Landmine Research: Technology Solutions Looking for Problems

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ABSTRACT

The global landmine problem came to the attention of researchers in the mid 1990's and by 1997 several advanced and expensive sensor research programs had started. Yet, by the end of 2003, there is little sign of a major advance in the technology available to humanitarian demining programs. Given the motivation and dedication of researchers, public goodwill to support such programs, and substantial research resources devoted to the problem, it is worth asking why these programs do not seem to have had an impact on demining costs or casualty rates. Perhaps there are factors that have been overlooked. This paper reviews several research programs to gain a deeper understanding of the problem.

A possible explanation is that researchers have accepted mistaken ideas on the nature of the landmine problems that need to be solved. The paper provides several examples where the realities of minefield conditions are quite different to what researchers have been led to believe. Another explanation may lie in the political and economic realities that drive the worldwide effort to eliminate landmines. Most of the resources devoted to landmine clearance programs come from humanitarian aid budgets: landmine affected countries often contribute only a small proportion because they have different priorities based on realistic risk-based assessment of needs and political views of local people. Some aid projects have been driven by the need to find a market for demining technologies rather than by user needs. Finally, there is a common misperception that costs in less developed countries are intrinsically low, reflecting low rates paid for almost all classes of skilled labour. When actual productivity is taken into account, real costs can be higher than industrialized countries. The costs of implementing technological solutions (even using simple technologies) are often significantly under-estimated.

Some political decisions may have discouraged thorough investigation of cost-effective alternatives to landmine clearance.

Keywords: landmine, demining technologies, political and economic factors, risk assessment

1. LANDMINE PROBLEMS

Most landmine researchers focus on the problem of locating individual landmines. However it is important to step back and understand the true nature of the global landmine problem to understand why much of the research that has been carried out is unlikely to lead to useful technological solutions.

The landmine problem starts with fear: most landmine contamination cannot be seen and it is the fear of dreadful mutilating injuries or even death that prevents people from using land that is believed to contain landmines. The affected people are forced to relocate and live, possibly for decades, as refugees in almost total destitution. These people are typically known as "internally displaced persons".

"Mine Action" is a general term to describe the response to this problem: it encompasses direct assistance to landmine victims including prostheses and rehabilitation, advocacy to prevent further use of landmines, "mine risk education" to help people understand the nature of the problem and how to avoid entering areas that might contain landmines and finally survey and landmine clearance to remove the threat permanently. The objective of this last aspect of mine action is to release uncontaminated land for people to use in safety. Within this last aspect of mine action, survey is often the most important. Most of the land released for people to use is released through survey operations investigating landmine contamination: land that has a sufficiently low risk of contamination is released immediately without further clearance. Initial surveys focus on mapping and indirect evidence of landmine contamination: have there been accidents on the land? Can landmines be seen? Is there evidence from local people that landmines were laid? Can any discarded

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packaging, safety pins or other equipment associated with minelaying be found in the immediate area? Are there any maps or records that indicate that this area was mined? Were there military confrontations in this area in which landmines may have been used? Was there are military post or an important piece of infrastructure on the land that might have been protected by a defensive minefield? If the answer to all these questions is "no" then in most cases the land would be immediately released for civilian populations to use. Otherwise the land is declared as "suspected contamination" and marked in a database for further investigation.

A more detailed survey may then be carried out to determine the extent, if any, of actual landmine contamination. Mine detection dogs and ground preparation machines are often used for a process known as "area reduction". In many cases a large proportion of the suspected area may then be declared "free of mine contamination". The remaining area may then be fenced or clearly marked as it may be some time before resources can be allocated to remove the remaining mines. The final phase, landmine clearance, is often the phase that receives the most attention in research: it is the most visible and obvious aspect of "demining" and yet is used only as a last resort because it is expensive and slow.

