Farming minefields: economics of remediating land with moderate landmine and UXO contamination

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Abstract

A significant proportion of the available agricultural land in many countries cannot be used because it is contaminated by landmines and other unexploded ordnance (UXO). Demining with current methods is slow and expensive. Aid agencies and governments need to support large refugee populations for several years because the threat of landmines has forced them off their land. Also, long delays in demining cause loss of fertility and degradation that could avoided if the land was used.

Experience in Afghanistan and other countries has shown that commercial agricultural and construction machinery can be modified to withstand the effects of antipersonnel landmine and small unexploded ordnance explosions, and provide effective operator protection.

This study looks at an alternative strategy to conventional humanitarian demining: to use modified commercial machinery for mechanised agriculture or forestry on contaminated land. The modifications ensure that operators and machinery are protected from landmine and ordnance explosions. In many regions, local farmers are doing this already without adequate protection: they accept the risk because the only alternative is destitution.

By using this strategy displaced local farmers could generate crop revenue sooner and reduce their dependence on aid funding. When not being used for agriculture, the machinery could be used to provide mechanical assistance for demining operations, particularly for vegetation clearance.

The economic model developed in this study is our first attempt to calculate the economics of the approach proposed by this study. This report outlines a set of variables that can be used to assess the viability of this alternative in comparison with conventional demining methods.

Preliminary results using conservative cost data from Afghanistan are encouraging. Further studies based on real data with more detailed analysis would give a more precise indication of the viability of this approach. However, the results of preliminary modelling show sufficient advantage to justify further research on this approach.

1.0 Introduction

Landmines are a major problem in many countries such as Afghanistan, Croatia, Cambodia and Vietnam. In such developing countries where agriculture is a major source of livelihood and export revenue, the presence of mine-contaminated agricultural land represents a major obstacle in social and economic reconstruction efforts.

Current demining of agricultural land first requires the clearance of vegetation with either hand tools or mechanically with vegetation cutters, flails, or similar equipment. This is always followed by manual demining operations (possibly assisted by mine-detection dogs). Agricultural activities are not permitted until after demining has been completed. However, in Cambodia and other countries, land holders are either farming mined land, or are clearing the land for themselves with significant risks to themselves and others (Bottomley 2001). This is because they cannot afford to wait (possibly for a decade or more) for organized demining teams to arrive.

With scarce resources, demining operations are planned using quantitative socio-economic decision making tools (World Bank 2001). Progress reported in Afghanistan before September 2001 suggests that it may take up to 10 more years before all designated high-priority areas can begin to be cultivated. This long clearance period presents problems in terms of depreciation in the economic value of the land, particularly as fruit trees are an important component of agriculture in Afghanistan, and it will take years to re-establish productive orchards.

The idea for this research project originated with the observation that the damage to agricultural machinery from anti-personnel mines 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 (Trevelyan 1999). Therefore, it is worth considering the costs and benefits from farming land with low residual mine contamination, without the expensive and time consuming manual demining process.

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

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

2. Preparation with a flail or armoured vegetation cutter to remove vegetation and allow landmine and UXO contamination levels to be measured and assessed,

3. 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

4. Mechanised cultivation, sowing or planting followed by mechanised crop harvesting, using suitably modified 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 or experience in many countries[1] has provided a wealth of practical knowledge to design the required modifications.

This paper describes an economic model that could be used to explore the feasibility of this alternative approach. Our model is based on the recent socio-economic modelling of mine action programs in Afghanistan by the World Bank (2001). Field data for a specific region or country would be needed for the model to be used in practice. A detailed feasibility study will be needed to obtain more accurate results before any trials are carried out.

2.0 How Mines Affect Agricultural Land

Many people in nations with landmine problems depend on their agricultural land for livelihood. The suspected presence of mines, whether on agricultural land itself or denying access to supporting infrastructure such as irrigation canals, would make the land unattractive to cultivate due to perceived risks[2].

The immediate socio-economic effects of mined agricultural land are numerous. These include loss of income for the local population leading to migration and refugee problems, aid dependency and cost of providing alternative supporting infrastructure such as irrigation water. These problems are well recognised.

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[1] 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.

[2] Land that is thought to be mined is often found to be completely safe in subsequent demining operations. However, it is the perception of risk that affects human behaviour, not the actual risk.

However, there are other effects caused by neglect arising from the perceived landmine risks which may pose increasingly serious problems. Examples of such problems are:-

Gradual loss of fertility of agricultural land due to reduction in nutrient levels caused by leaching.

Top soil loss caused by erosion,

Deposition of silt and debris trapped by (unwanted) vegetation during seasonal floods,

Nutrient loss caused by weed invasion,

Water logging caused by damage to or clogging of drainage systems,

Loss of fencing, irrigation pipes and other man-made infrastructure,

Infestation of soil weed seeds and runners and potentially destructive insect pests,

Growth of unwanted vegetation such as brambles, scrub, trees, vines etc.

Steadily increasing cost and difficulty of restoring land to fertile condition by removing vegetation, root systems, weed and insect infestations, and restoring nutrient levels.

Long term damage to remaining uncontaminated land that results from overgrazing and repeated high intensity cropping.

All these problems are compounded by delays in demining agricultural land. Further, they can make subsequent mine clearance considerably more difficult.

3.0 An Alternative Way to Manage Mined Agricultural Land

As outlined in the introduction, we are suggesting an alternative approach that would substantially reduce the long term damage to agricultural land and restore the livelihoods of the people who depend on it much sooner. We are proposing the use of anti-personnel mine resistant agricultural vehicles, such as suitably armoured tractors, to directly cultivate the mined land after appropriate risk assessment and mechanised ground preparation mechanised means such as flails.

Mechanised agriculture is not uncommon amongst countries with mine problems like Afghanistan. Local farmers already have the necessary equipment and knowledge to operate farming machinery. However, the present position of aid donors is that land can only be used after demining because unexploded ordnance poses a risk to both the machinery and operators. As mentioned preciously, demining is slow. By modifying local tractors to provide protection from the effects of remaining unexploded mines or other ordnance, cultivation could start without the need for costly manual demining. In fact, this direct cultivation strategy is already pursued by some farmers who take risks by cultivating potentially mined areas using unprotected equipment.

To save costs, we propose to armour the tractor only to resist anti-personnel mines and small UXO. Normally, anti-personnel mines are the most common types found on agricultural land. Anti-vehicle mines are less of a problem as they are more costly and tend to be laid along roads and tracks to interfere with vehicle movements.

Step 1: Survey, Selection and Risk Assessment

Accessibility, fertility, infrastructure and crop type are the four main factors that determine the selection of land. Firstly, the designated plot of agricultural land should be fertile and accessible to both a flail for initial clearance and tractor for ripping and cultivation. This suggests that the land should be relatively flat and have at least the potential for road access to be developed to reach critical infrastructure and markets. In addition, the climate should also suit crops that are suitable for mechanised agriculture, for example wheat or forestry. However, for maximum returns from the investment, several additional factors should be considered.

Minefields are typically surrounded by uncontaminated land or areas with unknown contamination which may also be suitable for cultivation with protected machinery. The layout of a typical area for which this approach may be considered is illustrated below.

