

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

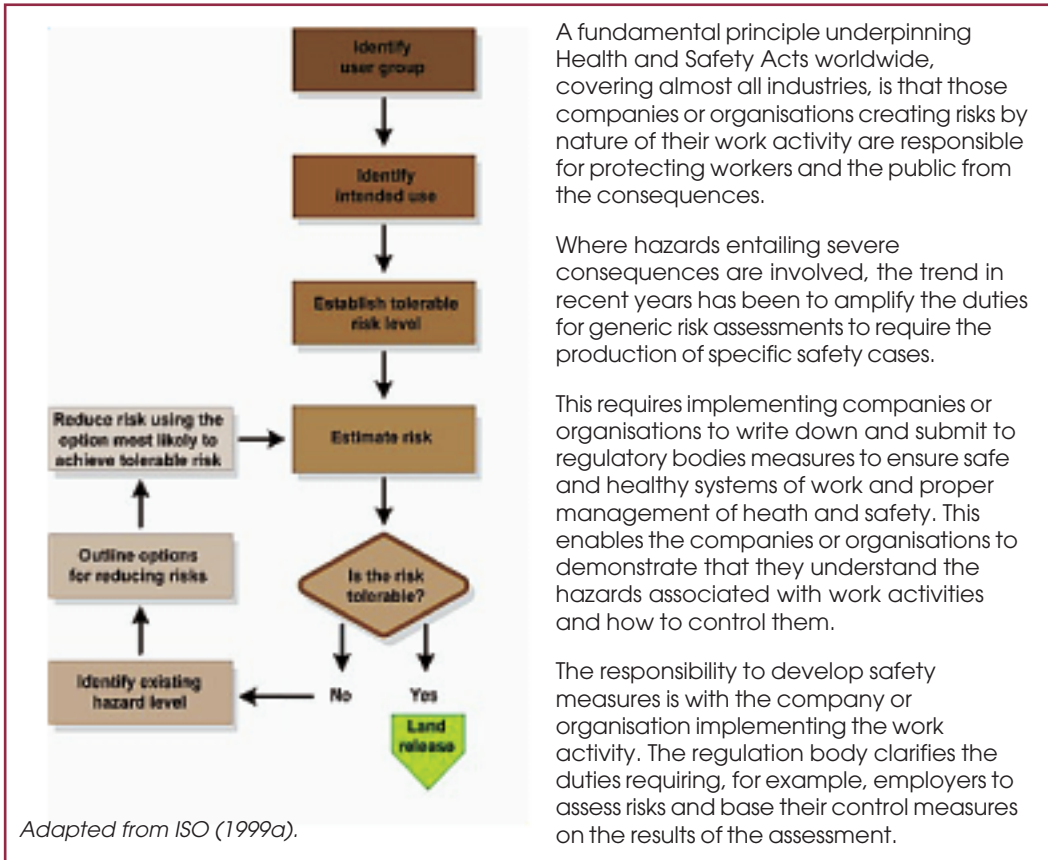
Risk assessment is a tool used to facilitate decisions about how to optimise the use of scarce resources. Risk assessment provides the basis for determining the risk involved in certain processes and justification for the actions that have been undertaken.

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



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.

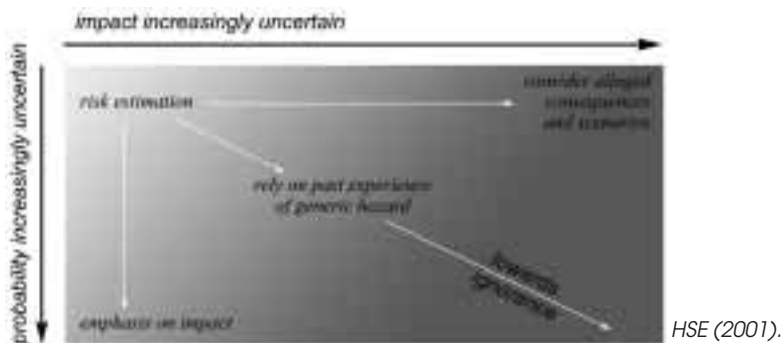
Step 4. Estimate the risk level

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



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 1 st 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.