The major problem, therefore, that faces most countries affected by landmines is large areas of land that are suspected to contain landmine contamination. In Croatia in 1999 between 6,000 and 10,000 sq km were suspected to contain landmine or unexploded ordnance contamination. By 2003 this had been reduced to approximately 1500 sq km. Almost none of this reduction was achieved by mine clearance: it was achieved by detailed survey operations and painstaking analysis of indirect evidence of landmine contamination. Although the remaining suspected area is significant, the area of land released is much greater and, given the economic constraints faced by Croatia, much of the residual land could not be economically used[*]. Attention then needs to be focused on the "socio-economic" impact of the residual landmine contamination[15]. Contamination in urban areas almost always has a much greater impact than remote mountain forests, for example. Landmine contamination that prevents access to maintain important infrastructure clearly has a much higher priority. Socio-economic impact analysis enables land to be prioritised for clearance operations that proceed at a slower rate than survey operations. Of course, in some cases there are still significant areas of land that need to be cleared. In Afghanistan, for example, around 140 square kilometres of land was classified as "high priority" in 2002 and a further 560 square kilometers of land were designated as low priority[12]. However, it is important to note that the preferred solution for most of this land is to identify areas requiring clearance and ensure that they are properly fenced and marked to eliminate risk to civilian populations. This enables clearance to be carried out over a much longer time scale.

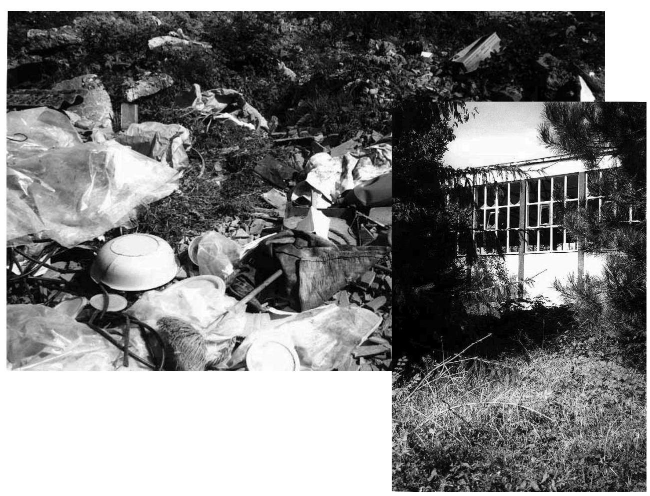

Figure 1: Photograph taken near Karlovac, Croatia, 1997 (author).

[*] Croatia has applied for EU membership but is not included in the current enlargement process. Trade barriers greatly restrict agricultural production so Croatia relies heavily on tourism: some tourists have to drive through contaminated areas.

To gain a further insight into the real nature of landmine problems it is useful to understand the enormous variety of land areas affected. It is also useful to understand the ways that landmines have been used.

Figure 1 shows two photographs were taken in 1997 near a factory complex near Karlovac, not far from Zagreb. The residential complex was trashed and looted before it became part of the confrontation lines between Croatian and Serb forces. Mines were laid in the piles of trash outside the buildings and the area has since become overgrown with vegetation.

Figure 2: Photograph taken in Sarajevo, July 1999. (D. Busuladzic)

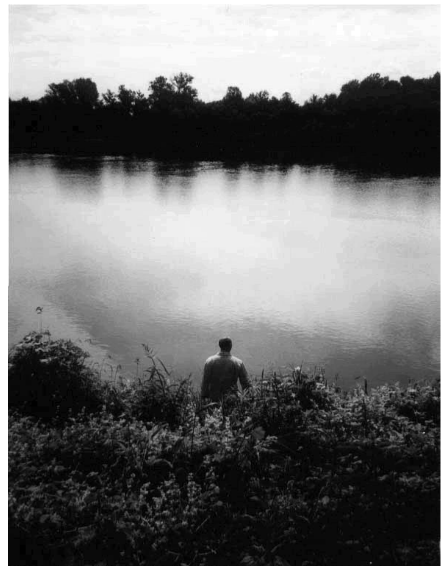

Figure 3: Photograph taken in Croatia, 1999. (author)

Figure 2 shows a similar scene, this time in Sarajevo. Here we can see a deminer at work. The rate of progress is extremely slow. Each piece of trash has to be treated as if it were booby trapped. A hook is attached carefully then the trash is pulled from a safe distance. Once again, vegetation complicates the job. Armoured excavators could make this job much easier but they cannot be used in this location because of anti-vehicle mines.

Hundreds of kilometres of river banks and the mud banks in the rivers are also potentially contaminated with mines. Rivers were often dividing lines between military factions and the banks were heavily fortified. In figure 3 the deminer is standing in Croatia looking across at Republika Serbska in Bosnia. Somewhere near here several tank traps were created in the river bed when the water was at a low level. Each trap consisted of approximately 500 kilograms of dynamite with an arrangement to detonate it remotely. These traps were designed to deter attempts to cross the river with amphibious armoured vehicles. In 1999 their location was unknown. No one knew whether the traps were still in place or whether the dynamite had been washed downstream in subsequent floods.