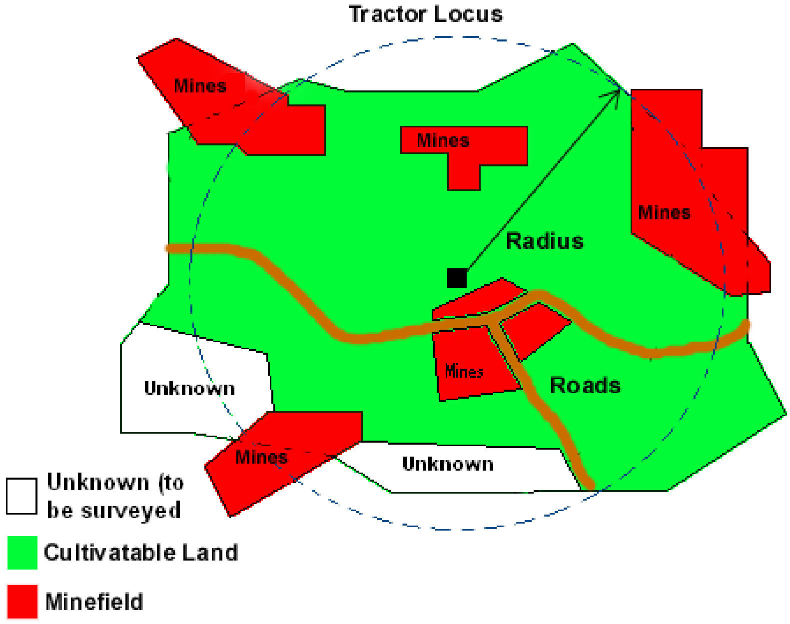

Fig. 1: Illustrative Layout of a Potentially Cultivatable Area

The tractor locus is the cultivable area over which it can be effectively used. It is affected by the speed at which the tractor can travel between its storage location and the area to be cultivated and other modifiers of transit time such as vegetation, availability or access tracks etc. The locus could be affected by the presence of roads or other means of transporting the tractor quickly. Ideally, maximum benefits are obtained when both the percentage of cultivable, contaminated land and the presence of minefields within the tractor's locus are high.

The final stage in selection is risk assessment. We suspect that the cost of anti-vehicle mine resistant machinery will be too high for most applications. Therefore, it is important to ensure that there is no possibility of encountering anti-vehicle mines in the selected areas. This requires assessment by experienced mine clearance staff. Also, risks will be lower if the initial level of mine contamination is low: this can also be assessed by experienced staff.

Step 2: Ground Preparation and Risk Assessment

The initial ground preparation using flail machines serves two purposes.

First, the flail destroys surface vegetation. This is an essential step in restoring the productive capacity of the land. The flail also destroys trip wires and will cause a proportion of mines and unexploded ordnance to be detonated. If used correctly the proportion of unexploded devices remaining after treatment is quite small.

Second, flail clearance also helps with risk assessment as skilled observers can usually determine the varieties and estimate the number of mines in an area with reasonable accuracy after clearing the first 20%. Should the level of risk be found to be acceptable, for instance, and one can be certain that no large UXO or anti-vehicle mines are present, reconditioning of the land could proceed using the modified tractors.

The number of explosions noted during flail clearance indicates the level of mine contamination, and will confirm the required absence of anti-vehicle mines. Given the appropriate use different clearance strategies and statistical analysis tools, this data will indicate the residual mine contamination level. For example, if the flail machine does not cause any explosions, and a subsequent check by using manual demining on selected (small) areas fails to find any mines, the risk of mine contamination would be assessed as being very low. However, this can only be done by highly skilled and experienced assessors who know where landmines are likely to be laid[3] in a given area of land.

Flail clearance is essential if the mine contamination levels are unknown or too high for armoured tractors to be used without prior risk reduction. Provided the area is accessible, mechanised clearance can be carried out using flails run on the ground rather than slightly above it as practised in most demining operations where manual demining is to follow.

Not all the land may be covered with thick vegetation. In Cambodia, for instance, many mined areas are farmed already by people desperate for a means to support themselves, or who are prepared to accept the risks in return for eventual land ownership. They graze their animals and even plough rice padis in known minefields. These factors can affect land selection and restoration costs.

After clearance, the land will have to be marked and fenced. Most people in mine-affected regions assume that cultivated land is free from mine contamination. Any project of this kind would need to be designed to ensure that people do not enter the cultivated areas with mine contamination as agricultural work would definitely result in resurfaced and possibly disoriented mines. Fencing, marking or other natural barriers would be needed in conjunction with community awareness. The community-based minefield marking project in Cambodia (associated with CMAC) provides some useful models and experience in this aspect.

Step 3: Restoration

This step requires the use of mechanical rippers or hoes to remove unwanted root systems and condition the soil for cultivation. This is a well-established practice when opening new land for cultivation in many countries. However, in some regions, no new land has been opened for agriculture for a long time and equipment may have to be brought in from other regions. This process will almost certainly result in residual mines and ordnance coming to the surface. If operators observe this, they can use flags and low cost GPS equipment to mark the locations so that manual deminers can destroy the mines and ordnance exposed in this way.

After restoration, the land would be left for some time to allow weed seeds to germinate and suckers to sprout. In some cases nutrient fertilizer and a germination agent may be needed to encourage a high enough proportion of seeds to germinate. A herbicide such as glyphosphate ("Round Up") could then be used before planting or seeding.

Before seeding or planting, irrigation and drainage infrastructure would have to be replaced or repaired. Again this would have to be done using mechanized equipment, suitably protected. A back-hoe and bucket loader could be used for most tasks. However, in some selected (and small) areas manual demining may be required where protected mechanized equipment cannot be used, or where unprotected machines must be used.

Step 4: Cultivation

The next step in this process is to begin cultivation. Ploughing and tilling can be carried out with a plough or tiller. This is followed by planting which is carried an air-seeder or equivalent planting machinery. After the crop has been planted, crop maintenance can be carried out periodically while the crop germinates. Pesticides, fertilizers and other chemicals can be mechanically applied. When the armoured tractor is not in use during this period, it can participate in other demining activities such as rolling or vegetation clearance. This will be detailed in a later section.

Fig.2: Inter 511 Tillage Implement

The last step is mechanical harvesting when the crop is ready.

Throughout this process, maintenance will be needed for the tractor and implements. The tractor and accessories are expected to set off various AP mines or other small ordnance during farming operations. Although the

[3] For example, in western Cambodia, landmines were often almost entirely in small ditches and depressions and along river banks in otherwise flat land.

design will reduce mine and UXO damage to a minimum, some repairs are likely to be needed as in any farming operation. Parts for the normal maintenance of the tractors should be available due to the use of local machinery, equipment and expertise.

The crop yield is unlikely to be fully restored in the first season. The presence of weed seeds, inexperience with 100% mechanised farming, and the need to restore nutrient levels over several years will mean that one could expect gradual improvement in yield over several seasons.

Step 5: Mine Clearance

Lastly, when all other high priority land has been demined, conventional or manual demining can be started on the areas previously cultivated by the AP mine resistant tractor. However, the cost of demining land being used for cultivation will be less because there would be no need to remove vegetation.

Ottawa Treaty Implications

Several articles of the Ottawa Treaty (ICBL 1997) require that all mines have to be destroyed by December 2007 (Article 1 clause 2, Article 5 clause 1). Other articles in the treaty permit extensions of the time limit (Article 5 clauses 3, 4 and 6). Some may argue that these clauses were not drafted to permit the kind of approach we are advocating now, and that to use the extension clauses in this way might infringe the spirit of the treaty. The next review conference for the treaty is not due until 2008. However, we believe that this gives sufficient time to run a trial and obtain sufficient results to justify this alternative method of dealing with mined agricultural land. Should widespread implementation prove to be feasible in the future, then the treaty could be amended to allow this alternative approach.