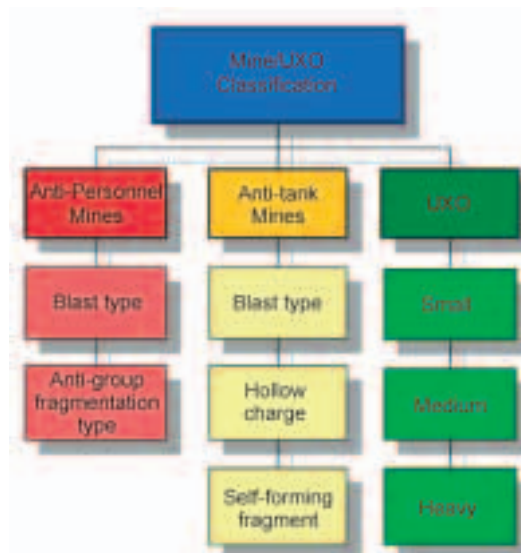
In Kosovo, the Mine Action Coordination Centre applied different clearance methods according to different explosive item risks. High-risk items included mines and cluster bombs. Clearance methods were used in areas known to contain these items. Other general munitions (mortars and artillery rounds, etc.) 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
<i>Manual clearance</i>	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.
<i>Dog detection</i>	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.
<i>Machines</i>	Machines such as flails and fillers 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

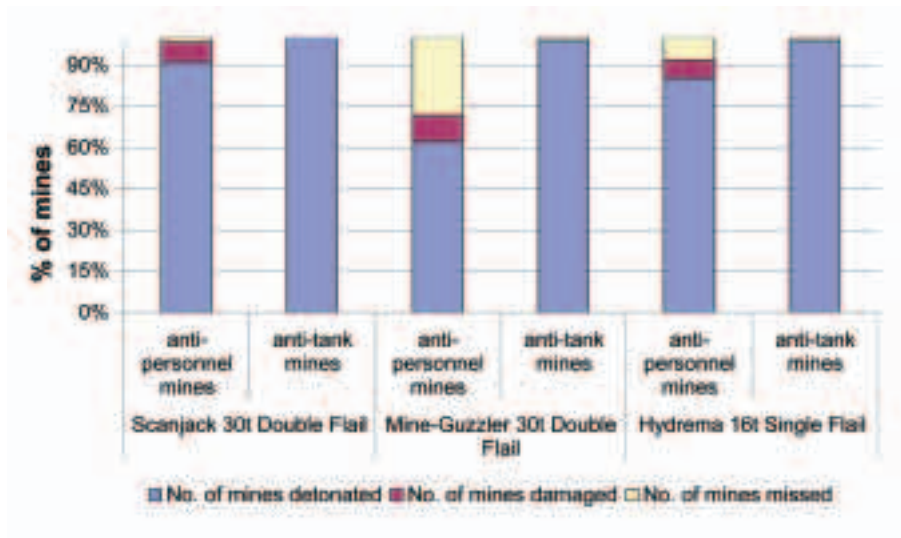


Figure 5 shows a significant effect of each machine type on detonation rates ($F_{(2,17)} = 20.78, p < .001$), with the Mine-Guzzler detonating fewer mines overall than the other two machines. There was no effect of mine depth on detonation rate ($F_{(2,17)} = 1.83, p > .05$) and no significant interaction 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

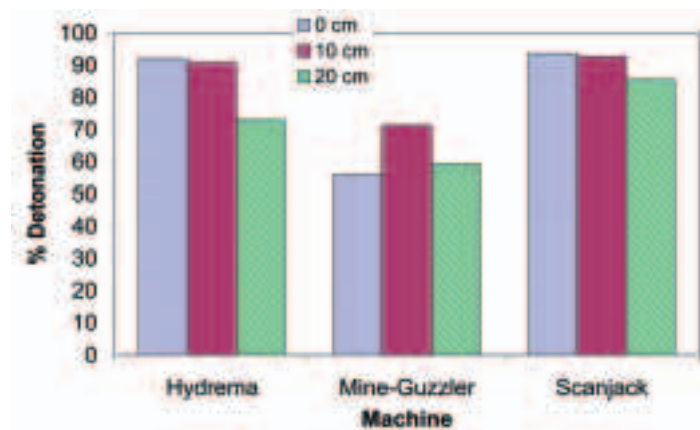


Figure 6 shows the results of operating the machines at different speeds. The Mine-Guzzler was operated at a much larger range of speeds than the other two machines and appeared to detonate a lower percentage of mines the faster it was used, although the negative trend was not significant ($r^s = -.17,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