The river often floods well above the level of the man shown standing in figure 3. When this happens large amounts of floating wreckage and vegetation become trapped along the river banks. Many antipersonnel mines have been discovered in this waterborne material. This means that special precautions have to be taken to prevent this material from re-contaminating cleared areas along the river banks.

Figure 4 shows part of a minefield in the Jordan River valley. It is a high priority for clearance because the land is the most productive agricultural land in Jordan. The photograph shows irrigation piping that was in place when the mines were laid after the 1967 war. Interestingly, the irrigation piping is about 50 cm above where the mines were found. The mines were laid according to British patterns. They were laid with great accuracy in a pattern marked by steel picket posts: each anti-tank mine was surrounded with three antipersonnel mines. The location of the minefield is accurately known: the steel picket posts are still in place. Yet, this minefield has proved to be extremely expensive to clear. Further, there are many more minefields like this in the Jordan valley. Once the mines were in place vegetation grew uncontrolled in the minefield areas. On the occasions when storms caused flooding in the valley, the vegetation trapped mud and silt carried by the water, increasing the ground level. In this way, the mines were gradually buried to their present depth up to 1 m below ground level. Around 80% of the mines are almost exactly where they were laid. The remainder have moved.

The minefield is being cleared by a painstaking manual method. Deminers work along the line of the original minefield carefully probing the ground where the mines ought to have been laid. For much of the time they have to dismantle vegetation including medium sized trees, and carefully remove the root structures underground. They work deeper in layers until they finally find the anti-tank mines. Once the anti-tank mines have been found they can locate the three antipersonnel mines at known distances away from each anti tank mine. If these mines are not within 20 - 50 cm of their specified locations they presume them to have been washed away.

Given the number of men involved in clearing this minefield and the rate of progress, using local labour rates, I calculated the clearance cost at approximately $250 per sq m or about 200 times the normal clearance cost for manual demining! Given that this minefield was laid in a precise military fashion and its location is exactly known with exact numbers of mines laid, this instance serves as a useful reminder to rebut the common argument that "minefields laid by organised military forces can easily be cleared".

Figure 4: Jordan river valley, 1999 (author).

Figure 5: Afghanistan April 1996 (Afghan Technical Consultants).

In figure 5 we can see the entrance to a bunker used during the conflict. It is likely that the last fighters who abandoned this bunker would have left antipersonnel mines inside to deny other factions the use of the bunker. Mines would also have been laid in the trench system outside the bunker. Military fortifications like this are likely sites where mines are almost certainly to have been laid. The effect of weather and erosion has been to bury the mines under layers of mud and rubble.

These examples show how landmine contamination varies enormously from one place to another even within the same country. Clearance techniques also have to be varied to suit the particular problem deminers are facing.

1.1. Response to Problem by Researchers

What has been the response of the research community to these problems?

Many conferences and meetings have been held to enable researchers and deminers to discuss details of the actual problems faced under field conditions. The first problem usually raised by deminers has been that of locating individual mines with a false alarm rate significantly less than encountered with metal detectors. This is not surprising because it is the principal problem encountered in landmine clearance by deminers who are tasked with removing landmines from a given area of ground. Deminers have also pointed out the need to remove vegetation and considerable development work has resulted in effective machines to help with this aspect of the operation.

Current landmine detectors respond to metal fragments and the number of metal fragments in most minefields is far greater than the number of mines. A detector with a low false alarm rate would certainly make the job of manual deminers easier than it is at the moment. This requirement has prompted by far the largest response from researchers who have developed single and combined sensors using electromagnetic metal detection, ground penetrating radar, nuclear quadrapole resonance, microwaves, infra-red, acoustics, thermal neutrons and several other technologies.

However, if we step back and take the broad view of the process that manual demining is a part of, the ultimate aim is to provide uncontaminated land to local land users. It is well known (from clearance records) that a large proportion of minefields cleared by manual demining are not found to contain any live mines. In addition, most of the area cleared in minefields that do contain live mines is subsequently found to be quite safe. Given an accurate knowledge of the location of mines around 90% of the land could have been declared safe without removing a single mine. A detector that would respond to the presence of explosive devices within a distance of 50 to 100 metres, without having to clear vegetation and with a satisfactory "false negative" response would enable large areas of land to be classified as either "safe" or "in need of further investigation". Finding the exact location of explosive devices is useful during clearance process of course. However, by releasing most of the land much sooner, without the need for vegetation clearance, would provide by far the most significant improvement imaginable in mine clearance technologies.