4.0 Operator and Machinery Protection

We assume that all operations require a driver and possibly a second operator in a tractor cab. This space requires protection from AP blast mines and fragmentation mines as well as small UXO effects. While the specific design of the armouring on the tractor is not considered in depth in this paper, we will look briefly at the basic design necessary and some materials that might be considered.

Fig. 3: Polycarbonate Windows on a Armoured Backhoe Cab

Source: Landmine Research at UWA Website

Original Photo courtesy of UNOCHA Islamabad

The tractor, which should be locally available, would be modified to a level such that it would only be protected from AP mines and small UXO explosions. Generally these would be AP Blast Mines or Fragmentation Mines, grenades or other unexploded ordnance. The damage from an AP blast mine is mostly from secondary fragmentation. The wheels of the tractor would cause the majority of mine detonations. The initial blast would be sufficient to blow a conventional tyre. The damage caused by the rubber (secondary fragmentation) would be fairly minimal and could easily be averted with a blast shield under the vehicle near the wheels to deflect the pieces.

Figure 4

Typical agricultural spray equipment used for chemical control of weeds and insect pests, or for applying chemical crop treatments.

Blowing a tyre is still expensive and it is desirable to minimise the repair cost. Instead of a conventional tyre, there are 3 alternatives. Solid rubber tyres could be used: the vehicle can continue after it has hit a mine, because the tyre will not be deflated. Steel wheels can be used with an open structural design. The force from a blast mine would be insufficient to destroy/fragment the steel wheels, so the mine would not damage the vehicle. Lastly, conventional tyres can be covered in a chain-mail-like covering to protect the tyre from blasts GICHD (2001).

Fragmentation mines and small UXO are potentially more damaging. Some shielding would be necessary to protect the underside of the vehicle. An appropriately designed plate inside the wheel arch can be used to deflect fragments.

The armour would be required to protect vulnerable areas of the vehicle and the operator. As the explosion is generally directly under the vehicle the vehicle mass could be exploited to protect the operator from any blast. The motor and fuel would obviously need to be protected. Experience suggests that exposed hydraulic hoses are sufficiently robust and do not require shielding.

6 mm thickness BisAlloy (or comparable steel) is sufficient for protecting the operator cabin. Composites could also be considered. They may provide low cost alternatives that could be 'sacrificed' in the event of a detonation, and cheaply replaced. Pineapple fibre for instance is strong and inexpensive and in a polypropylene matrix it can provide a high strength low mass composite armour. Experience in Afghanistan suggests that glass windows in the cabin would be replaced with 25 mm thick polycarbonate, with a further 3 mm layer on the outside that can be replaced cheaply if it becomes scratched (Edwards 1998).

Secondary fragmentation could also occur from the equipment attached to or towed by the tractor and this must be taken into account when designing armour for the cabin. Consequently some modification may also be required for ploughs, seeders, spreaders and harvesters which must survive the blast as well as deflect secondary fragmentation away from the cabin. Once again, experience in Afghanistan has shown that this is less of a problem than originally expected.

6.0 Methods of Financing and Tractor Ownership

We are proposing that donor funds would be used to acquire machinery for projects of this kind.

Although we suggest the use and modification of locally owned and available tractors, this may not be possible in all situations. In addition, the provision of accessories and implements for mechanised agriculture may not be possible at prices affordable to the local population. However, there is a large world market for second-hand agricultural and construction machinery so this would not pose serious difficulties. However, the cost of obtaining such accessories would be one of the most significant factors in determining the success of this proposal.

Another option for financing the machinery cost is through microcredit or similar low interest lease arrangements. These may be partially subsidised to make the machinery more accessible to the local population. Tilli (2000) suggests that if an appropriate source of finance is available, individuals with land affected by landmines may be willing to finance the cost of clearance, especially if the waiting time for clearance is substantially reduced.

The main focus of this study is to explore the economics of farming mine-contaminated land so we have not examined all the possible ways to handle tractor ownership and financing. However, the options we proposed above are currently the most practical and would be worthwhile subjects of further study. In any case, local conditions and practice would provide the best framework applicable in any particular country so that landowners would be familiar with the arrangements.

8.0 Factors to Consider for Implementing a Test Trial

A carefully planned trial would be needed to establish all the detailed processes needed to make this alternate approach work in practice. Firstly, a partner organisation would be needed to carry out the project on a trial basis. Possible candidates possessing the necessary experience and organisational infrastructure may be Ronco Inc. and Halo Trust. In particular, GICHD (2001) in their recent report on Guidance to mechanical mine clearance/ground preparation using commercial tractors and front loaders has demonstrated that they have previous experience using modified commercial tractors for demining work. In Afghanistan, ATC (Afghan Technical Consultants) have experience with armoured tractors, but they are not involved with farming operations and would need partners to provide the agricultural expertise required.

Fig. 5: A Belarus 300 Series Tractor

The economic model developed in this study would help with the initial selection of attractive trial locations but further feasibility studies as well as community based consultation and decision making would be needed. In addition, an agricultural consultant would be needed to help with the crop selection as well as refine or adapt local cultivation techniques. Depending on the local state of affairs, Afghanistan might be a suitable country to conduct a test trial because farming land is relatively flat and clear of vegetation. In addition, Afghanistan is also well equipped with Belarus and other Russian tractors, and the expertise to support their use.

At least two modified tractors are needed to operate together, or within a short distance of each other. This is necessary in the event of a tractor breakdown due to mechanical failure or damage from exploding ordnance. The second tractor would be needed for rescue and recovery operations. Practical experience necessitates the availability of a third modified tractor so that maintenance and repairs can be performed on one tractor without affecting interrupting operations in contaminated areas.

Mine-resistant tractors are already commercially available. The Pearson survivable demining tractor available from Pearson Engineering is one such example. Bucat and Neric (2001) in their review of the commercial mine resistant vehicles suggest that the Pearson survivable demining tractor would be a suitable candidate for agricultural activities. Although such commercially available mine resistant vehicles are useful candidates for a test trial, we note that most current commercially available mine-resistant vehicles are designed to survive anti-vehicle mines[4]. Hence, they may be too costly to expect reasonable commercial returns with this approach. By operating in areas without anti-vehicle mines, the cost of protecting the vehicle can be substantially reduced.

Lastly, the security and storage of the tractor and equipment would have to be considered in the test trials. A central location would be needed to allow the vehicles to move easily to areas where they are required while at the same time ensure that they are secure during periods of storage.

9.0 Other Uses for Modified Machinery

Since a tractor is a versatile piece of machinery which can be coupled with many different attachments and accessories, the use of a AP mine resistant tractor would not be limited to agricultural activities. With attachments such as a front-end loader or a back hoe, the tractor can participate in mine clearance activities such as unblocking and repairing irrigation canals, repairing roads, restoration of electric power and drainage and other services to the local community. The recent GICHD (2001) report *Guidance to mechanical mine clearance/ground preparation using commercial tractors and front loaders* shows that such armoured tractors can play useful roles in many demining operations. Indeed, the provision of an AP mine resistant tractor would have numerous secondary benefits besides being able to engage in direct cultivation. Tractors could be leased out to commercial demining operators as a source of revenue to recoup the initial cost outlay.

10.0 Economic Model

The model we present here is a preliminary one. There are many simplifying assumptions, and further work is needed to obtain a more accurate forecast of cash flows.

