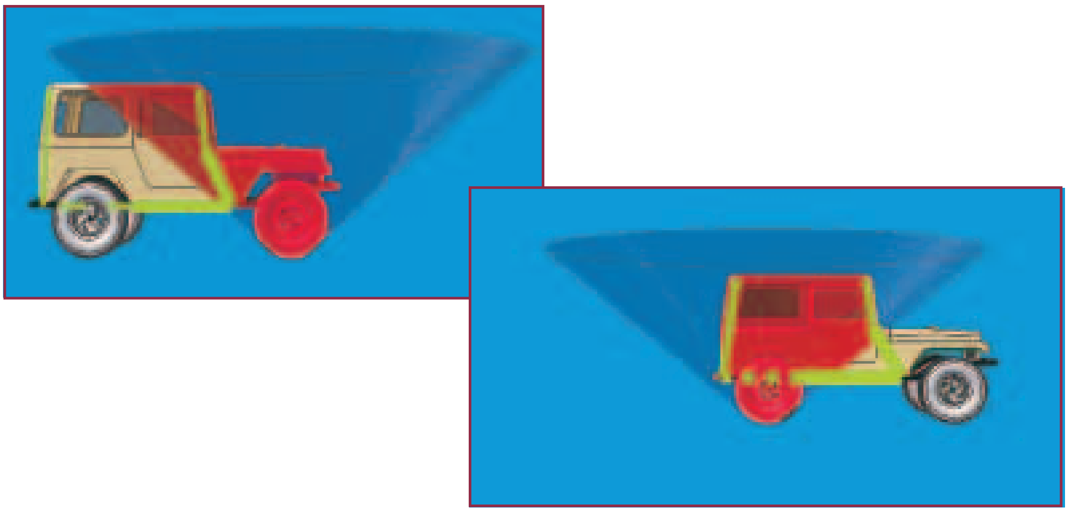
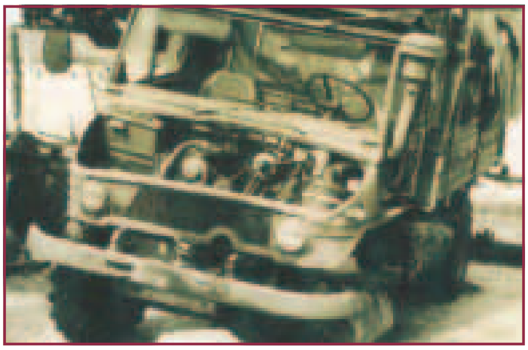


Figure 22 depicts a Unimog vehicle fitted with protection plates in the wheel area and tyres filled with water. This vehicle detonated a TM 57 anti-tank mine under the right wheel. Damage is considerably less than it would otherwise be, and is limited to the wheel area.

Fig. 22. Unimog vehicle fitted with protection plates in wheel area and wheels filled with water



However, it should be noted that the use of water in the wheels and the installation of deflection plates will only render protection against *single* anti-tank mines detonating underneath the wheel (MTL-03A).

Deflection of blast away from the hull

The effect of blast against the hull of a vehicle can be reduced considerably by incorporating steel plates at an angle to the direction of blast. Reflected pressures are generated when the blast direction is at a 90º angle to the plate. Side-on pressures are approached if the blast direction corresponds to a 0º angle to the plate angle. It can thus be expected that the resultant pressure will be reduced to a value between the reflected pressure and the side-on pressure, should the plate be angled between 0 and 90º. In classical gas dynamics this is referred to as an oblique reflected shock wave. This approach has lead to the introduction of V-hulls, which have been successfully used in the mine protection of light- and medium-sized vehicles.

Protection can be rendered to lightweight vehicles against single anti-tank blast mine detonations underneath the hull (MTL-03B) by incorporating the design of a V-shaped capsule onto the chassis of a standard light commercial vehicle. The additional mass of the armour plating involved and the engine power limit the size of the capsule, therefore maximum use must be made of the deflection principle in the design. Design options are further limited by the vehicle configuration itself. Figure 23 depicts one of the successful designs issued to farmers in mine-affected areas in South Africa during the mid-1980s.

Fig. 23. An example of a V-shaped capsule mounted on the chassis of a light commercial vehicle

It is also important to prevent the "entrapment" of the blast wave. Lightweight, "blow away" panels should be used in areas within the cone of destruction, such as in the wheel wells.

Distance from the detonation point

The blast effect diminishes drastically with the distance from the detonation point. Thus, by increasing the ground clearance height and by spacing the wheels further apart, maximum distance can be obtained from the detonation point. Practical considerations such as mobility, turning circle and ease of driving limit the extent to which this principle can be applied.

These principles were incorporated in the design of the South African Casspir MPV as depicted in Figure 24. Note the maximum use of wheel spacing (the wheels run on the outside of the body), the V-shaped hull to incorporate maximum deflection of the blast wave and optimal use of ground clearance.

Fig. 24. Rear view of South African Casspir MPV

Principles for the protection against the fragmentation effect of mines and UXO

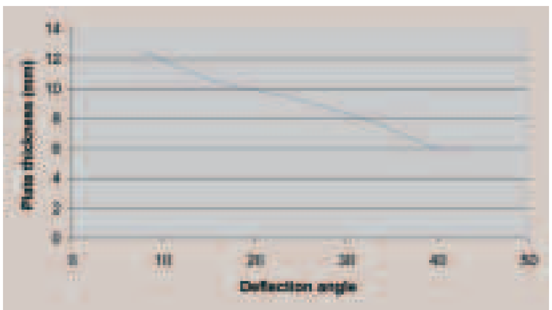
Protection against fragmentation is achieved by using steel plating and armoured glass of sufficient thickness. Normal ballistic protection levels as required for military combat and armoured vehicles are used effectively for the protection against the fragmentation effect of mines and smaller UXO (MTL-02). The plate thickness required to render protection against blast usually renders protection against the fragmentation effect of mines and smaller UXO (MTL-02).

A commonly used standard is to protect against the penetration of North Atlantic Treaty Organisation (NATO) 7.62 x 51mm anti-personnel rounds. These protection levels are defined in Military Standards such as STANAG 4569.

Armoured plating is currently being used instead of mild steel to create vehicles with lower weight. A rule of thumb is that an armoured plate of a given thickness renders the same ballistic protection as a mild steel plate of twice the thickness (thus half the mass).

The principle of deflection can also be used in designs to render protection against the fragmentation effect. Figure 25 illustrates the effect of incident angle on the thickness of a

Fig. 25. Effect of incident angle on plate thickness required to stop 7.62 x 51mm NATO anti-personnel rounds

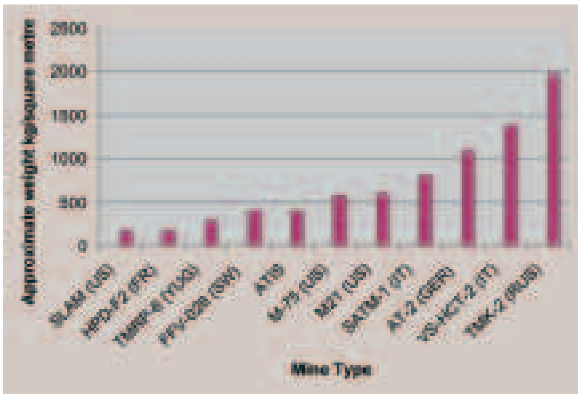


typical armour plate required to stop penetration from a NATO 7.62 x 51mm anti-personnel round.

Principles for the protection against hollow charge (HC) and self-forming fragment (SFF) mines

The amount of steel (armoured plate) required to neutralise the effect of various HC and SFF mines is depicted graphically in Figure 26. From this graph it is evident that the Soviet TMK-2 HC mine poses the biggest threat. Fortunately this mine is rarely encountered in current humanitarian and commercial demining operations.