In other words the most pressing requirement is for a "no mines detector". We may be close to achieving this. The Nomadics FIDO sensor [4] requires further testing but could, for the first time, provide the basis for such a detector.

1.2. Manual Demining Performance

Most researchers have focused on the issue of "close-in" mine detection and localisation. However, detectors of this kind usually require vegetation to be removed before they can be used. They also require that land be clearly marked into "safe" and "unknown, possibly dangerous" areas. Vegetation removal and marking dominate the cost of manual clearance so even if a false alarm rate close to zero can be achieved (unlikely, given present results) only limited improvements in cost effectiveness are possible.

The Mine Action Centre for Afghanistan (under the UN umbrella) maintains a database of the minefields cleared in Afghanistan since 1990. We used this database to construct a statistical model for clearance time for manual demining. This was building on initial work done by Trevelyan[8]. Our aim was to be able to be able to predict clearance time for a given minefield, given the factors affecting clearance time, such as area, number of metal fragments, ground hardness, vegetation type and density, and any other factors available in the database.

The MACA database was compiled from daily field reports submitted by all demining agencies in Afghanistan. The format of data recording has been reasonably consistent since 1993. The database combines level 1 and level 2 survey information with the clearance data. It defines the position and boundary of each minefield, original information sources, land use type, surface category, area reduction during survey operations, which agencies survey and cleared the minefield, what was found (fragments, anti-personnel mines, anti-tank mines, UXO), the area surveyed, area after survey (area reduction) and area cleared.

The Mine Action Centre for Afghanistan (MACA) database provided the field data for analysis. Bartley[1,2] provides a rigorous statistical analysis of the data and derived the following models.

1.2.1. Model with all statistically significant parameters

The final model fitted to the data (the ‘data driven model’) contained all parameters determined to be statistically significant (at α=0.05). It was based on 635 of the original 710 points, the outliers having been removed in order that the model represent most of the data, rather than be shaped by a small number of highly influential points. The final model may be presented as:

$$\mathbf{ln}(CLEARTIME) = b_0 + b_1.\mathbf{ln}(FRAGS) + b_2.(AREA)^{0.5} + b_3.\mathbf{ln}(AP+1) \quad ….(1)$$

(See appendix for details, table 1 for coefficient values)

1.2.2. Simplified WLS model

The most basic descriptive model was simply to fit the model for clearance time in terms of fragments and area. It took four iterations to get to a model that had a reasonable consistency in influential points, and the final data set had 660 of the original 710 records:

$$CLEARTIME = b_0 + b_1.FRAGS + b_2.AREA \quad ….(2)$$

Table 3 (appendix) shows that b_1, the 'Per Fragment Allowance' is about 1.8 ± 0.1 bpmin/frag (breaching party minute per fragment: one breaching party is two deminers). This is roughly in agreement with the simulated field experiments that have suggested that detection and marking time is around 25 – 35 seconds, with 45 seconds for excavation – approximately 1.3 minutes total[11]. The fact that the experimental value is lower is possibly due to conditions being more controlled and ideal. In the absence of fragments, the land is cleared at a rate of about 0.45 ± 0.06 bpmin/sqm.

The resulting models suggest that the number of fragments was the single most important factor affecting clearance time, followed by minefield area. The effects of the different types of vegetation, land use, and surface, and different demining agencies, were also modelled. The result is a number of models suitable for predictive and descriptive purposes. These results confirmed earlier less rigorous research, and extended it in terms of thoroughness, statistical validity, and inclusion of new variables.

These results suggest that the improvements which might be gained from advanced technology detectors are not as significant as one might expect. We would hope that an advanced technology detector would eliminate most of the false alarms by discriminating between fragment targets and mine-like targets.

Two frequently cited complementary sensors for metal detectors are:
a) Combined metal detector and ground penetrating radar (GPR)
b) Combined metal detector and nuclear quadrapole resonance detector (NQR)

Both of these detectors require accurate target location using the metal detector channel. The GPR detector requires accurate positioning relative to the target and the ground for reliable discrimination between mines and metal fragments. The NQR detector requires high electric power levels that cannot be used continuously. Depending on the particular technology used, the accuracy of detector location required for the subsequent step (i.e. discriminating between metal fragments and explosive or mine-like targets) may vary.