We have used a Net Present Value (NPV) cash flow analysis. Cash flows over the life of a project are and are then discounted using an appropriate expected rate of return to account for the time value of money. The resultant NPV represents the returns expected over and above the discount rate in 'today's dollars' or *real* terms. It follows the bigger or less negative the NPV, the more effective the use of donor funds.

The model only calculates the project NPV for the donor. The approach we are advocating has clear advantages for the population: they generate income from farming operations much sooner than with the current demining approach. However, this benefit is not included in the model because the cash benefit accrues to the local population, not the donor. The donor benefit arises from savings in aid expenses needed to support the local population dependent on the land, offset by the investment in machinery. If the model predicts that the alternate method is more expensive for the donor over time, then we would have to model the benefits to the local population as well. However, as we shall see, there are direct benefits to the donor from the alternative method proposed here.

Summing all the variables at their present values will give us a cost to remediate contaminated land in a given area and re-introduce the displaced local population. We have developed two calculations: one for the current method of demining and another for the alternative we have proposed here.

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[4] Anti-vehicle mines are much larger than anti-personnel mines and will totally destroy any normal machinery or vehicles.

The cost structure for Afghanistan was selected to examine the effectiveness of this alternate approach. We chose Afghanistan because the economic and cost data from the World Bank (2001) report was available to us. Where required values for cost variables in Afghanistan were not available, we assumed local Australian cost factors based on the purchasing *power parity theorem*[5]. While this may not give us absolutely accurate results, we recognise that the aim of the model is to give an indication of the relative effectiveness of this project, not the actual dollar returns.

The Net Present Value or cost of remediating a contaminated area under both current and the alternate method is basically calculated as:

NPV = PV (annual demining cost)

+ PV (clearance and restoration costs incurred at some point in time)

+ PV (aid cost for supporting population dependent on the land until they become self-sufficient)

Detailed formulas for the calculation of the NPV under both methods are provided in Appendix A of this paper.

The main difference in NPV between the current and the alternate method proposed in this study arises from the potential savings in aid. This would come sooner under the alternative method due to earlier self-sufficiency of the local farmers because they do not have to wait for demining ro be finished before they can start working their land. It must be noted that under the alternate method, the potentially contaminated agricultural land which is cultivated using the tractor is still demined, but only after the local demining team has fulfilled all other demining commitments in the region. This is offset by the capital investment needed for machinery purchase and modifications.

An Excel spreadsheet was created to perform the calculations. This sets out the formulas and inputs for evaluating the NPV of clearing a contaminated agricultural area under both the current practise and the alternate method. The details are included in the appendix.

11.0 Model Results

Using the costs from Afghanistan, we used the following variable values:

Reference	Name of Variable	Assumed Value
B2	Required Rate of Return	5%
B3	Unmined Agricultural Land Currently In Use	10 km^2
B4	Mined Agricultural Land In Region	4 km^2
B5	Other Mined Land In Region	2 km^2
B7	Demining Cost	$0.6/m^2
B8	Demining Rate	1000 m^2/day
B9	Days/Year Demining Activities are carried out	300 days /year
B11	Relocation Cost over entire area	$200000
B12	Reconditioning Cost over entire area	$200000
B13	Annual Cost of paying Deminer Teams (in addition to demining cost B7)	$0 /year
B15	Aid Expense incurred over entire area (Refugee cost, medical expenses, alternate housing costs, food, etc.)	$200000 /year
B17	How many years from now is the mined agricultural land expected to be cleared (current method)?	12 years

[5] The purchasing power parity theorem states that in an efficient market, when factors like interest rates, inflation and exchange rates are accounted for, the price of goods between two countries are actually the same as the absolute purchasing power of currency does not vary.

	cleared (current method)?	
B18	Total Capital Cost of armouring Tractors over entire area	$20000
B19	Cost of Using a Flail	$0.30/m^2
B20	Cost of Using a Ripper	$0.30 /m^2
B21	Cost of using tractor for demining activities	$0.20 /m^2
B22	Rate of Tractor Demining Clearance	2000 m^2/day
B23	Cost of Subsequent Mine Clearance (on cultivated areas)	$0.30 / m^2
B24	Rate of Subsequent Mine Clearance (on cultivated areas)	1200 m^2 /day
B26	how many days a year can the tractor work	300 days
B27	Number of tractors	3
B28	Tractor Speed	3 km/hr
B29	Hours Working Per Day	10 hours
B30	Tiller Width	6 m
B31	Seeder Width	6 m
B32	Sprayer Width	6 m
E32	Number of passes for spraying of fertisliser and pesticides.	3 passes
B33	Harvester Width	6 m
B35	How much (%) of the "Other Mined Land" will the tractor be helpful on?	0.7 (70%)
B38	The tractor can be leased out for $/day to private deminers or farmers	$100 /day
B39	Days per year demand expected	400
B45	How many years between crops	1
B46	What percentage of productivity is expected initially?	0.5
B47	How many crops until near full (95%) productivity is expected	3

Using the above values, we calculated the NPV of remediating the mined agricultural land under both methods.

Under the current demining practice, the model results in a NPV cost of $5,749,838 to the donor to remediate an agricultural area of 16km^2 (of which 6km^2 is mined). This includes the aid cost to support the displaced population in that location there in terms of aid and housing until they are self sufficient. The major components of this are (in $ values at the start of the project):

Demining cost over 20 years	Aid cost over 12 years	Further aid cost	Cost of restoring farming land
2,243,198	1,878,715	68,780	1,559,145

The alternate method yields a NPV cost of $4,650,970 to the donor for the same area. The major components are:

Demining cost over 9 years	Aid until first crop	Further aid cost	Land restoration at commencement	Capital cost	Tractor hire income
1,775,914	190,476	123,603	2,800,000	20000	259023.85

Although we have no access to current field data, the principal values we have estimated above already yield a significant saving in cost of approximately $1 million for the above region of 16km^2. This result shows that the direct cultivation approach proposed by this study is worthy of further research.

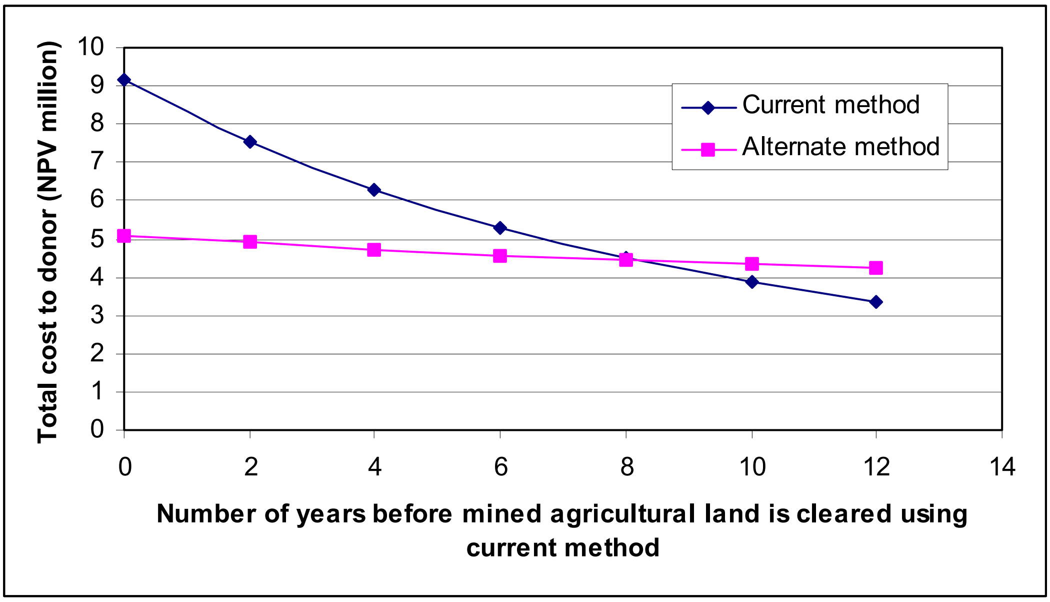
It should be noted that the land restoration cost (determined by the cost of using the flail and ripper, at a total of $0-60 per sq metre) is a major component of these costs. This cost depends very much on the initial condition of the land: we have chosen relatively high costs assuming the land is in poor condition.