Fig. 26. Amount of steel required to neutralise the effect of various HC and SFF mines



Protection against HC mines

The Munroe effect associated with HC mines requires a stand-off distance in free air to form the high-speed jet. This stand-off distance is usually determined by the cone diameter and length of the charge. The optimal formation of this high-speed jet can be prevented by positioning a "capture plate" between the vehicle hull and the ground surface. This capture plate can cause the break-up of the jet. This will reduce the penetration capability of the jet against the vehicle hull.

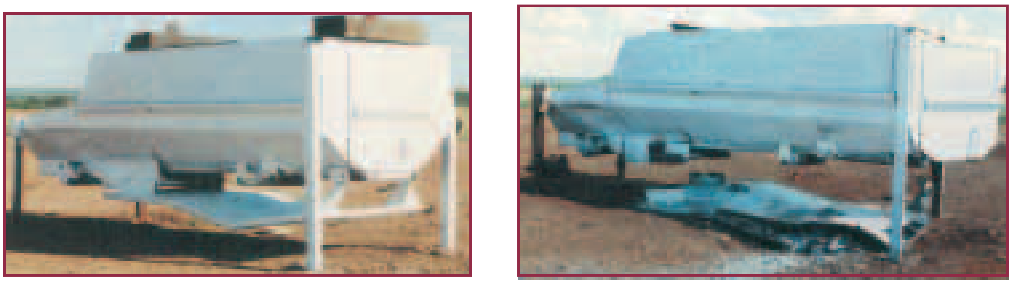
This concept will reduce ground clearance of the vehicle considerably and thus impairs vehicle mobility, especially in wet conditions.

Protection against SFF mines

The high-speed slug formed in SFF anti-tank mines requires less distance to optimally form. The effect of this mine can be reduced by introducing a thick "capture plate" between the vehicle hull and the soil surface. This plate must be thick enough to stop the slug completely. Current designs incorporate the use of armour plate and composite materials to reduce mass. The vehicle hull above the "capture plate" must be able to withstand the associated blast and shock effect of the mine as well. A typical "capture plate" underneath a V-shaped hull is depicted in Figure 27, as well as the after-effects of the SFF test mine.

The capture plate neutralises the effect of the V-shaped hull when fitted underneath a vehicle. If the vehicle detonates a conventional blast mine, either under the wheel or directly underneath the capture plate, the blast effect is trapped underneath the capture plate. The vehicle is then subjected to higher impulse and momentum transfer than in the case where the V-shape deflects most of the blast effect.

Fig. 27. Effect of a SFF test mine on a capture plate fitted underneath the hull of a MPV capsule



Application of other principles to render protection against the effect of mines and UXO

Consideration should be given to the application of the following general principles to further increase the protection level of vehicles:

- use of safety belts,
- seating design and footrests, and
- "good housekeeping" (no loose items).

Use of safety belts

Although the measures described above can all reduce the blast effect on a vehicle, significant impulse and momentum transfer to the vehicle may still occur. This causes a sudden vertical acceleration of the vehicle, i.e. the vehicle is thrown into the air. The lighter the vehicle, the more pronounced is this effect.

This sudden vertical acceleration, coupled with the original forward movement of the vehicle, can cause serious injuries to the occupants if they are not properly strapped into their seats. Conventional safety belts as used in the automotive industry do not render sufficient protection. Double straps with at least four adhesion points to the hull should therefore be used.

Seating design and footrests

The shock associated with the blast wave is transmitted through the steel hull of the vehicle when subjected to the blast effect of a detonating mine. If the seats are attached to the floor of the vehicle, the shock wave can be transmitted through the steel directly to the seat and subsequently into the body of the person occupying the seat. This additional shock, in conjunction with the sudden vertical movement of the vehicle, can increase the extent of injuries sustained. As a result, it is far better to suspend seats from the side, or even better from the roof of the vehicle, to reduce shock transmission.

The same effect is encountered when occupants rest their feet directly onto the floor of the vehicle during a detonation incident. The shock wave is transmitted through the floor directly into the feet and lower limbs of the occupants, causing injury to those body parts. This effect can be minimised by producing footrests attached to the side of the vehicle or forming part of the seat arrangement. Footrests should not be attached directly to the floor section.

"Good housekeeping"

Good housekeeping implies that the interior of the vehicle should be kept clean and free from foreign objects lying on the floor. Nuts, bolts, spare parts, tools and other foreign objects lying around on the floor of the cabin can be accelerated due to the blast effect and associated vertical movement into the air. These objects can cause injury to personnel inside the cabin.

Annex 1.

Trigonometry regarding the cone of destruction

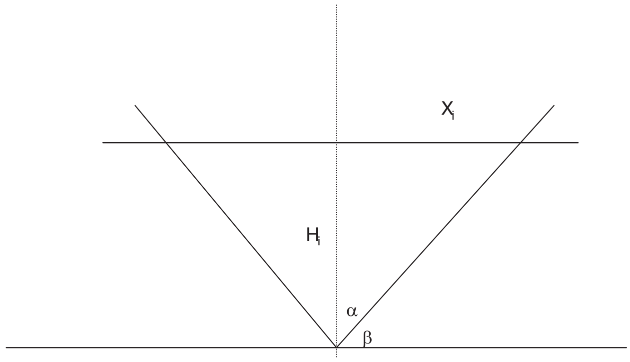


Table 1. Trigonometry relations for the cone of destruction

Angle *a*	Tan *a*	Height H_i (metres)	Cone radius X_i (metres) H_i tan *a*	Cone diameter (metres) $2X_i$
50	1.19	0.5	0.595	1.19
50	1.19	1.0	1.190	2.38
50	1.19	1.5	1.785	3.57
50	1.19	2.0	2.380	4.76
50	1.19	2.5	2.975	5.95
50	1.19	3.0	3.570	7.14
50	1.19	3.5	4.165	8.33
50	1.19	4.0	4.760	9.52
50	1.19	4.5	5.355	10.71
50	1.19	5.0	5.95	11.90

a

Annex 2.

Guidelines to estimate the survivability of vehicles, plant equipment and their occupants in the field

The following guidelines have been established in order to allow technical advisors assigned to a mine action centre or other entity involved with the coordination or regulation of mine action, to make decisions regarding the suitability of vehicles, plant equipment and their occupants faced with specific mine threats.

The assessment process

There are very few defined "yes-no" situations in assessing the survivability of mine protected vehicles (MPVs), plant equipment or their occupants against a mine threat. However, the following process should eliminate a number of uncertainties and thereby reduce risk:

- establish the mine threat level;
- establish the required protection level in terms of the survivability of the occupants and the repairability of the vehicle;
- establish the stated protection level claimed by the designer or manufacturer;
- verify the protection level achieved in the final product;
  - design process,
  - materials used,
  - construction processes,
  - design features,
  - test and evaluation; and
- ask for assistance.

Mine threat level (MTL)

Ensure that the assessment is conducted against the primary threat level. This will normally be a combination of MTL-01 (anti-personnel blast) and MTL-02 (anti-tank fragmentation) and MTL-03 A and B (anti-tank blast) in the humanitarian demining scenario. MTL-06 (anti-tank SFF) is currently restricted to the Balkans.

Protection levels

Establish the protection levels required by donors, the regulating authorities, as well as insurance requirements and operators. This is in fact a statement of acceptable risk and should be determined by taking into account aspects such as availability of medical facilities, casevac SOPs and availability of repairing facilities.

Stated protection level

Establish the stated protection level of the system or product. This is easily done by extracting data from the manufacturer's product data sheet or brochure. If the manufacturer does not have the data available in this format, simply ask him.

Establish if this stated protection level meets the requirements of the actual mine threat and required protection level. A sound understanding of the actual threat and required protection level is required to achieve this.