Here it is important to make two important qualifying remarks. First, metal detectors do not always accurately determine the location of metal fragments. Very weak targets (typical of minimum metal mines) may be more easily detected at the edges of the coil rather than the centre. Also, when more than one fragment is close enough to be detected at the same position, the location errors are often large. Second, there are many large metal fragments present in minefields, particularly in areas formerly occupied by people or battlefields. So far I have not seen data on the extent to which such fragments will disrupt the operations of GPR or NQR detectors. One can reasonably expect that a certain proportion of these larger fragments will have to be checked manually.

Let us assume then that the GPR and NQR detectors will still require time for target localization, finding the position of strongest signal, even for targets classified as "safe". (We do not yet know what proportion of metal fragments can safely be classified this way.)

These detectors will need a further "discrimination" time for all targets, and an additional manual excavation time for targets classified as "unsafe".

This in turn allows us to estimate the likely improvement in cost effectiveness[11].

A typical deminer in Cambodia and Afghanistan costs about US$10,000 per year to support in the field. This is calculated by dividing the overall cost of a demining program by the number of deminers in the field, which is a more accurate indication than the deminers' salary cost. The salary cost is a small component of this (approx $1800 per year). In Bosnia and Croatia, deminer costs are significantly greater, and costs up to US$40,000 have been given by some sources.

In a country with minimal vegetation problems such as Afghanistan, the performance gain and cost savings from using an advanced technology detector are significant. Given the costs mentioned above, savings of between US$20,000 and US$30,000 per deminer might be achievable. In a country with significant vegetation like Cambodia, but with a comparable cost structure, the savings could be as little as $5,000 - $8,000 a year. In a high wage cost environment, the savings are clearly greater.

1.3. Perceptions of "Minefields"

One of the reasons why some research programs have failed to provide useful outcomes is that many researchers have accepted mistaken ideas on the nature of the landmine problems that need to be solved. The problem here may simply be in the word "minefield". It is tempting for American or European scientists to confuse this with the appearance of a "field", a flat or gently undulating area of cropped grass to feed grazing animals. Most researchers who have worked on the landmine problem have never visited mine-affected regions to see the problems for themselves. Another issue may be the reluctance of many scientists express when it is suggested that they should visit landmine affected countries. Many demining organisations have issued open invitations for scientists and researchers to visit them yet few have responded.

Figure 6: Croatia 1999 (author) Suspected mined area in village: a common problem where a major objective is re-settlement of internally displaced persons and houses need to be reconstructed. Dense vegetation has grown since the village was 'ethnically cleansed' in the early 1990s.

One team of researchers in Europe, working in response to the landmine situation in the Balkans, developed a vapour sniffing sensor mounted on a balloon that would be tethered and positioned by cables over a suspect area of ground. A flexible plastic "trunk" approximately 200 mm in diameter and 2 metres long provided a means of collecting vapour from locations close to the ground. After being shown photographs of typical mined areas in Croatia (figure 6, for example) they were most concerned and asked one of their team to inspect likely locations where the device could usefully be deployed. The team member returned with photographs showing that the problem was actually worse than I reported and that it was difficult to see how a vapour collection device (particularly of the kind they had been working on) could possibly be used in the field.

2. POLITICAL AND ECONOMIC FACTORS

Most of the funding for landmine clearance is supplied from foreign aid budgets in the USA, Canada, Europe, Scandinavia, Australia, United Arab Emirates and Japan. There have been many attempts at "local capacity building" with the aim of enabling countries to deal with their own landmine problems rather than relying on foreign aid donations. These attempts had not been widely successful because in many countries landmine clearance is not a high priority for their local populations. This may be surprising to many people who live in Western countries for whom landmines seem to be a major worldwide problem.

I visited Cambodia in 1998. As part of my visit I spent several hours discussing everyday problems with local people in Battambang, a town in the centre of one of the worst affected areas with landmines in Cambodia. I asked them to tell me about all the different problems that they faced. The first problem they talked about was finding enough water to drink: the typical house in that part of Cambodia has four large earthen jars in which rainwater collects, one at each corner of the roof. Usually there is almost no rain between December and June. A town water supply was their greatest need. They talked about poor drainage and sanitation facilities and how many of their children either died or were seriously ill from malaria, hepatitis, cholera and typhoid. They told me they would like medical clinics to provide more effective treatment for their children and schools with trained teachers to provide a sound education. At the time of my visit there were no telephones in Battambang except in government offices and the satellite phones owned by demining NGOs and other aid agencies. They also told me how much improvement in agricultural production would be possible if they had irrigation water, fertiliser and improved seed varieties. After two hours in which landmines had not been mentioned once, I finally had to ask them about landmines: how did the landmine problem affect their lives? They told me that if all the other problems were solved they would be able to deal with the landmine problem themselves.