It should also be noted that many of the costs we have included in the model are not normally part of demining projects. However, we have to take an overall view of the problem of restoring a productive community to assess the relative benefits of our approach.

12.0 Sensitivity Analysis

Sensitivity analysis of four key variables that affect the two models differently can be varied to find the influence of some major variables. Some of these variables may be hard to determine. However, if they do not significantly change the result over a wide range of values, then we need not be concerned. We looked at *Required rate of return*, *Capital cost*, *Annual aid cost*, and the *Projected time to clear the mined agricultural land*.

Required rate of return determines the amount that future cash flows are discounted, to account for the time value of money. A higher required rate of return means future cash flows are more heavily discounted. This may be due to higher rates of interest, inflation or other factors. So delaying demining expenses, or spreading them out over several years means they are discounted and thus 'cheaper' than spending the money now. Consequently the large initial outlay on capital required under the alternative method and the fact that demining is completed more quickly (so expenses incurred more rapidly) increase the NPV expense of this method with a high required rate of return. But for lower required rates of return, the fact the total monetary outlay in smaller under the alternative method mean that this saving is more heavily weighted than the timing of the savings. Given that the money used to fund the demining operations are donated, a low required rate if return is very likely.



The sensitivity of this factor is demonstrated by varying the required rate of return while holding other values the same. The exact point of indifference between the two models (when the total cost to the donor is the same) will vary depending upon the other variables.

Capital Cost of purchasing and armouring tractors has simple linear effect on the NPV of the alternative method: the cost is expended at the start of the project. Increasing the capital cost by $100,000 increases the NPV of the alternate method by the same amount.

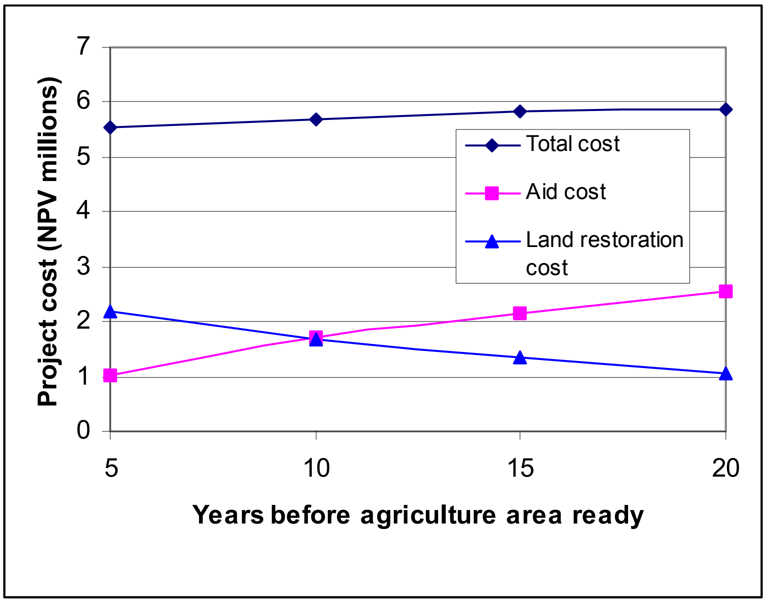
As the cost of purchasing and armouring the tractors becomes more significant, this approach is less attractive. For this reason it would be preferable to armour tractors that are already in service in the area and armour them, so that farmers can cultivate previously unworkable mined land. Some arrangement could also be made to allow the tractors to be used in demining activities when they are not in use.

Annual aid expense is a very significant expenditure under either method. But the alternative method allows cultivation of mined agricultural land to begin almost immediately, so aid expenditure is only required until the first crop is harvested and sold. Under the current method, people who would normally be dependant upon the mined agricultural land are entirely dependant on aid until that land is cleared.

The greater the cost of supporting displaced people, the more attractive the alternate method becomes.

If the land is to be used for forestry, the first crop will not be available for several years, resulting in significant aid dependency. This could be dealt with in two ways. First, the aid could be financed by long term loans repayable when the tree crop is harvested. Second, the forestry could be arranged such that part of the area is used for producing short-term products such as fresh or dried fruit, bamboo, brushwood or thinnings for fuel etc.

The *projected time to clear the mined agricultural land* under the current method also has a significant effect. The longer the delay in clearing the mined agricultural land the longer people will be dependant upon aid. However, the NPV cost of restoring the land is deferred as well, and depending on the rate of return (or discounting), this will offset the aid cost to a greater or lesser extent. However, the socio-economic benefits to the region will be far greater because the value of crop production would normally far exceed the subsistence cost of aid for displaced people. However, the crop production value is not modelled here because this model looks only at the costs to the donor: the donor would not normally expect income from the sale of crops.



We have assumed the same land restoration cost under both the alternate and current methods: use of a flail or other machine to remove above ground vegetation, and then the use of a hoe or ripper to remove roots and condition the soil. However this is a highly conservative assumption. Given the extended period that will pass before demining and land restoration occurs using current methods, the extent of above ground and below ground vegetation will be far greater, the actual cost of treatment will be far higher than we have estimated.

The alternative method is of most benefits when *required rates of return* are low, *capital cost* is minimised by armouring tractors already in service and when the *aid expense* is high, and would continue for a longer period of time before the mined agricultural land would otherwise be cleared. The alternative method is also more beneficial when the tractor is able to be used a high proportion of ‘Other mined Land’ to enable maximum benefit.

13.0 Socio-Economic Benefits

The economic model developed looks purely at the costs and benefits for the donor of these two methods of land remediation. However, there are other benefits of the alternative method that are less quantifiable or do not benefit the donor directly.

Many people in countries affected by mines are dependant on agricultural land. Mines spread across agricultural land rob people of their living. In many regions people are so desperate that they will cultivate the agricultural land despite the risk the mines pose with no protection. The proposed alternative method would allow cultivation to be undertaken safely. The alternative method would possibly reduce the amount of deaths and injuries, yielding benefits that could be calculated using methods proposed by the World Bank (2001).

Agricultural in many regions may not be mechanise to any significant extentd. The alternative method requires that all stages of cultivation in a mined agricultural area be mechanised to ensure the safety of the farmers. This would allow the new equipment to be used on other (non contaminated) agricultural land in the area when it is not being used on mined land. There would be a potential increase in productivity and time saving for these farmers as well. This means that the benefits would extend beyond the immediate area of the project.

In addition, the alternative method would allow cultivation to start almost immediately. This would provide an immediate stimulus to an entire community and improvements in their sense of well-being. Deminers have often commented to us about this intangible benefit: one that our proposed alternative would bring much sooner.

Lastly, there are benefits in terms of improved travel time, more people returning to their original homes sooner, and reduced loss of livestock due to mines. The World Bank (2001) report examines these socio-economic benefits in greater depth and the alternative method proposed allows many of these benefits to be realised sooner, hence increasing their time value.