For instance, a manufacturer may claim ballistic protection for a particular vegetation-cutting machine or flail, based on a commercial tracked excavator, against the fragmentation of a PROM-1 mine 10 metres away from the cab. This assumption would not represent the real threat. The PROM mine can be activated by tripwire. The machine may activate a tripwire with its working part 10 metres of the machine, but it could initiate a PROM mine within one metre away from the machine. If the design allowed for protection at 10 metres away, the possibility exists that no protection will be rendered at one metre, thus resulting in the death or injury of the operator.

Verification of the protection levels achieved in the product

Design process

Request the manufacturer to submit design detail such as drawings and calculations to verify the claimed protection level. Ask questions such as "Why is this plate this thickness, or why did you use this angle of deflection?" If the manufacturer is not capable of answering these basic questions, the design of the product becomes questionable. Establish the total mass of the vehicle or machine.

Materials

Establish what materials are used and in what position. Ductile steel with sufficient toughness should be used in the lower regions close to the blast and the more brittle armour plates used higher up along the hull. Request material certificates from the suppliers of the steel to verify what material was used in the design.

Construction methods

Establish what construction methods were used in the design. Bolted sections securing the lower part of the hull immediately identifies a questionable design. Capped welding in the lower areas would be better with bending of the plates as the best solution.

Design features

Evaluate the product's design features through visual inspection.

Assess the free height of the hull above ground level. This height will determine the intensity of the impulse and area size of the shock wave. Visualise the size of the cone of destruction at this height and look out for the following:

- any bolted sections within this area?
- are all welded sections capped in this area?
- did they use a ductile material in this area?
- is the design smooth and clean to deflect the blast sufficiently?

- Are there any pockets to trap gas underneath the hull?
- Will the fuel tank be subjected to direct shock?
- Can water be used in the wheels to effect blast reduction?

Assess the ballistic protection of the product. If armour plate thinner than eight millimetres (or, in the event of mild steel, 16 millimetres) has been used, ballistic protection is deemed to be insufficient. Bullet resistant glass with a thickness less than 53 millimetres should not be used for windows. Pay attention to the screening off of hydraulic piping, electrical cables and other systems to reduce secondary damage caused by fragmentation.

Inspect quality of the welding and check for undercuts.

Test and evaluation

Ask the manufacturer if the design of the product had been verified through blast testing. If so, request test data and results. If the machine or vehicle had been involved in previous mine incidents, request incident and investigation reports for further analysis and study.

Chapter 6.

Mechanical cost-effectiveness

Summary
This chapter establishes a methodology for the calculation of the cost-effectiveness of mechanical demining equipment, in particular through the Cost-Effectiveness Model (CEMOD) software programme. This software can be used to assess past or projected costs or to evaluate past or projected plans.

Introduction

Mechanical clearance equipment has been used by demining organisations almost since the beginning of mine action in the late 1980s. Initial mechanical clearance often relied on equipment whose design was influenced by the military objective of clearing a navigable path through a minefield rather than on the humanitarian objective of removing all mines in an area. More recently, special-purpose clearance machines have been developed, but to date, with the exception of mechanical excavation methods, none of these are perceived as capable to conduct full clearance without follow-up by either manual demining or MDD teams.

The apparently limited success in the use of mechanical clearance methods means that most demining organisations continue to rely heavily on manual clearance techniques. While manual techniques may be a reliable way of ensuring that acceptable clearance standards are met, they can be slow, expensive and dangerous.

The growing number of purpose-built mechanical mine clearance machines in use and under development and the increasing variety of ways in which machines are used to support mine clearance makes it an opportune time to assess the cost-effectiveness of mechanical mine clearance. This information can help to serve at least two purposes. First, a greater awareness of the cost-effectiveness of various methods of mine clearance may help demining agencies to use their existing resources more effectively. Second, more widely available and standardised data on the cost-effectiveness of mechanical equipment relative to other clearance methods could help planners and developers allocate support to the machines and techniques that offer the greatest promise.

The aim of this chapter then, is to establish a methodology as to how an organisation calculates the cost and the productivity of a machine working in a minefield, and how its cost-effectiveness should be established, in comparison with equivalent clearance carried out by manual or MDD teams. The CEMOD cost-effectiveness software model is available from the GICHD on CD-ROM upon request. It allows a manager to decide whether machines or manual methods are more economically viable for certain clearance tasks.

For both mechanical and manual mine clearance methods, annual data is likely to provide a more accurate picture than weekly and monthly costs. A shorter reference period can be more easily distorted by atypical costs, so annual data on items like spare parts is likely to provide a more accurate picture. Similarly, a longer reference period may give a more accurate reflection of labour costs and productivity, because these can be affected if a significant component of the time period is devoted to training.

Moreover, in monsoonal environments, costs are likely to differ between wet and dry seasons. For example, in the wet season, soils may break up more easily, aiding the detection or disablement of mines. Offsetting this, some clearance methods may not be possible in the wet season due to the bogging of machines and the inundation of land preventing the use of mine detectors. Hence, both costs and productivity may differ across seasons and this can distort comparisons if data for different methods relates to different seasons. The use of an annual reference period can be thought of as averaging across the various seasons, and so allows greater consistency of comparisons.

In cost-benefit analysis the term "economic" is generally taken to include shadow pricing with the objective of assessing social[1] benefits and costs from a national perspective. The objective of this study is to improve the cost-effectiveness of mechanical demining by implementing agencies. As such, the emphasis should be on the actual costs they face (whether distorted or not). For this reason our analysis will be based on estimates of *financial* costs and benefits.

This report describes how the Cost-Effectiveness Model (CEMOD) should be used to analyse the effect of, for example, donated equipment on *financial*[2] viability — i.e. is it ultimately more cost-effective to purchase the desired machine rather than to "make do" with one donated. It allows calculation of performance indicators (e.g. cost per square metre) based on alternative assumptions to establish viability:

- actual costs faced by project managers, e.g. donated equipment at zero cost; and
- "real cost" to funders of demining activity.

The Cost-Effectiveness Model (CEMOD)

Model purpose and overview

Economics is the study of how society manages scarce resources. Each year resources available for mine action are sufficient to tackle only a small proportion of mine-affected areas worldwide. Mine action is an expensive activity that can often be undertaken using a number of different methods. Data already available suggests that there is a wide range in the unit cost of these methods, even after adjusting for quality and variation in other key variables. Clearly it is essential that scarce mine action resources be deployed in such a way as to achieve the best possible outcomes. Cost-effectiveness analysis has a key role to play in achieving this goal.

Cost-effectiveness analysis can be approached in two ways: a) to determine the least- cost method of achieving a known goal, or b) to find the policy alternative that will provide the largest benefits for a given level of expenditure (the *fixed budget approach*). This report is concerned with the fixed effectiveness approach.

There is an important distinction between cost-effectiveness analysis and cost-benefit analysis. Cost-benefit analysis can assess both a) whether any of the alternatives are worth doing (whether benefits to society exceed costs), and b) how alternatives should be ranked if more than one has benefits that exceed costs. On the other hand, cost-effectiveness analysis cannot tell the analyst whether a given alternative is worth doing (this requires a cost-benefit analysis), but if a decision is made to achieve a particular goal, it can help in deciding which policy alternative will do so most efficiently.[3]

The design of the CEMOD is based on the concept of the "mine clearance method" i.e. any method used to achieve the IMAS standard. There is little point in comparing different machines in isolation if they make different contributions to mine clearance. The only useful comparison is between alternative methods that achieve the same goal.[4] For example a given piece of land might be cleared to the same standard by four alternative *methods*:

1. manual mine clearance only;
2. flail followed by manual mine clearance;
3. vegetation cutter followed by manual mine clearance; or
4. flail followed by dog teams, supported by manual mine clearance

A vegetation cutter might have a lower cost per square metre than a flail, however the overall cost of method 2 might be lower than method 3 because manual mine clearance is faster after a flail.

The following sections of the report describe how the CEMOD can be used to estimate the cost-effectiveness of alternative mine action methods.

Analysis functions

The CEMOD may be used for four main types of analysis (see Table 1).