This perception can be confirmed on a qualitative basis by comparing landmine incident statistics in Cambodia with road accident statistics in Australia. Although Cambodian statistics have been questioned, it is generally acknowledged that the number of landmine incidents causing injuries and death is between 1000 and 2000 each year. Australia, with around twice the population of Cambodia, has approximately 40,000 deaths and serious injuries resulting from road accidents every year. (I have included injuries that involve serious hospital treatment roughly equivalent in physiological impact to typical landmine injuries). Although people in Australia see road accidents as a major problem there are many other issues that justify much higher levels of public expenditure, where investment can achieve more significant benefits. Therefore it is not unreasonable that Cambodian government resources are directed at improvements in security, transport, water supply and sanitation, education and communications: these priorities reflect community views. Expenditure on landmines is still a priority but less so than other issues. This helps to explain why countries like Cambodia spend relatively little on landmine remediation and rely almost entirely on foreign aid donations.

2.1. High cost operating environment

Contrary to popular perceptions, operations in mine-affected regions, like many developing countries, tend to be expensive and it is easy to underestimate operational expenses.

There is a widespread perception in industrialised countries that costs in less developed countries are lower. Often this comes from experience as a "backpacker". Living and working in the same environment is quite a different experience. Whatever the activity, input costs are almost certainly higher. Electricity, when available at the meter, often costs more. However it may only be available for a few hours per day so most businesses will require their own generation capacity resulting in energy costs between two and 10 times higher than in a typical industrialised country. Most necessities have to be imported adding significantly to the cost: transport, customs duties, sales tax, bribes and facilitation charges can add between 50 and 200% of the original cost. Telephone facilities in some developing countries are very good but in others may be nonexistent and organisations may require satellite phones, VHF and HF radio for reliable communications. Mobile telephones are often available in urban environments but are seldom provided in areas where landmine contamination occurs.

Access to health facilities is expensive and typically remote. Exposure to disease pathogens in environment is high and insurance premiums are high because of high risks. Accommodation providing a reasonable level of comfort and security, particularly for wives and children, can be as expensive as in any industrialised country.

Above all, general education levels are low, and the simple task of getting something done can cost far more than one might think.

Take for example the simple task of delivering a package to a business associate. In Australia your secretary would simply arrange for a local courier company to deliver the package for a fee of about $7. In a typical developing country environment you would usually entrust this task to an office boy. He would be required to wait at the destination and deliver the package to the intended recipient in person, obtaining his signature. He may have to wait for the whole day to do this. Packages left with typical reception staff can be placed under the desk and lie unnoticed for weeks. The office boy is probably paid a salary of $80 per month, around $1,000 per year. The overheads associated with employing a person like this can be between $4,500 and $7,000 per year, bringing the total daily cost to between $25 and $40. Add to that the cost of transport and it is not hard to see how the cost can be considerably higher than in Australia.

2.2. Aid project drivers

Some aid projects have been driven more by companies trying to find a market for demining equipment than by the needs of the aid recipients.

Many large machines have been proposed as the ultimate solution to deal with landmines. Most started as ideas with individual engineers motivated by the desire to make a contribution to solving the global landmine problem. They have inspired companies who were misled by public domain information from usually reliable sources that the world faced the task of removing more than 100 million mines at a cost of $1000 per mine. Often the companies have been successful in securing government contracts (under a foreign aid budget) to construct prototypes for testing in landmine affected countries. Sometime later the machines have been delivered to perhaps Cambodia or Afghanistan for testing. It takes several months for local mine action centres to arrange systematic trials in appropriate locations for the machines. Some machines have shown some promise in limited situations but often there have been breakdowns and long delays in securing spare parts from the original manufacturers. The original manufacturers, by now, have realised that the market for demining machinery is much smaller than they first thought and the engineers have been diverted onto other activities: the companies have often not been able to provide effective field support for the trial machines.