14.0 Further Study

The financial modelling in this study concentrated on the economic aspects of remediating landmine contaminated land with respect to the donor. Many other socio-economic benefits, for instance the value of saving human lives, are not quantified by this model. We propose that a more detailed model should be developed that includes benefits to the local community. Should the opportunity costs between both the current and the alternate approach prove to be very significant, *real options analysis* should be used instead of the current *NPV analysis*.

A full feasibility study focussing on the technical issues of this alternate approach is also recommended before commencement of the first trials. This should focus on issues such as the recommended type of crop, tractor financing and ownership details, safety and security issues as well as engineering proposals for armouring the tractor. The aid of various consultants in each of the specialised fields of study should be sought to obtain a more precise estimate of the benefits associated with the alternate approach.

15.0 Conclusions

Landmines are a major obstacle to social and economic reform in many formerly war-torn countries. As there is a large amount of work involved in demining with limited funding available, the importance of alternate approaches to demining cannot be over emphasized.

The economic modelling in this study has shown that direct cultivation of mined agricultural land with modified commercial machinery, as proposed in this study, is one alternate approach that would probably save both time and money. This method has the potential to reduce the cost of landmine remediation, and complete the process faster, while at the same time allowing the community dependant on the land to begin to function more independently.

There are other socio-economic benefits derived from this method of demining that we have not quantified or do not apply to the donor directly, and as such are not included in our modelling of costs and benefits of mine clearance.

Further evaluations of this method with field data will hopefully verify these results and justify a field trial. There is also scope to extend the economic model to take the particular circumstances (e.g. cropping patterns) of a proposed trial area into account.

16.0 References

Bottomley, R (2001) Returning life to field and forest: demining by villagers in Cambodia, Journal of Mine Action, Special Issue: Landmines in South East Asia, v5.1, available at http://maic.jmu.edu/.

Bucat, M. & Neric, D. 2001, *Cultivating Mined Agricultural Land Using Mine Resistant Vehicles*, 3rd Year Mechanical Engineering Project, University of Western Australia.

Edwards, D. 1998. (Former regional manager for Mine Action Centre for Afghanistan) Personal Communication.

Geneva International Center for Humanitarian Demining 2002, *Mechanical Demining Equipment Catalogue,* Geneva International Center for Humanitarian, Geneva, Switzerland. (http://www.gichd.ch/)

GICHD 2001 *Guidance to mechanical mine clearance/ground preparation using commercial tractors and front loaders*, Technical Notes for Mine Action 09.50/01, Geneva International Centre for Humanitarian Demining.

ICBL (1997). Convention On The Prohibition Of The Use, Stockpiling, Production And Transfer Of Anti-Personnel Mines And On Their Destruction, available from http://www.icbl.org/.

Tilli, S. 2000, *Microcredit Funding for Landmine Clearance*, Department of Mechanical and Materials Engineering, University of Western Australia.

Trevelyan, J. P. (2000a) Landmines in Croatia and Bosnia Herzegovina [Online], Available: http://www.mech.uwa.edu.au/jpt/demining/ or from the authors.

Trevelyan, J. P. 1999, Afghanistan Country Report, [Online]. Available: http://www.mech.uwa.edu.au/jpt/demining/ or from the authors.

World Bank / UNDP 2001, *Study of the Socio-economic Impact of Mine Action in Afghanistan (SIMAA)*, (Draft copy, available from MAPA, Islamabad, copy with Sabbia Tilli, Department of Mechanical Engineering)

17.0 Bibliography

Trevelyan, J. P. 2000b, *New Technologies and New Ways of Thinking about Mine Action*, Department of Mechanical and Materials Engineering, University of Western Australia

Appendix A – Details of NPV Analysis

Explanation of Financial Terms and Values Used in Model

Note: the spreadsheet is available as a compressed zip file as:

http://www.mech.uwa.edu.au/jpt/npv-alt-2002.zip

This method determines the Net Present Value (NPV) of remediating land for a given area under two methods, the current demining method and the proposed alternative method. The net present value method calculates the cash flows over the life of the project and discounts them to today's dollar terms. Future cash flows are discounted due to the fact that money has a time value. An example of this is that if one dollar is needed in one years time, 91 cents can be taken now and put it in the bank at 10% interest and at the end of the year $1 will be received. Similarly if there is a known cash inflow of 1 dollar in a years time , 91c can be borrowed now at 10%, to spend now. At the end of the year one dollar will be owed and can be paid with the one dollar received. So future cash inflows and outflows can be discounted to take this into account.

Discount Factors are a common financial tool. They are a multiplier to determine the dollar value today of a cash flow in n years time, when I can borrow or lend at r% interest.

$$\text{Discount factor (n,r)} = \frac{1}{(1+r)^n}$$

These discount factors are embedded in the excel file, and can be called by the function **df**(n,r) where n and r are cells containing the years that will pass before the cash flow and r the interest rate. This is multiplied by the cash flow to determine its present value.

Annuity factors are another common financial multiplier. If there is a known cash inflow or out flow received at each of the next n years, then each payment could be discounted by the appropriate discount factor depending on when the cash flow occurs. It can be show that the sum of these discount factors can be simplified to

$$\text{Annuity factor (n,r)} = \frac{1}{r} \cdot \left[1 - \frac{1}{(1+r)^n} \right]$$

These annuity factors are embedded in the excel file and can be called by the command **af**(n,r) where n and r are cells containing the number of years over which the cash flow will occur and r is the interest rate. This is multiplied by the annual cash flow to determine its present value.

Explanation of Variables, by cell

[B2] *Required Rate of Return* is the percentage return (r) required by the investor. Given that the money is donated this value would be better evaluated as the interest rate for bank deposits.

[B3] *Agricultural Land Currently in Use* is the area of land in the selected area that is not contaminated with mines and UXO and currently in use for agricultural crop production (A_c).

[B4] *Mined agricultural land* is the amount of land in the selected area that had previously been used for agricultural activity, and is marked as mined (A_g).

[B5] *Other Mined land* is land not used for agricultural, eg roads and residential areas, that are suspected to be mined and require demining (A_m).

[B7] *Demining cost* is the cost of clearing a square metre of mined land, using the current method (c_d).

[B8] *Demining rate* is the area in square metres that the demining team can clear in one day (a_c).

[B9] *Days demining per year*, this should take into account that teams might not work weekends or in certain periods of the year when the weather is unsuitable (d_d).

[B10] *Annual Demining Cost* is evaluated as ($c_d\ a_c\ d_d$)

[B11] *Relocation cost* is the entire cost of bringing all displaced persons back onto the mined agricultural land after demining (C_{RL}). This would potentially include costs of rebuilding or repairing housing.

[B12] *Restoration Cost* is the cost of restoration needed before cultivation can commence (C_{RC}). This includes a fertilizer and chemical subsidy and the cost of infrastructure restoration. The costs of clearing the land using a flail and a ripper to remove roots are calculated separately. This is the cost for the whole area of land A_g.

[B13] *Demining Personnel Cost* is the annual cost of paying deminer salaries. (This is added to the demining cost calculated above only if salaries were not originally included. As salaries and all other costs are normally included in the cost per square metre c_d, this value would normally be zero.)

[B15] *Annual Aid Expense* is the annual cost incurred by the donor organisation to people displaced from, or dependent on the mined agricultural land. This includes shelter, food, medical aid, and any other expenses incurred by the donor organisation to support these people.