1. *Past costs*: Implementing organisations can analyse the *past* cost-effectiveness of alternative methods of mine clearance, given the particular conditions faced by their organisation. The "real" cost of donated equipment is not included.
2. *Projected costs*: Implementing organisations may use CEMOD to project *future* expenditure using existing or new mine clearance methods.
3. *Planning (Past)*: Planning organisations can compare the past performance of different implementing agencies, including adjustments to create a "level playing field". The "full market cost" of donated equipment is included.
4. *Planning (Projected)*: Planning organisations can project the future cost effectiveness of alternative methods of mine clearance, including adjustments to create a "level playing field".

Table 1. Types of analysis performed using CEMOD

	Implementation function	Planning function
Past expenditure	Analyse the cost-effectiveness of alternative methods of mine clearance. *Based on "actuals".*	Analyse the cost-effectiveness of alternative methods of mine clearance. *Based on "actuals".*
Projected expenditure	Project the future cost-effectiveness of alternative methods of mine clearance *Based on expected costs faced by the implementation agency.*	*Adjust to create "level playing field".* Project the future cost-effectiveness of alternative methods of mine clearance *Based on "expected costs". Adjust to create "level playing field".*

How to determine costs

Allocation to cost categories and cost centres

All costs should be broken down into staff salaries, staff allowances, consumables and capital equipment and allocated to the available cost centres (management and administration, mine survey, medical, dog teams, manual mine clearance and mechanical mine clearance; separately for each machine type).

If the organisation operates more than one of a particular type of machine it will usually be appropriate to allocate costs to these machines as a group. However costs can be allocated to each machine separately where a separate analysis is desirable. In this case each machine should be given a separate name (e.g. Flail A, Flail B, etc.). Machines that use a variety of attachments can be analysed separately or as a group. If analysed separately then a proportion of the cost of the "base unit" must be allocated to each of the attachments.

Salaries and allowances

Staff salaries cover the employment costs of all personnel including senior management. Both local and expatriate staff should be included (except that implementing agencies should not include those expatriate staff costs which are donated). The staff allowances category should be used for items such as field allowance, travel allowance, etc. However agencies can choose, if they wish, to combine all such costs under the staff salaries subheading.

Consumables

This covers all items that are generally consumed within a year, e.g. petrol, stationery, machinery repair costs, dog food, rent for buildings, etc.

CEMOD is not designed to take account of changes in stock levels, so consumables cost data should reflect *use* during the reporting period rather than *change in stock levels*.

Capital equipment

This covers all items that usually have a working life of more than one year. It includes major items such as mine clearance machinery and vehicles. Also included are smaller items such as mine detectors and dog kennels. Buildings constructed (or purchased) by the project should also be included.

In each case effective working life should be estimated. This is used to estimate the annual cost of capital equipment (based on capital cost divided by working life). In some cases judgement may be required; some examples may prove useful:

Table 2.

Example	Working Life
Based on past experience the average working life of a manual mine detector is estimated to be three years. Value of discarded equipment is negligible	*3 years*
Vehicles are kept for four years then sold. They usually realise around 33 per cent of their cost new. Add 33 per cent to working life to account for salvage value.	*4 years*
Project will last more than five years. Equipment is expected to last for five years and will then be donated to local mine clearance organisation.	*5 years*

Management and administration costs: defining the unit of analysis

The unit of analysis should usually be the whole implementing agency that carries out mine clearance activities. In some cases it may be appropriate to include a particular *part* of an agency, e.g. in cases where separate divisions have quite separate activities that may be unrelated to mine clearance. In this situation management and administration costs should be entered for the *whole* organisation, and an estimate made of the percentage attributable to mine clearance activities. Management and administration costs for separate headquarters organisations should not be included. This should increase the comparability of data between organisations. So, for example, the home country or regional[5] headquarters cost of an NGO involved in mine clearance activities would not be included.

Types of analysis: Appropriate treatment of capital equipment, donations and overhead expenditure varies according the type of analysis performed. This is summarised in Table 3 and covered in more detail below:

Table 3. Treatment of capital equipment, donations and overhead expenditure

	Existing capital equipment	Possible new equipment	Donated equipment	Remarks
Implementation function				
Past costs	Depreciate over effective working life		Only include costs to the implementation organisation	*Market cost of donated items NOT included*
Projected costs	Depreciate current salvage value of existing equipment over remaining working life	Depreciate expected cost of new equipment over expected working life	Only include actual/expected costs to the implementation organisation	*Purchase price of existing equipment is treated as a sunk cost*
Planning function				
Past costs	Depreciate over effective working life		Include full cost (net of any donated element)	*Market cost of donated items INCLUDED*
Projected costs	Depreciate over effective working life	Depreciate over effective working life	Include full cost (net of any donated element)	

Past costs

This analysis function should be used to analyse the past cost-effectiveness of methods of mine clearance used by an implementation agency.

- Enter all costs faced by the implementing agency over a given reporting period (usually one year).
- All management and administration costs are entered, but only a percentage of these are allocated to mine clearance (this percentage is entered by the user).
- Enter all capital items used by the agency.[6]
- Only enter the cost of donated equipment that is actually paid by the implementing agency e.g. do not enter the capital cost of donated equipment, but enter "actual costs" e.g. running costs, cost of repairs, etc.

Projected costs

This analysis function should be used to analyse the projected (future) cost-effectiveness of methods of mine clearance that may be used by an implementation agency.

In most respects the method of determining costs is the same as for past costs. Projected costs should be based on past data (where available) or in the case of new equipment or new methods, on data from other agencies working under similar conditions.

When deciding whether or not to *replace* existing equipment, we need to compare the projected cost of existing equipment (treated as a sunk cost) against the projected cost of the new equipment (depreciated over its expected working life). In this case, enter the *salvage value*[7] of the existing equipment and the *full expected cost* of the possible new equipment. In this case enter *remaining*[8] working life for existing equipment.

If the new equipment will be used to *expand mine clearance activities* (not to replace existing equipment) enter the actual cost of existing equipment and the *full expected cost* of possible new equipment.

Planning (past and projected)

This analysis function is used to analyse the past/projected cost effectiveness of alternative methods of mine clearance. In order to increase comparability, donated cost items should be included at their real/market price.

All capital items should be entered at their actual or projected cost.

Allocation of costs

Cost-effectiveness analysis requires the development of an appropriate system to allocate all direct and indirect costs to each cost centre. The cost allocation system needs to be reasonably accurate, without being too onerous in its data requirements. CEMOD includes the following cost centres:

- management and administration costs,
- mine survey,
- medical support, and
- mine clearance "procedures" (e.g. manual, dog teams, machines).

The following notes summarise the way in which costs are allocated in the CEMOD software.

Management and administration costs (including mine survey)

- Calculate the total cost of management and administration for the implementing agency (excluding international and regional headquarters costs).
- Estimate the percentage of management and administration costs attributable to mine clearance activities.
- Estimate mine clearance management and administration cost (based on above).
- Add the cost of mine survey activities.
- Divide by total area cleared in last reporting period to arrive at management, administration and survey cost per square metre.

Medical support

- Calculate total medical costs (avoid double counting, e.g. inclusion of any of the management and administration costs included above).
- Estimate the percentage of medical costs attributable to:
  - manual mine clearance and clearance by dogs,
  - mechanical mine action.
- Estimate medical costs per deminer or dog handler day for manual mine clearance and clearance by dogs (it would not be appropriate to use a per square metre measure in this case since a deminer clearing a larger area/day should have a lower per square metre medical cost).
- Estimate medical cost per square metre for mechanical mine clearance (this should be a reasonable approximation, although medical cost per square metre will also vary with machine speed and crew size).