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

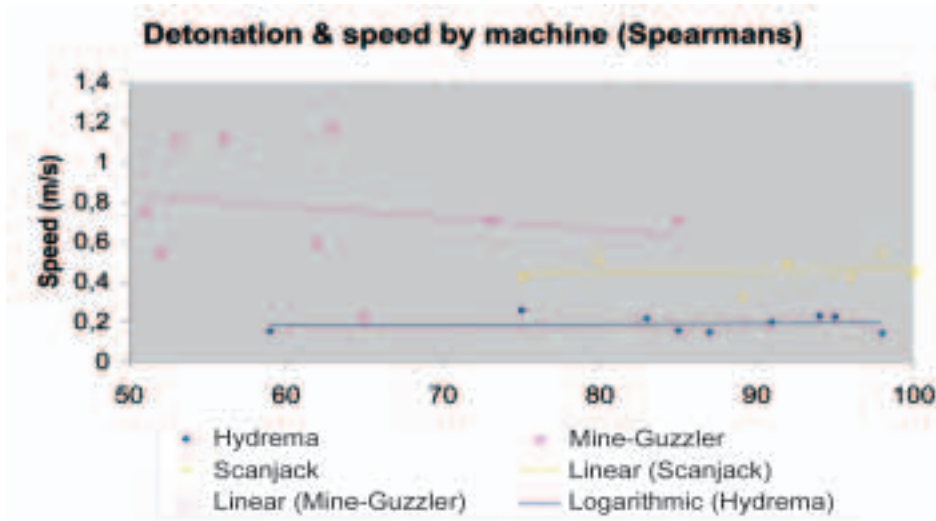
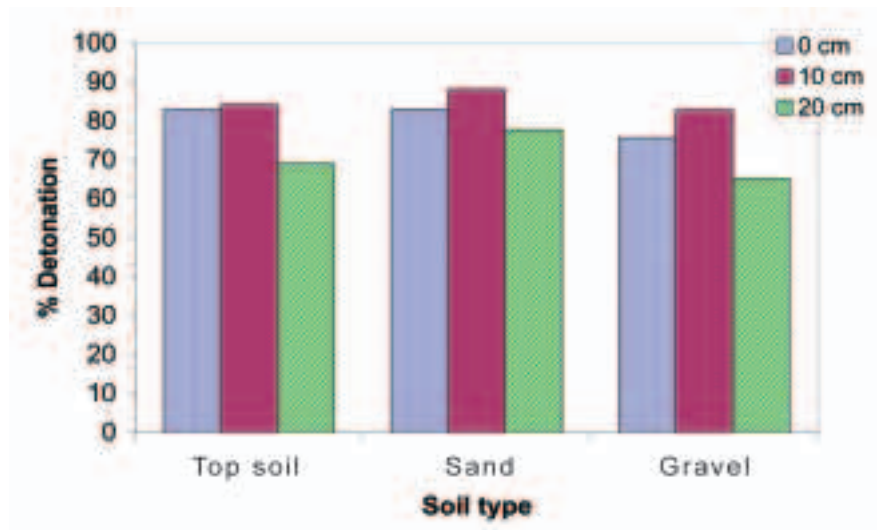


Figure 7 shows no significant effect of mine depth ($F_{(2,17)} = 1.31, p > .05$) or soil type ($F_{(2,17)} = 0.47, p > .05$) on the detonation rate. This means that the machines achieved similar detonation rates regardless of soil type and mine depth.

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. Table 7 shows the number of mines found, detonated, damaged and unaffected by machines.

Fig. 8. Machine effect on mines encountered

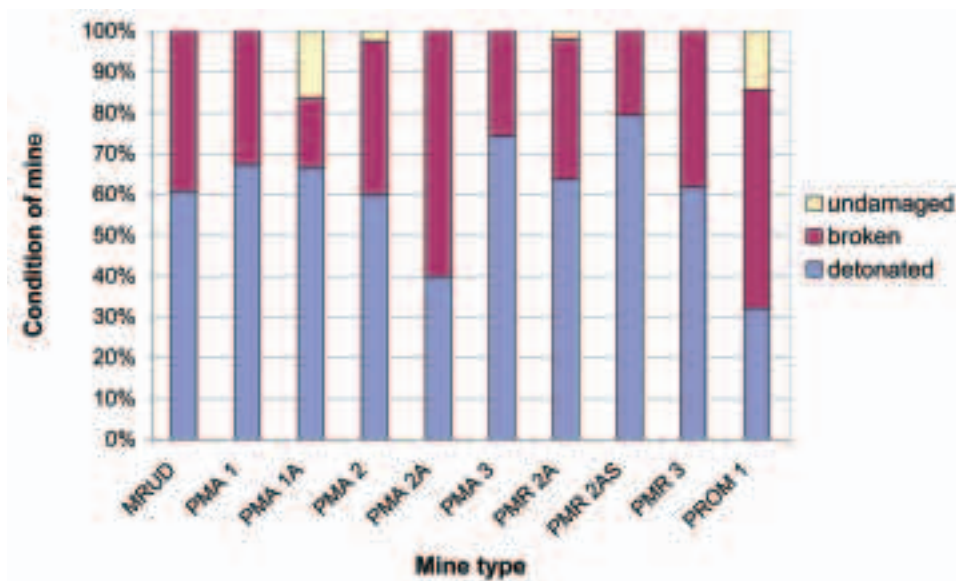


Table 7. Number of mines encountered, detonated, damaged and unaffected as a percentage of the total processed by machines