[B17] *Time to demine land* represents the estimated number of years (y_d) before demining resources will be available to clear the mined agricultural land.

[B18] *Machinery capital cost* is the cost of purchasing sufficient tractors and machinery and modifying them, or simply (preferably) the cost of modifying equipment already in service in the region. Some additional equipment might also need to be purchased for the tractors to allow them to perform useful demining and land restoration tasks.

[B19] & [B20] *flail costs* and *ripper costs* These represent the cost of initial land clearance per square metre. The flail would be needed to clear the land of vegetation and, in the case of the alternative method, to reduce mine contamination in the mined agricultural area. The ripper would be used to tear up root systems and trees left by the flail.

[B21] *Tractor demining costs* is the cost of using the tractor for demining per meter square as well as any hiring fee incurred from the farmer who owns the tractor as the tractor may still remain within the ownership of the farmer who wishes to be reimbursed for leasing it out to external agencies.

[B22] *Tractor clearance rate* is the amount of land on which the tractor can usefully be used for demining or vegetation clearance in one day (a_t).

[B23] *Cost of Subsequent Mine Clearance* is the subsequent cost (per metre) of clearing the land after it has been worked by the tractors (c_{dt}).

[B24] *Rate of subsequent mine clearance* is the improved rate of mine clearance that would be expected after clearing of vegetation by the modified tractors. This would improve the rate manual demining teams can work at. (a_{dt})

[B26] *Total Tractor Days* is the days a year a tractor can work due to climate variations, working weeks and any other restrictions. This should be the total amount of days the tractor can work at *any* activity, including agricultural activities. (d_t)

[B27] *Number of Tractors.* This variable represents the number of tractors that are being used. Practicality, this would suggest a minimum of two or three, so that one can be repaired without significant disruption, and to allow rescue if the other tractor stops after a mine blast or breakdown (n_t).

[B28] *Tractor Speed*. The speed of the tractor, in km/h is used to calculate how long it will take the tractor to do its agricultural activities (v_t).

[B29] *Working hours per day* is used to determine the amount of time it will take the tractor to complete its demining activities (h_{dt}).

[B30] to [B33] *Tiller*, *Seeder*, *Sprayer* and *Harvester width* are again used to determine how long many days the tractor will be take to perform its agricultural activities. All parts of the agricultural process will need to be mechanised, to make the cultivated mined agricultural land safe (w_t, w_{sd}, w_{sp}, w_h).

[E32] *Number of Sprayer / Spreader Passes Required*. The sprayer/spreader implement might need to be towed through the cultivated several times during a crop cycle to apply pesticides and weed control chemicals. (n_{sp})

[B34] *Days available after agricultural activities*. This is a calculated result representing the days each tractor has available after completing its agricultural activities. It is determined by the difference between the *Total Days Available* and the *days to perform tilling*, *seeding*, *spraying* & *harvesting* considering the *number of tractors available*, given *tractor speed* and *implement size* as well as for a given *crop frequency* (see below), over both the mined and non-mined agricultural Land.

The *Days to perform tilling* can be calculated as:

$$\frac{(\text{"Mined Agricultutal Land"} + \text{"Agricultural Land"}) \cdot 10000000}{(\text{"Days Tractor Can Work"} \cdot \text{"Tractor Speed"} \cdot 1000 \cdot \text{"Tiller Width"} \cdot \text{"No. Tractors"} \cdot \text{"Years between harvests"})}$$

Similar equations are determined for each of the other activities, namely *seeding*, *spraying* and *harvesting*.

The resulting final equation (after re-arranging) is;

$$\text{"Total Tractor Days"} - \left(\frac{1}{\text{"Tiller Width"}} + \frac{1}{\text{"Seeder Width"}} + \frac{1}{\text{"Sprayer Width"}} + \frac{1}{\text{"Harvestor Width"}}\right)$$

$$\text{x}\ \frac{(\text{"Mined Agricultutal Land"} + \text{"Agricultural Land"}) \cdot 1000000}{(\text{"Days Tractor Can Work"} \cdot \text{"Tractor Speed"} \cdot 1000 \cdot \text{"No. Tractors"} \cdot \text{"Years between harvests"})}$$

In the Excel Spreadsheet, this is represented by

$$= \text{B26} - \left(\frac{1}{\text{B33}} + \frac{1}{\text{B32}} + \frac{1}{\text{B31}} + \frac{1}{\text{B30}}\right) \cdot \left[(\text{B3} + \text{B4}) \cdot 1000000 \cdot \frac{\left(\frac{1}{\text{B45}}\right)}{(\text{B28} \cdot 1000 \cdot \text{B29} \cdot \text{B27})}\right]$$

(Note: factors of 1000000 and 1000 are used for converting to metre units)

[B35] *Land Suitability Multiplier (%).* This factor is a percentage modifier the amount of *other mined land* (non-agricultural) the tractor can work on to support demining operations. Steep slopes, rocky land, residential areas and forests will be areas where tractors could not be used to support demining operations. These areas will have to demined at the higher manual demining cost and slower rate. This information is also used to determine how much land there is for the demining tractor to work on, and how much time this will take per year. Areas that should be excluded by this modifier are excessively rugged terrain and areas potentially mined with AV mines, as the tractors can only withstand blasts from AP mines.

[B36] *Annual demining cost of the alternative method* is calculated as the number of years taken to complete all the demining in the subject area with the associated costs involved.

The Annual demining cost is;

The amount '*Other Mined Land*' suitable for tractor work, cleared per year, at the cost of using the tractor and the subsequent manual demining plus;

The cost of demining the remaining '*other Mined Land*' using conventional manual demining method and costs per year plus;

The cost of clearing the mined agricultural land at the *reduced cost of subsequent mine clearance*, after the all other land has been cleared.

The resulting equation is;

$$\text{"Land Suitability Modifier"} \cdot \left[\text{"Other Mined Land"} \cdot \frac{1000000}{\text{"Years to Complete Demining"}} \cdot (\text{"Tractor Demining Cost"} + \text{"Cost of Subsequent Mine Clearance"})\right]$$

$$+ (1 - \text{"Suitability Modifier"}) \cdot \left(\text{"Other Mined Land"} \cdot \frac{1000000}{\text{"Years to Complete Demining"}} \cdot \text{"Demining Cost"}\right)$$

$$+ \left(\text{"Mined Agricultural Land"} \cdot \frac{1000000}{\text{"Years to Complete Demining"}} \cdot \text{"Cost of Subsequent Mine Clearance)"}\right)$$

In the Excel Spreadsheet, this is represented by

$$= B35 \cdot \left[B5 \cdot \frac{1000000}{B54} \cdot (B21 + B23)\right] + (1 - B35) \cdot \left(B5 \cdot \frac{1000000}{B54} \cdot B7\right) + \frac{B4}{B54} \cdot 1000000 \cdot B23$$

[B37] The *Days Tractor Idle* is the number of days in a year the tractor is available after it has completed its demining and agricultural activities. This is calculated by;

$$\text{"Days Available after Agricultural Activities"} -$$

$$\left(\text{"Land Suitability Modifier"} \cdot \text{"Other Mined Land"} \cdot \frac{1000000}{\text{"Years to Complete Demining"}} \cdot \text{"Number of Tractors"} \cdot \text{"Tractor Clearance Rate"}\right)$$

In the Excel Spreadsheet, this is represented by

$$= B34 - \left[B35 \cdot B5 \cdot \frac{1000000}{(B54 \cdot B27 \cdot B22)}\right]$$

[B38] *Tractor Fee.* If the tractor is owned by the donor organisation, it may be hired out to private farmers or deminer's for a daily fee. This is the fee charged per day. If the tractor is not owned or leased to third parties this value should be entered as 0.