Manual demining

- Calculate total cost of manual demining operations (e.g. salaries/pay, staff allowances, equipment, transport, etc.).
- Estimate deminer days (no. of deminers x no. of demining days) by activity. This should be available from standard log books used by most demining organisations e.g.:
  - manual only,
  - manual after flail,
  - manual in support of dog teams,
  - others,
  - total deminer days.
- Assign cost of manual demining operations to each activity based on average cost per deminer day x no of days engaged in each activity.
- Estimate per square metre costs based on logbook records of area demined using each method.
- In the case of manual in support of dog teams the actual area manually demined should be recorded (e.g. the clear lanes required by the dog teams), not the total area cleared using dog teams and manual combined.

Dog teams

- Calculate total cost of dog team operations (e.g. salaries/pay, staff allowances, equipment, transport, dog training, international technical assistance, kennels etc.).
- Estimate dog handler days (no. of dog handlers x no. of operating days) by activity (this should be available from standard log books used by most demining organisations):
  - dog teams only,
  - dog teams after flail,
  - dog teams after vegetation cutter,
  - total dog team days.
- Assign cost of dog team operations to each activity based on average cost per dog handler day x no of days engaged in each activity.
- Estimate per square metre costs based on log book records of area demined using each method (the net area cleared by dogs excluding the lanes cleared using manual mine clearance).

In some contexts (e.g. Bosnia) each unit of land is cleared by two independent dog/handler teams. In this case the actual daily output per dog handler/day is double that entered in the spreadsheet. An example may make this clearer:

The demining organisation enters:

- Area cleared by dog teams 320,000 square metres
- Dog handler days to clear this area 1,600 days
- This implies area cleared per DH day 200 square metres

However to clear 200 square metres requires coverage by two separate dog teams e.g. 400 square metres per day.

Mechanical mine clearance

- Calculate total cost of mechanical operations for each machine (e.g. capital equipment, salaries/pay, staff allowances, equipment, running costs, transport, international TA, etc.).
- Capital costs have been annualised using straight line depreciation, assuming no salvage value.
- Calculate machine costs per square metre.

Model output and interpretation

Model output includes cost-effectiveness, cost saving and machine costs per year.

Key indicators include:

- Annual cost and cost per square metre for each mine clearance method;
- Annual cost saving from use of mechanical support;
- Cost saving from use of mechanical support per square metre;
- Cost ratio mechanical support: manual mine clearance; and
- Time for machine to pay for itself.

Model output is demonstrated in Table 4.

Table 4. Model output

Variable	Item in ToR	Remarks
Cost per m² (actual and "real") Cost per unit	Cost effectiveness	Cost effectiveness is estimated by comparing cost per unit cleared with base case (manual clearance or another chosen method). In the Past Cost and Projected Cost functions, cost effectiveness is based on costs "actually" faced by project managers. In the Planning function, cost effectiveness takes account of the "real" cost of donated demining equipment.
Total cost saved compared to manual (or other method)	Cost saving[9]	Cost saving is be calculated relative to manual clearance or another selected method.
Cost per time period	Define weekly or monthly manual and machine costs	Annual data on running costs, spare parts, etc. provides a more accurate picture. Some staff may be salaried but cannot work in some months of the year.
Sensitivity Analysis or Switching Values	Highlight variables relating to cost effectiveness	Effect of change in assumptions on cost per m², total cost saved, etc. – highlighting variables with greatest effect on cost effectiveness (see above).

How to calculate cost per square metre

The CEMOD system calculates mine clearance costs per square metre for each method of mine clearance. CEMOD allocates management, administration, survey and medical costs in a standard way that will facilitate comparison between different mechanical clearance systems, and between mechanical and manual or manual/dog systems.

This report includes guidelines for the treatment of donated items and headquarters administration/supervision costs. Four analysis functions are described, since the "real" cost of mine action depends on the perspective of the decision maker — whether they are an implementing or planning agency and whether the analysis covers past or projected costs.

Cost per square metre should only be compared "where all other factors are equal", i.e. for clearance of mined land of similar characteristics. Differences in cost per square metre between minefields may be a reflection of changes in mine field characteristics — rather than the cost-effectiveness of alternative mine clearance procedures.

How to determine the cost-effectiveness of alternative methods of mine clearance

Analysis of the cost-effectiveness or productive value of mine action machines is integrated into the comparison of alternative methods of achieving the same goal (mine clearance to a given standard). This allows direct comparison of alternative combinations of procedures including area reduction, area preparation and combination machines with multiple tool attachments.

CEMOD also produces data on annual machine costs and cost per operating day. Comparisons based on machine cost per square metre will be valuable where different machines perform similar tasks. Data on cost per operating day highlight the importance of maximising the effective operating hours of expensive pieces of capital equipment.

Manual mine clearance provides a useful benchmark (base case); against which alternative mine clearance procedures can be assessed. Alternatively, a mechanical method may be entered as the base case. CEMOD compares the cost of alternative methods of mine clearance with the base case (it provides cost per square metre and the cost per square metre of each method as a percentage of the base case). Data is also provided on potential annual cost savings relative to the base case if each method had been used over the entire area cleared. Some judgement is required in using these figures appropriately, since in many cases use of a single method over the entire area would not be feasible.

Sensitivity analysis

Sensitivity analysis tests how changes in key assumptions affect the key output from the model (e.g. cost per square metre). The analyst concentrates on the changes which, based on past experience, are most likely to occur. For example how would the key indicators change if:

1. area cleared per machine per year was 30 per cent less or more?
2. area cleared manually per day was 30 per cent more or less?
3. area cleared manually (or by dogs) after a machine was 30 per cent more or less?
4. management and administration costs per square metre were 30 per cent more or less?

To carry out sensitivity analysis using CEMOD:

- Enter data into CEMOD using actual past data (or your best estimate of what will happen in the future). Print Standard Reports. Save to an appropriate name e.g. CEMOD Base Case;
- Change a key assumption e.g. decrease are cleared per machine per year. Print Standard Reports. Save to an appropriate name e.g. CEMOD Scenario 1;
- Continue for as many alternative scenarios as appropriate; and
- Review results.

Discussion of CEMOD results should be backed up by a discussion of the how sensitive key indicators are to changes in key assumptions. For example:

> "*Mine clearance using method 1 (Mine Shredder followed by manual clearance) had the lowest overall cost per m^2. However achievement of this cost level requires annual clearance by Mine Shredder of 500ha. Based on past experience of … there is a significant risk that this will not be possible, in which case method 2 would have the lowest cost per square metre.*"

Factors affecting cost-effectiveness

The cost-effectiveness model is designed to provide standardised calculations of the cost of mine clearance using actual or projected data. Many factors are likely to influence the cost-effectiveness of particular methods of mine clearance in particular settings (see Table 4). Foremost among these will be labour and machine costs, and the comparative productivity levels of manual clearance teams, dog teams and mechanical clearance machines (whether in a support or leading role). However, other idiosyncratic factors are also likely to be important and these are not incorporated into CEMOD even though they are likely to be relevant to the decisions that agencies make about the most effective way to clear a given area.

For example, an agency may use different machines to do a similar task (say, vegetation clearance), but on land with different characteristics. While it would be possible to have a model that considers factors such as slope *v.* flat, dry *v.* wet, such a model would be quite complicated and it would be more difficult to use the model for planning purposes. Instead, it is expected that when the current model gives costs for each machine, the user can work out if the higher cost for one machine is justified by the more difficult terrain it is working on.

Table 5. Key variables affecting cost-effectiveness

Variable	Remarks
Administration & support costs Medical costs	Substantial variation between countries and organisations, etc.
Labour costs	Vary with country, skill levels, employing organisation, etc.
Machine costs	Should (in theory) be similar for equipment procured internationally, but transport costs, tariffs/duties, availability of supply, etc., may cause considerable variation.
Labour productivity	Key variables include: i. work practices, training and labour turnover, ii. weather and seasonal conditions, iii. degree of metal contamination (including laterite soils), iv. terrain and amount of vegetation, rubble, etc., v. number and type of mines present, and vi. rate before and after machine use.
Machine productivity	Key variables include those detailed above, and: i. area suitable for demining by that machine, ii. work practices, training and labour turnover, iii. type of role undertaken by machine, iv. result of machine action (degree of contribution to the entire clearance method), v. feasibility/difficulty of moving machine to site, vi. reliability (amount of down time due to mechanical problems), vii. clearance depth (see below), and viii. number and type of mines present.