2.3. Market size

The analysis presented above explains why the total expenditure on mine action projects is constrained largely by the humanitarian aid budgets of the principal "donor" nations. Estimates of the total vary between $200 million and $350 million annually. No more than about 5% of the budget is usually available for equipment purchases so the size of the market for all humanitarian demining equipment purchases is between $10,000,000 and $20,000,000 annually.

Research programs that emphasize industrial participation such as European Union and many Australian funded programs, therefore, will not attract high quality proposals because companies will find it hard to justify substantial participation. The market size is small and is perceived to be controlled by government aid and political priorities. Insufficient funding is set aside to take research outcomes through to the commercial product development phase because current models of government support for R&D rely on private investor funding for theses later activities. In countries such as the USA and Russian Federation military countermine technology programs have been supported partly with the expectation that there would be useful outcomes for humanitarian mine clearance.

The total research budget has been considerably larger than the market for equipment. Even if only 1% of this research were successful, the rule of thumb that $100 is needed to commercialise every dollar of research spending suggests that the market size is still too small to justify the investment.

Some of this research investment has led to useful outcomes. However, significant research and development of vegetation clearance machinery and advanced technology detectors has not resulted in a significant increase in cost effectiveness of landmine clearance operations (Mansfield 2004). This is reflected in a renewed emphasis on finding cost-effective improvements in the manual demining process. Manual demining has been considered the most expensive option for landmine clearance and the international community has worked on the assumption that new technologies would reduce the need for manual clearance, but the hoped-for improvements have not occurred.

The cost of clearing mine-affected land remains stubbornly high and casualty rates from mine incidents appear to be much the same as they were when the problem was first raised. Research, it seems, has yet to make an impact on this problem.

3. ALTERNATIVE APPROACHES?

The grass-roots campaign that led to the Ottawa Treaty and subsequent monitoring of landmine problems has provided the large and on-going political support for aid programs and research. However, the focus on the treaty has also narrowed the range of solutions that can be 'legitimately' considered, possibly excluding some of the potentially most socio-economically cost-effective approaches.

Land contaminated with mines and other unexploded remnants of conflict often lies abandoned until resources are available for mine clearance. However, local people are often prepared to accept the risk of using the land to establish provisional ownership rights (or re-assert their continuing ownership rights) and to harvest some agricultural production before clearance can be organized[2]. We have suggested that investment in mine-resistant agricultural vehicles needs to be considered as an option to help re-establish agriculture on contaminated land.

This is controversial in the mine action community. First, the Ottawa Treaty calls for the complete elimination of anti-personnel landmines. Second, the mine-action community is unwilling to release land until every possible measure has been taken to eliminate landmines, and is reluctant to consider any measure which does not aim for 100% clearance.

The major risk is anti-vehicle (anti-tank, AT) mines. We reviewed evidence from Afghanistan[12] that shows that, at least in one country where evidence is available, the risks are manageably low. While many commercial vehicles have been effectively protected against anti-personnel mines (AP), effective AT mine protection usually requires a specially designed vehicle rather than modifications to an existing commercial vehicle. If modifications are possible they tend to be extensive and expensive: South African engineers are among the most experienced. For reasons of economy therefore, we need to treat the AT mine threat with great care. In most regions where recent conflicts have taken place no one can guarantee the absence of AT mines. Therefore the proposal to use agricultural machinery on 'unsafe' land requires the effective use of risk management tools. The major weakness of this approach is that risk management is not (currently) well understood by the mine action community. However, risk management seems to be well understood by both governments and local people in mine-affected regions of the world (at least at an informal level[2]).

Investment in mine-resistant vehicles could also help make mine clearance operations more cost-effective. Often it is difficult to justify the purchase of a special vehicle to support a limited mine clearance operation because the vehicle is expensive to support and may not be used for much of the time. If, however, mine resistant vehicles were already available and could simply be rented from nearby farms, mine clearance organizations would almost certainly use them. Anti-personnel mines typically cause only minor damage to vehicles: typically this is no greater than the damage occurring from normal farming accidents when machines collide with stumps, rocks etc. Modified commercial tractors with back-hoe and bucket excavators have been used in mine clearance operations for many years in several countries. Experience in Afghanistan and elsewhere has shown that modest protection measures can provide operator safety from anti-personnel landmine and small UXO explosions[6,9].