[B39] *Days of External Demand.* This represents the expected demand for the tractor from external agencies or individuals in terms of number of days per year. This can be more than 365 if there several tractors. The Excel spreadsheet will determine if there is sufficient time available for this level of demand.

[B40] *Days per year the tractor will be leased out* is determined to be the lesser of: a) *Days of External Demand* for tractors and b) the *Days Tractor Idle* multiplied by the *number of tractors*. This value can be greater than 365 if there are several tractors.

In the Excel Spreadsheet, this is represented by

=MIN(B27*B37,B39)

[B41] *Annual Revenue from leasing tractor* is evaluated as (*Days per year the tractor will be leased out*) x (*Tractor Fee*).

In the provided Excel Spreadsheet, this is entered as

=B38*B40

[B45] to [B47],[F45] & [F46],[B51],[B56] These variables are used to calculate the potential aid savings expected as the locals become self sufficient due to crop revenue. As full crop yield is not expected during the first year of cultivation perhaps due to factors such as inexperience, weeds or insufficient land reconditioning, the reduction is aid is expected to be gradual and is modelled here as an exponentially decaying function.

The two values ([B45]-[B46]) entered are inter-related. The amount of aid required to support the people is dependant upon the (area of) *mined agricultural land* and will be constant until they produce their first crop on this land. This crop will be assumed to have a reduced productivity because the land has lain idle for some years. Therefore the people will still need some aid to make up for the short-fall. The amount will be reduced after several crop cycles and tends to zero in the long term.

[B45] *Years between Crops*. This factor represents the number of years between crops. If a crop is expected once a year this would be 1, is there are 2 crop a year this would be 0.5 and so on.

[B46] *% Initial Productivity* represents the initial productivity expected in the first year of cultivation. For example, 0% productivity = 0 and 100% productivity = 1.

[B47] *Crop cycles to Achieve 95% Productivity.* This variable represents the number of crop cycles will it take to achieve 95% productivity where the local farmers are expected to be able to support themselves.

Using these three values the amount of percentage of the annual aid expenditure in year (t) is modelled as an exponential decay;

$\exp^{(-A*t+B)}$, where it can be shown;

$$A = \frac{\ln(1 - \text{"\% Initial Productivity"}) - \ln(0.05)}{(\text{"Years Between Crops"} \cdot \text{"Crop Cycles to Acheive 95\% Productivity"} + 1)}$$

In this Excel Spreadsheet provided, ‘A’ is entered in cell [F45] as

$$= \frac{(\ln(1 - B46) - \ln(0.05))}{B45 \cdot (B47 - 1)}$$

In a similar manner, the variable B is

$$B = \ln(0.05) + A \cdot [\text{"Year Between Crops"} \cdot (\text{"Crop Cycles to Acheive 95\% Productivity"} + 1)]$$

This is entered in cell [F46] of the Excel Spreadsheet as

=LN(0.05)+F45*(B47+1)*B45

[B51] & [B56] Using the exponential decay factor calculated previously, we can determine what is essentially an annuity factor that also takes into account the fact that the cash flow in each year is decaying according to the above rule.

The *DecayedAidNPV* in cell [B51] and [B56] represents this decayed annuity factor. It is evaluated in macro “Calc” and calculated as

$$\sum_{n = \text{"Year of First Harvest"}}^{\text{"Year Demining is Complete"}} (\text{"Discount factor (in that year)"} \cdot \text{"Decay Function (in that year)"})$$

[B49] *Years to complete under the current method.* This represents the amount of time needed to complete demining under the current practice. This is evaluated as;

$$\frac{(\text{"Other Mined Land"} + \text{"Mined Agricultural Land"}) \cdot 1000000}{\text{"Demining Rate"}} \cdot \text{"Days Demining per Year"}$$

This is formula entered in cell [B49] of the Excel Spreadsheet is

=(B5+B4)*1000000/(B8*B9)

[B50] The *NPV of the current method* is the net present value or cost of demining using current practises. It is evaluated as;

= -1* Annuity Factor(Year to Complete Demining) * Annual Demining Cost;

subtract Annuity Factor(Year first crop is grown) * Annual Aid Expense;

subtract Discount Factor(Year Mined Agricultural Land is Cleared) *(Flail Cost + Ripper Cost + Relocation Cost + Reconditioning Cost);

subtract Discount Factor(Year First Crop is grown) * Decayed Aid NPV * Annual Aid Cost ;

subtract Annuity Factor(Year to Complete Demining)* Annual Demining Teams Salary;

In the Excel Spreadsheet provided, this is entered in cell [B50] as:

=-af(B49,B2)*B10

-af((B17+B45),B2)*B15

-df(B17+B45,B2)*B51*B15

-df(B17,B2)*(B20*B4*1000000+B11+B12)

-af(B49,B2)*B13

[B54] *Years to complete under the Alternative Method.* This variable is a calculated value representing the amount of time needed to complete demining under the alternate approach of farming with a protected tractor. It is essentially:

= Years to clear agricultural mined land at improved clearance rate;

plus Years to clear part of 'other mined land' at improved clearance rate due to tractor

plus Years to clear remaining 'other mined land' at the original demining rate.

In this model, the value is calculated as:

$$= \frac{\text{"Mined Agricultural Land"} \cdot 1000000 + (\text{"Suitability Factor"} \cdot \text{"Other Mined Land"} \cdot 1000000)}{\text{"Rate of Subsequent Mine Clearance"} \cdot \text{"Days Demining per Year"}}$$

$$+ \frac{(1 - \text{"Suitability Factor"}) \cdot \text{"Other Mined Land"} \cdot 1000000}{\text{"Clearance Rate"} \cdot \text{"Days Demining per Year"}}$$

In the Excel Spreadsheet, this is represented in cell [B54] as:

$$= \frac{(B35 \cdot B5 + B4) \cdot 1000000}{(B24 \cdot B9)} + \frac{(1 - B35) \cdot (B5 - 1000000)}{B8 \cdot B9}$$

[B55] *Alternative Method NPV.* The net present value of this alternate approach to demining is calculated as:

Annuity factor(Years to complete demining) * tractor revenue;

subtract Annuity factor(Years to complete demining) * Annual Demining Cost;

subtract Discount factor(Year of first crop) * Decayed NPV * Aid Expense;

subtract Annuity factor(Year of first crop) * Aid expense;

subtract Capital Cost of Armouring Tractor;

subtract Cost of flail and ripper for Mined agricultural land;

subtract Cost of relocation;

subtract Cost of Reconditioning of Land;

subtract Annuity factor(Years to complete demining)* Annual Demining Teams Salary

In the Excel Spreadsheet provided, this is represented in cell [B55] by:

= -af(B54,B2)*B36

-df(B45,B2)*B56*B15

+af(B54,B2)*B41

-B18

-B4*1000000*(B19+B20)

-af(B45,B2)*B15

-B11

-B12

-af(B54,B2)*B13

Both of the NPV's evaluated would be negative and as they are both outflows in cash which represent the amount required from a donor to pay for clearing of the land. Thus the method with the least negative NPV is the cheapest method to demine the area for the donor. The NPV represents the amount the donor would have to donate now to pay for all the tasks over the time it takes to clear the mined area. If this money is held with an interest rate equivalent to the require rate of return and withdrawn as the expenses are incurred, all costs will be covered.