A similar complication comes from the type of mine that is expected in a given field. Mechanical procedures that are feasible when working with anti-personnel mines may not be feasible when working on anti-tank mines and the use of suitably armoured machinery is likely to affect the cost comparisons. Hence, the information provided by CEMOD cannot replace the detailed knowledge of project managers, instead it is designed to provide additional information so that they can make better informed decisions about mine clearance.

There are at least two additional factors that must be considered so that the cost effectiveness calculations can be put in their correct context. First, as noted above, there is no explicit premium for timeliness in the calculations carried out by CEMOD. However, while the reports allow methods to be compared on an area unit basis, they also indicate clearance rates and cost per day, so information on the timeliness of particular methods can be extracted. It is unlikely that a standardised model could provide more detail because local factors (such as the pressure on land) will dictate what value is placed on timeliness. Second, although square metre seems to be an accepted metric for recording output, there is some argument for considering the depth of clearance. A hidden (dis)advantage of some machines may be that they clear to a (lesser) greater depth than is possible with other techniques. A comparison solely on the basis of costs per square metre will miss this point and may unfairly indicate an advantage for one machine or method in the comparisons.

Endnotes

1. i.e. from the point of view of, for example, Bosnian society as a whole. Such economic calculations might for example be adjusted for taxes, tariffs and other price distortions. They might include a shadow cost of labour lower than actual rates paid to those working on demining — to reflecting the high local rate of unemployment.
2. See note 1.
3. This paragraph is summarised from D.L. Weimer and A.R. Vining (1999), *Policy Analysis: Concepts and Practice*.
4. Subject to differences in conditions and other variables (discussed below). There is no explicit consideration of the time taken to achieve the goal because the value of timeliness may differ greatly between projects. However, timeliness is one of many factors that users of the model must bear in mind when interpreting the results.
5. Regional in the sense of covering a group of countries.
6. The present model does not account for inflation. This should not normally significantly affect results since most capital items have a fairly short life and many agencies will enter costs in US$ terms (and the U.S. inflation rate is at low levels). This could be a problem if cost data is entered based on a currency with a high inflation rate.
7. The money that could realistically be obtained if the equipment was sold.
8. Number of years you expect existing equipment to remain in service from the analysis date.
9. It is assumed that the term productive value in the TOR (item 1) is the same as cost saving.

Main study conclusions and recommendations

Conclusion 1.

Under certain circumstances, machines are capable of achieving full clearance.

Even when employed only in the ground preparation role, some machines have shown, through the testing and empirical performance data available, and when operating in a suitable environment no live mines are left in a condition that could pose a further threat. Where mechanical excavation is concerned, clearance is achieved down to the depth at which operators remove suspect soil.

Recommendation 1.

Machines used for primary clearance can achieve the IMAS specification of mine clearance quality in suitable environments against certain mine types. The residual threat — ordnance that is unlikely to be fully destroyed by a particular machine in a particular environment — should be understood by the operator and the relevant demining authority. Any post-mechanical clearance by manual or mine detection dogs (MDDs) should be tailored to meet the identified residual threat in order to make clearance operations more rapid.

Conclusion 2.

With regard to flails and tillers, the physical interaction between the destructive tool, the ground and the mine/UXO, is not completely understood.

Some of the negative effects — such as throw-outs or burying — have been identified but their exact causes can not yet be fully explained.

Recommendation 2.

The demining and the scientific communities need to conduct further research into the following areas:

- *To determine how the following issues:*
  - *impact stress and soil movement;*
  - *limits imposed by soil/terrain/vegetation;*
  - *flail hammer geometry;*
  - *engine power;*
  - *flail shaft height above the ground;*
  - *forward speed, and;*

· mine type

are responsible for the negative results of:

· soil bulking/overburden;
· throw-outs;
· skipped zones;
· slipstreaming (tillers only), and;
· burying and bow wave (tillers only).

Better understanding of the causes will lead to suppression/control of the effects; mechanical clearance results should be predictable.

- *Where mines/UXO are not detonated but are broken up by machine use, the remaining fragments may or may not constitute a further threat. Relating to different mine types, guidelines should establish the level of damage to a mine such that it no longer poses a threat to subsequent clearance personnel or users of the land. Where ordnance fails to detonate, a definition of what level of destruction constitutes a non-hazardous mine/UXO, when broken up, is required.*
- *Some mechanical tools penetrate the ground, often resulting in removal of top soil, leaving pulverised earth and destroying shallow root systems. The short- or long-term ecological damage that might be caused to soil and the implications this has for agriculture should be established.*

Conclusion 3.

The clearance capability of some mechanical demining systems is not always predictable.

In part this is due to a lack of testing with a sufficient number of ordnance targets. Due to the efforts of the European Committee for Standardization, Workshop 12 (CEN WS 12), more and better testing data is likely to be available in the coming years. Another reason for the lack of understanding of machine effectiveness is the limited availability of machine clearance data from field operations which could be used to assess mechanical systems empirically. With such information, a greater understanding of mechanical clearance capability would emerge.

Recommendation 3.

The demining community should record mechanical clearance data in a standard, internationally recognised format. This would provide a clear, comparative format for assessing the true capabilities of various mechanical systems involved in demining. Empirical data could then be used to argue the case for further employment of machines in mine clearance. Templates and software for the collection of standardised mechanical clearance data is under development at the GICHD.

Conclusion 4.

Mine clearance is in reality a risk reduction process. However, the total removal of risk cannot be guaranteed due to the limitations applicable to all known clearance methods.

A structured risk assessment with its attendant understanding of local, tolerable risk criteria will assist deminers in making the most appropriate decision as to where to carry out clearance (prioritisation), and by what means. Currently, the worst case scenario is generally applied, resulting in an attempt to clear all suspected hazardous areas — often not the most efficient use of scarce resources.

Recommendation 4.

- *Demining agencies should consider using a structured risk assessment process to get the best out of their clearance. General survey information should be assessed by physical action, i.e. technical survey, in order to make the decision whether or not to commit deminers to an area.*

- *In the right physical environment, machines are often the most effective means of acquiring accurate information about the ordnance hazards in a suspect area.*
- *Machines should be used for technical survey as part of a risk assessment process. Currently, this use for machines is not practised widely. Increased use of machines in this role will allow deminers to confidently rule out the necessity for further clearance in some areas. In areas where subsequent demining is required, the risk to deminers is reduced as quantities of existing ordnance may be destroyed and ground will be prepared making subsequent post-mechanical clearance faster. The attempt to clear all suspect areas all the time is not required and will only slow down the worldwide effort to remove landmines and UXO.*
- *Manufacturers should consider the information gathering abilities afforded by clearance and detection tools attached to mechanical systems, and attempt to incorporate such assets in their designs. Further research on machine attachments other than the primary working tools, such as vapour detectors, magnets, ground penetrating radar, global positioning systems (GPS) and thermal imaging is encouraged.*

Conclusion 5.

Today, the great majority of suspect land cleared is subsequently revealed not to contain mines.

Much time is spent in the search for ordnance, particularly where general survey information is poor. Data analysed by the GICHD from 15 separate national demining authorities indicated that of all land cleared, it is possible that an average of less than less than three per cent of suspect land ever contained mines or UXO. Knowing where landmines are located and therefore where to clear, is possibly the best way to increase demining efficiency.

Recommendation 5.

Where no clear evidence of a threat is confirmed, suspect areas can be eliminated through a systematic mechanical area reduction process. The same would apply to areas where hard evidence of the presence of mines exists but quick confirmation as to true disposition is required.

Conclusion 6.