Instead of the current manual demining methods used in most countries, we proposed a radically different approach in four basic steps:

- A survey to locate suitable agricultural land and select crops that can be grown and harvested using entirely mechanised methods,

- Preparation with a flail or armoured vegetation cutter to remove vegetation and allow landmine and UXO contamination levels to be measured and assessed,
- Restoration of the soil by ripping and possibly hoeing with modified commercial machinery to remove unwanted root systems and condition the soil, restoration of irrigation and drainage infrastructure, and
- Mechanised cultivation, sowing or planting followed by mechanised crop harvesting, using AP mine-resistant commercial machinery.

We have assumed that all operations on contaminated land would be fully mechanised using modified tractors and other commercial machinery following standard agricultural or forestry practises routinely used in most countries. The operator cabins and other vital components would require modifications to provide full protection. Years of experience in many countries[*] has provided a wealth of practical knowledge to design the required modifications.

4. CONCLUSION

Given the enthusiastic response to the landmine problem from researchers and widespread public support, it is disappointing and frustrating that, as yet, there has been little improvement in mine clearance cost-effectiveness has resulted from all the research. There have been improvements, but these have resulted mainly by using existing technologies in new ways: machinery, mine detection dogs and metal detectors.

This paper explains some of the reasons for this situation, quite apart from the well known fact that mine detection is a difficult technical problem to solve.

At the core of the issue, however, is a need to understand that while research has been well supported, the steps and resource levels needed to convert successful research into field use in a small nonprofit market sector are not well understood. The economics of applying advanced technologies in less developed environments also need to be better understood. Too few researchers have understood the problem well enough to have a high chance of a successful outcome. Too many research projects with low chances of success have been funded and there are insufficient resources to take successful research outcomes into a non-profit but highly worthwhile field operation.

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[*] Demining machinery and mine-resistant vehicles are produced in several countries. South Africa has the longest experience. Other countries with expertise include Australia, Finland, Germany and United Kingdom.

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APPENDIX

Data Driven Model

$$\mathbf{ln}(CLEARTIME) = b_0 + b_1.\mathbf{ln}(FRAGS) + b_2.(AREA)^{0.5} + b_3.\mathbf{ln}(AP{+}1) \quad \text{….(1)}$$

Variable / parameter	Definition
AP	Number of AP mines found in a minefield.
AREA	Area, in sqm (m^2).
AT	Number of AT mines found in a minefield.
CLEARTIME	Clearance time, in team hours.
FRAG	Number of metal fragments found in minefield.
PFA	Per Fragment Allowance, in bpmin/frag or tmhr/frag (see Glossary).
TPA	Time Per unit Area, in bpmin/sqm or tmhr/sqm (see Glossary).
u_i	Represents random disturbance.
UXO	Number of pieces of UXO found in a minefield.

Table 1 Model variables and parameters

		Parameter	b_0	b_1	b_2	b_3
(R^2=85.2%)			Constant (lnTmhr)	Fragment Slope (lnTmhr/lnFrag)	Area slope (lnTmhr/sqrtSqm)	AP (lnTmhr/ ln(AP+1))
Base figure			-1.77	0.536	0.00345	0.0107
Additional effects	Land use	**Grazing**, Irrigation, Road				
		Agricultural			0.00067	
		Residential		0.022		
	Has UXO	No				
		Yes	0.13			
	Hard surface	No				
		Yes		0.014		
	Vegetation	**Bushes**, Grass, None				
		Prickly bushes		0.013		
		Trees			0.00054	
	Demining agency	ATC				
		DAFA	0.09			
Total						0.0107

Table 2 Data-driven model parameters – sum column to calculate parameters

Simplified WLS model

CLEARTIME = b_0 + b_1.*FRAGS* + b_2.*AREA* ….(2)

General				n (number of points)	710
				Num pts removed (influential or outliers)	50
				s	1.20
				R^2	77.5%
Model Parameters	**Constant**	b0	tmhr	Value	7.33
				+/- 95% CI	2.32
	Per fragment allowance (PFA)	b1	tmhr/frag	Value	0.00247
				+/- 95% CI	0.00013
			bpmin/frag	Value	1.78
				+/- 95% CI	0.09
	Time per unit ara (TPA)	b2	tmhr/sqm	Value	0.000619
				+/- 95% CI	0.000086
			bpmin/sqm	Value	0.445
				+/- 95% CI	0.062

Table 3 WLS Model parameters

*The conversion from team hours (tmhr) to breaching party minutes (bpm) is done by multiplying by 12 breaching parties / team and 60 minutes / hour.