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

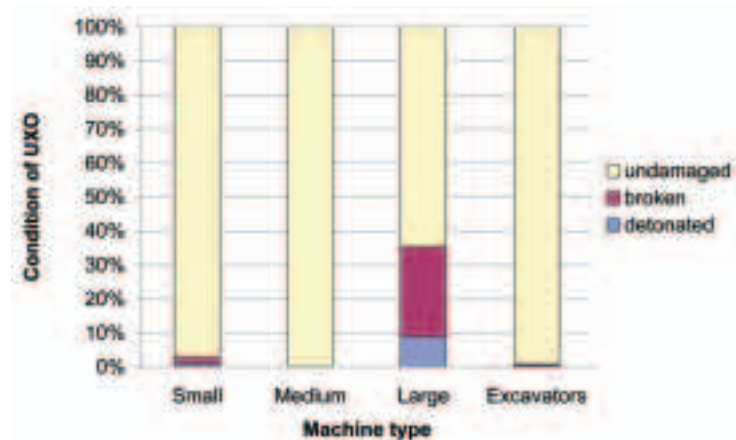
As Croatia legally requires an additional clearance method (a form of follow-up) when using a machine, information regarding each machine's effectiveness was obtained in the follow-up process. Sixty-three per cent of the mines were detonated by the machine. The 3.65 per cent which were undamaged are 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 undetonated 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

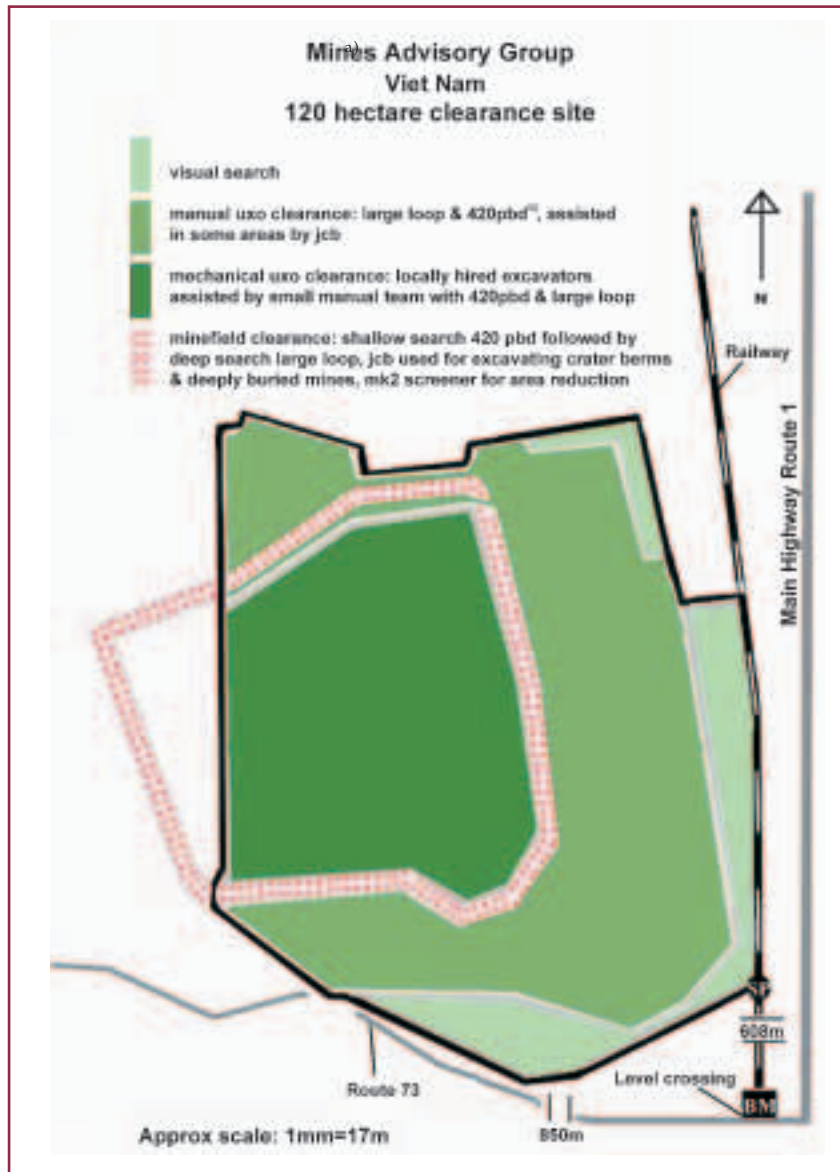
Information from the technical survey confirmed the location of the mines and that no mines were expected inside the firebase. Additionally, the condition and nature of the UXO meant mechanical excavation would be possible (abandoned UXO only, which had not been fired). Locally-hired excavators were 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.