Preparing ground by machine for subsequent demining methods — manual or mine dog detection — significantly increases the speed at which clearance can be conducted as many common obstacles will be removed.

The greatest benefits brought to manual or MDD clearance teams are the cutting of vegetation and the removal of tripwires, the breaking up of soil surfaces, and the removal of metal scrap contamination. The hierarchy of importance of these obstacles can vary, depending on the physical environment, threat type and the machine available to prepare the ground. A machine that can remove all of these obstacles, in as few passes as possible, will contribute the most to manual and MDD clearance operations.

Recommendation 6.

Manufacturers should develop machines that can remove all main obstacles facing deminers; cut vegetation and remove tripwires, break up soil, and expose and remove metal fragments.

Demining organisations should buy and use machines that can defeat as many of the common obstacles as possible in order to bring the greatest operational and cost-effective benefits to their programmes.

Conclusion 7.

The involvement of machines in the mine clearance process can contribute to significant improvements in productivity.

Evidence of this is found in the case studies included in the chapters of this report covering area reduction and ground preparation; the productivity increase in the most extreme example was in excess of 2,000 per cent. Although more moderate figures are typical, in general, machines will improve the cost-effectiveness of demining operations.

Recommendation 7.

Where conditions are suitable, the wider employment of mechanical systems in demining programmes, particularly for area reduction and ground preparation, will often significantly enhance productivity and cost-effectiveness.

Bibliography

Brown, S. (1999)
"Mine action – The Management of Risk", *Journal of Mine Action*, Mine Action Information Center, James Madison University, Harrisonburg, Virginia, available at: *maic.jmu.edu*.

Bundeswehr (2002)
Erfahrungsbericht zum 1. Minebreakersatz. N Afghanistan vom 3/9 – 6/12 2002 bei KMNB ISAF.

Church, H.K. (1981)
The Excavation Handbook, McGraw Hill, U.S.

CMAC (Cambodian Mine Action Centre) (2002)
Progress Report 2002, available at: *www.camnet.com.kh/cmac*.

_____ (2001)
Test Plan #00499 Rhino, CMAC, Cambodia.

CROMAC (Croatian Mine Action Centre) (2000a)
Oracle test report, April-June, CROMAC, Croatia.

_____ (2000b)
Mine Guzzler in Croatia, May-June, CROMAC, Croatia.

Edmondson, J.N. (2001)
Risk Assessment Safety and Reliability Directorate, in press.

Flanagan. J. (2000)
Humanitarian mine action versus military clearance, Workshop on regionally focused mine action, Thessaloniki, Greece, 4-5 May 2000.

GICHD (2004)
Mechanical Demining Equipment Catalogue 2004, GICHD, Geneva.

_____ (2003)
Mine Detection Dogs: Training, Operations, and Odour Detection, GICHD, Geneva.

_____ (2002)
Mine Action Equipment: Study of Global Operational Needs, GICHD, Geneva.

_____ (2001)
Designer Dogs: Improving the Quality of Mine Detection Dogs, GICHD, Geneva.

HADI (2002)
Minenräumer FMR 2000, Minenräumprotokol, 8 August 2002, Vienna, Austria.

HALO Trust (2001a)
Pearson Full Width A/P Mine Roller field results, Internal report, Scotland.

_____ (2001b)
Monthly Mechanical Results, HALO Trust Cambodia, Siem Reap.

_____ (2000a)
Final report, Mechanical Area Reduction in Abkhazia, 1 August 1999 – 31 July 2000, Georgia.

____ (2000b)
Interim report, 1 January - 31 March 2000: Abkhazia Humanitarian Mine Clearance Programme, Georgia.

_____ (1999a)
Proposal to the Government of the Netherlands, Mechanical Area Reduction in Abkhazia, Georgia.

_____ (1999b)
Budget line summary (January – November 1999), Georgia.

Handicap International (2000)
The Use of Mechanical Means for Humanitarian Demining Operations, Mines Coordination Unit, Handicap International, Belgium.

Health & Safety Executive

_____ (2001)
Reducing risks, protecting people, HSE's decision making process, HMSO, United Kingdom.

_____ (2000a)
Successful Health and Safety Management, HMSO, United Kingdom.

_____ (2000b)
The cost of accidents at work, HMSO, United Kingdom.

International Campaign to Ban Landmines (2001)
Landmine Monitor Report 2001, Toward a Mine-Free World, Human Rights Watch, United States.

ISO (International Organisation for Standardization) (1999a)
Safety of Machinery – Principles of Risk Assessment, Guide 14121, ISO, Switzerland.

_____ (1999b)
Safety Aspects – Guidelines for their inclusion in standards, ISO, Switzerland.

Israeli Ground Forces Command (2001)
Rhino evaluation in Israel – Summary Report, GFC Planning Division R&D Department.

Joynt, V.P. (undated)
"Extracts from incident reports issued by the SADF" (courtesy of V.P Joynt).

Kaydos, W. (1998)
Operational Performance Measurement: Increasing Total Productivity, St. Lucie Press, U.S.

Lower, B. (2002)
Strike Force Calculations and Strike Pattern, Internal document, Mines Advisory Group, UK.

McCracken, D.W. (2002)
Mechanical Area & Risk Reduction, paper prepared for the GICHD, Geneva.

_____ (2001)
Mechanical Assistance to Demining: Thailand Case Study, Canadian Center for Mine Action Technology, Vancouver.

_____ (2000)
Level Two Technical Survey Standing Operating Procedures, Thailand Mine Action Centre, Bangkok.

Mechem (1998)
Project Terra Limpa & Corrumane Field, Mozambique, Internal report, Mechem, South Africa.

Petes, J. (1983)
"Blast and fragmentation characteristics", *Annals of the New York Academy*, Vol. 152, Part 1, pp. 283-316.

Phelan, J.M., and S. W. Webb (2003)
"Chemical sensing for buried landmines: fundamental processes influencing trace chemical detection ", in *Mine Detection Dogs: Training, Operations and Odour Detection*, GICHD, Geneva.

RMMS (2000)
RSA-MIL-STD-37 (2000) Landmine Protected Wheeled Vehicles: Design, Development and Evaluation Of, Standard four. Issued by RMSS October. Elements of Material Science. Van Vlack.

Saratha, M. (2001)
Pearson Tools Trial, 5-23 March 2001, Internal report, HALO Trust Cambodia, Siem Reap.

Shankla V.S. (2000)
Unravelling flail-buried mine interaction and neutralization, Defence Research Establishment Suffield, Medicine Hat, Canada.

Soth, D. (2002)
Desk Evaluation of Tempest Project, MAG Cambodia internal report, Phnom Penh.

Stiff, P. (1986)
Taming the Landmine, Galago Publishing, South Africa.

STANAG 4569 (1999)
Edition 1 issued by MAS, May 1999.

SWEDEC (Swedish Explosive Ordnance Disposal and Demining Centre) (2002)
Tests of Mineguzzler, Scanjack, Hydrema, Internal report, SWEDEC, Sweden.

_____ (2001)
Mineguzzler, Internal report, SWEDEC, Sweden.

Van Dyk, J. T, Smit, D., and Joynt, V. P. (2002)
Guidelines for the mine protection of vehicles and plant equipment used in humanitarian and commercial demining, GICHD, Geneva.

List of acronyms

APC	armoured personnel carrier
ARR	Area Reduction Roller
BAC	battle area clearance
BiH	Bosnia and Herzegovina
CEN	European Committee for Standardization (*Comité Européen de Standardisation*)
CCMAT	Canadian Centre for Mine Action Technologies
CEMOD	Cost-Effectiveness Model
CMAC	Cambodian Mine Action Centre
CROMAC	Croatian Mine Action Centre
DRES	Defence Research Establishment Suffield (now Defence Research and Development Canada - Suffield)
ELS	European Landmine Solutions
EOD	explosive ordnance disposal
GICHD	Geneva International Centre for Humanitarian Demining
HALO	Hazardous Areas Life-Support Organisation
HC	hollow charge
hp	horsepower
IMAS	International Mine Action Standards
ISO	International Organization for Standardization
IR	increase rate
JAHDS	Japanese Alliance for Humanitarian Demining Support
LAF	Lebanese Armed Forces
LNDO	Lebanese National Demining Office
LMDS	Land Mine Disposal System
MAG	Mines Advisory Group
MDD	mine detection dog

MgM	Menschen gegen Minen
MPV	mine protected vehicle
NATO	North Atlantic Treaty Organisation
NPA	Norwegian People's Aid
NVESD	Night Vision & Electronic Sensors Directorate (U.S. Army)
QA	quality assurance
QC	quality control
R&D	research and development
REST	Remote Explosive Scent Tracing
rpm	revolutions per minute
SDTT	Survivable Demining Tractor and Tools
SFF	self forming fragment
SHA	suspected hazardous area
SOP	standing operating procedure
STS	Safety Technology System
SWEDEC	Swedish Explosive Ordnance Disposal and Demining Centre
TMAC	Thailand Mine Action Centre
TNT	trinitrotoluene
U.K.	United Kingdom
UNMAPA	United Nations Mine Action Programme for Afghanistan
UNMAS	United Nations Mine Action Service
U.S.	United States
UXO	unexploded ordnance

Appendix 1

The User Focus Group

Armtrac	Steve Brown
Bofors Defence	Allan Carlsson
Canadian Centre for Mine Action Technology	Geoff Coley
CSIR Defencetek	Theo Van Dyk, Danie Smit
Dok-Ing D.O.O	Vjekoslov Majetic, Josip Tulicic
ELS	Rob Jones
GICHD	Håvard Bach, Mark Buswell, Johannes Dirscherl, Alexander Griffiths, Leonard Kaminski
The HALO Trust	Gerhard Zank, Simon Conway
Institute for Defense Analyses	Hal Bertran
ITEP/Qinetiq	Chris Leach, Peter Blatchford
LNDO	Wassim Saleh
MAG	Barry Lower
Mechem	Ashley Williams, Freek Kruger
Minetech Int'l	Lionel Dyk, Hugh Morris
NPA	Erik Tollefsen, Paul Collinson
NVESD	Charlie Chichester, Chris Wanner
Redbus LMDS	Bob French
SWEDEC	Kaj Hörberg, Jan-Ole Robertz, Bo Malmberg
UNMAS	Noel Mulliner
Consultant	Roger Hess

Appendix 2

Glossary of terms and abbreviations[1]

anti-personnel mine
a mine designed to be exploded by the presence, proximity or contact of a person and that will incapacitate, injure or kill one or more persons.

anti-tank mine
a landmine other than an anti-personal mine designed to be detonated by the presence, proximity or contact of a vehicle.

area reduction
the process through which the initial area indicated as contaminated (during the general mine action assessment process) is reduced to a smaller area.

Note: Area reduction may involve some limited clearance, such as the opening of access routes and the destruction of mines and UXO which represent an immediate and unacceptable risk, but it will mainly be as a consequence of collecting more reliable information on the extent of the hazardous area. Usually it will be appropriate to mark the remaining hazardous area(s) with permanent or temporary marking systems.

booby-trap
an explosive or non-explosive device, or other material, deliberately placed to cause casualties when an apparently harmless object is disturbed or a normally safe act is performed.

casevac
casualty evacuation.

CEMOD (cost-effectiveness model)
Excel-based software model with visual basic interface design for managers of mine action programmes to evaluate cost-effective methods of clearance.[2]

cost-effectiveness
an assessment of the balance between a system's performance and its operational costs, relative to other methods of doing the same job.

demining
activities which lead to the removal of mine and UXO hazard including technical survey, mapping, clearance, marking, post clearance documentation, community mine action liaison and the hand-over of cleared land. Demining may be carried out by different organisations, such as NGOs, commercial companies, national mine action teams or military units. Demining may be emergency based or developmental.

demining lane
the generic term for any lane, other than a boundary, cleared by a survey or clearance team to the international standard for cleared lane. This may include access lanes for machines to enter the minefield.

Note: A breaching lane is also a demining lane.

1. This glossary is for the purposes of this study only. Where an existing IMAS definition exists, this has been used.
2. CEMOD was developed for the GICHD by Dan Marsh and John Gibson.

deminer
a person qualified and employed to undertake demining activities or work on a demining worksite.

demining organisation
refers to any organisation (government, NGO, military, or commercial entity) responsible for implementing demining projects or tasks.

dummy mine
objects used to represent a mine. Used for testing and demonstration.

follow-up
the process of conducting clearance subsequent to the use of a machine or any other initial method of clearance.

ground preparation
preparing the ground, usually by mechanical means, by removing or reducing terrain obstacles.

increase rate
refers to the number of times the clearance rate of a deminer/s has been increased.

intrusive machine
any machine that is capable of operating inside a mined area or minefield as it is capable of protecting the operator from the effects of blast and fragmentation from mine and UXO detonations and has a high level of survivability. Intrusive machines can be operator driven or remotely controlled.

Note. Machines are fitted with tools designed to clear mines e.g. flails.

mechanical application
the generic term to describe the use of machines conducting various roles within mine clearance operations.

mechanical clearance
the application of mechanical systems as the primary clearance tool.

mine risk education (MRE)
a process that promotes the adoption of safer behaviours by at-risk groups, and which provides the links between affected communities, other mine action components and other sectors.

mine threat
Mine and UXO threat. An indication of the potential harm from the number, nature, disposition and detectability of mines and UXO in a given area.

mined area
an area which is dangerous due to the presence or suspected presence of mines

minefield
an area of ground containing mines laid with or without a pattern.

Note. Differs from a mined area as dimensions of the area, the quantity and type of mines and ordnance are better understood.

Note. A minefield is considered to have a pattern when information about the location of one or more mines can be used to predict the location of others. A minefield is considered non-patterned when information about the location of one mine cannot be used to predict the location of others.

non-intrusive machine
a machine which works from the fringes of minefields (in safe or clear areas) as it affords the operator limited protection from a effects of mine or UXO blast.

Note: machine is usually fitted with ground preparation tools.

quality assurance (QA)

quality control (QC)

part of the management focused on providing confidence that quality requirements will be met. (ISO 9000:2000)

Note: QC relates to the inspection of a finished product.

R & D

research and development

residual risk

in the context of demining, the term refers to the risk remaining following the application of all reasonable efforts to remove and/or destroy all mine or UXO hazards from a specified area to a specified depth.

residual threat

in the context of demining, the term refers to the mines and UXO remaining in the ground after a machine has been applied as a single stage in a multiple stage clearance process.

risk

is the combination of the probability of occurrence of harm and the severity of that harm.

risk assessment

a process of identifying potential areas of harm to enable informed decisions to be made.

risk reduction

control measures taken to reduce the impact and/or probability of risks.

surrogate mine

a replica of a mine, the same in all aspects less a main charge. Used for testing and demonstration. In some cases, surrogate mines may contain a live fuze mechanism, particularly when used in testing machines.

technical survey

the detailed topographical and technical investigation of known or suspected mined areas identified during the planning phase. Such areas may have been identified during the **general mine action assessment** or have been otherwise reported.

tolerable risk

the degree to which a risk is acceptable.

unexploded ordnance (UXO)

explosive ordnance that has been primed, armed or otherwise prepared for use or used. It may have been fired, dropped, launched or projected yet remains unexploded either through malfunction or design or for any other reason.

Geneva International Centre for Humanitarian Demining
Centre International de Déminage Humanitaire - Genève

Geneva International Centre for Humanitarian Demining
7bis, avenue de la Paix
P.O. Box 1300
CH - 1211 Geneva 1
Switzerland
Tel. (41 22) 906 16 60, Fax (41 22) 906 16 90
www.gichd.ch