STRATEGIC STUDY OF THE HUMANITARIAN DEMINING PROSPECTS
The role of RT&D analysed as a Europe-wide issue

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EXECUTIVE SUMMARY

The European Union has chosen to concentrate its humanitarian demining strategy in support of the South Eastern Europe Stability Pact to remove the landmines and the unexploded ordnance that are the legacy of the recent Balkan conflict. To support this strategy, the European Commission has recommended a funding level of at least 180 MEuro for the period 2000-2006.

Experience has shown that large areas of infected countries that are suspected of containing landmines are, in fact, totally free of landmines. It is increasingly now the procedure, at the outset of a mine clearance campaign, to conduct a survey of such suspected areas and as soon as possible to conduct "Level 2 Surveys" in order to verify the suspicion or to confirm that the area is free of landmines. This approach has proved to be very effective in releasing large areas of ground for productive use relatively quickly (area reduction). The technologies used here are diverse and it is unlikely that one single technology will provide a universal solution. Current techniques use dogs (possibly combined with vapour trace collection), metal detectors and mechanical systems. For the near future some interesting solutions are being investigated ranging from vehicle-borne sensor platforms to advanced airborne and spaceborne systems. Urgent improvements to the conduct of Level 2 surveys and area reduction are needed, since as much as 80 % of the suspected areas finally turn out to be mine-free. Hence new methods for fast and reliable minefield delineation and area reduction have a tremendous impact on overall clearance efficiency, safety and restoration of socio-economic activity.

When the actual area that is infected with landmines has been delineated (minefield delineation) as a result of the Level 2 survey, the process switches to a slow, labour-intensive one in which "close-in detection" is followed by manual prodding and removal of the mines. At the present, the individual mines are detected primarily by using metal detectors. This technique is slow and the metal detector is plagued by false alarms generated by metallic debris such as bullets and shrapnel, each piece of which must be laboriously lifted by hand with the same care as if it were an actual mine. It is in this area of close-in detection that most of the European Commission's funding for R&D has been invested until now, because major improvements in the technologies are urgently required. Since 1998, 11 collaborative projects have been initiated with a commitment of about 15 MEuro with a comparable sum having been committed by the industrial partners. However, it appears that there is reluctance by industry to take the solutions from the demonstrator phase through to production. The reasons for this reluctance are widely recognised, the principal ones being the uncertainty of the prospective sales volume, the extensive and expensive trials required to prove the performance achieved and the very real risk that these trials will fail to confirm the original expectations of the user (deminer) community. The present study has addressed these central problems in detail and *recommends a suite of actions to ensure that a reasonable path is created from R&D through to productionisation and deployment in the field*. Besides the concern of ensuring continuity and constancy from R&D up to exploitation in humanitarian demining, the study also *emphasises the need for supporting R&D in completely new technologies and new combinations of existing technologies*, possibly borrowed from application domains other than humanitarian demining.

A path from R&D to productionisation and deployment in the field

The proposals formulated for the "path from R&D to productionisation and deployment in the field" have been made on the particular worked example of ***handheld*** (and to a limited extent, also vehicle based)

systems for close-in detection by means of multisensor probes (the main subject of current IST research projects).

None of the proposals made for taking demonstrators through to production and deployment in the field requires any departure from normal contractual procedures of the European Commission and all of them retain the necessary competitive elements. It is proposed that the European Commission should initiate simultaneously and as soon as possible, two *Accompanying Measures* of 1-year duration, both of which will be competed and then funded at 100%. One of these contracts will be to undertake, for the first time ever, a technical-economic ***Systems Study***, the object of which will be to quantify the reduction in clearance costs (Euro/sq.m) as a function of the technical performance of a new close-in detection system, taking into account factors such as the wages of the operators and the price and lifetime of the equipment. The estimated cost of this Study is 1MEuro. A preliminary analysis, undertaken during this present study, has shown that considerable savings can be made by reducing the frequency of false alarms by a modest amount. The other *Accompanying Measure* would be to design and construct a mid-size ***Trials Site*** "seeded" with surrogate mines and pieces of debris that have actually caused false alarms in mine clearance operations and which have been collected for this purpose. Earlier studies have shown that in order to measure the performance of a detection system with the confidence required, very much larger trials are required than the ones that can be provided by the existing instrumented trials facilities within Europe. The Trials Site recommended here should cover an area of 10,000 sq.m and be seeded with about 1,000 surrogate mines and 20,000 pieces of debris. It is estimated that the cost to the European Commission for the design and construction of the Trials Site would be about 1-2 MEuro.

During this first year, industry would be invited to offer demonstrator equipment to be measured on the Trials Site and for the results to be interpreted as potential cost-benefit using the model that will have been generated during the Systems Study. At present time, six hand-held systems and one vehicle-borne detection system are being supported by the European Commission, all of which will have produced demonstrators by the time these *Accompanying Measures* have been completed. The invitation to industry would therefore include these consortia but would not be limited to them. With the invitation would be a clear statement of how the trials of demonstrators would be conducted on a competitive basis, the way in which the results will be interpreted in terms of cost-benefit and the subsequent procedure to be used by the European Commission. The present study recommends two alternative procedures to be adopted after the demonstrators have been ranked in terms of cost-benefit. The key objective behind both alternatives is to evaluate the performance of promising new systems in a much wider and realistic range of scenarios than will be provided by even the relatively-large Trials Site upon which the selection will have been made. In these alternative proposals, contracts will be placed for a number of pre-production or production units which will then be loaned by the European Commission to mine clearance organizations working under small contracts comprehensively to evaluate the units under a very wide range of environmental scenarios present within South Eastern Europe.

In the first of these alternative proposals it is recommended that the European Commission should place contracts for 6 pre-production units of each of the 2 demonstrators that were ranked highest at the conclusion of the competitive trials. The cost of both contracts together is estimated to be in the region of 4 MEuro and the subsequent evaluation phase should be completed by about 4 years after commencement of the *Accompanying Measures*. The European Commission would then publish the results of this wide-ranging evaluation by organisations using the 2 systems. Providing that one or both systems confirmed their earlier promise, the manufacturers should have enough confidence to fund the subsequent productionisation phases on their own funds. ***By this route it is expected that one or two new systems having convincingly demonstrated cost-benefit over current detectors will be on the market in about 6 years form the start.***

The second of these alternative proposals is basically the same as the first with the difference being that only the demonstrator ranking highest after the competitive trials would be selected by the European Commission. The manufacturer of this system would then be placed under contract to deliver 100 early production units for thorough and comprehensive evaluation by clearance organisations using operators with a representative range of aptitudes, various clearance procedures and over a wide range of environmental conditions. The established cost-benefit and any limitations of this system would be published with the expectation that the system would then be widely purchased, leading to significant reductions in cost and time taken to clear minefields. ***The productionised system should be on the market after only 5.5 years*** and the cost to the European Commission for the 100 production units for evaluation would be about 5 MEuro. This alternative route would therefore cost rather more to the European Commission but would ensure that a new, effective and proven system would be on the market as soon as possible.

Supporting R&D in completely new technologies

Besides the detailed study of handheld systems for close-in detection of mines, the study has also addressed other new technologies covering most tasks of structured demining as described by the UN. Considering that the market for humanitarian demining equipment is very limited and identifying a lack of interest from large companies in making the considerable investments for developing and productionising the results of R&D, a pro-active measure is required for identifying transferable technologies from other application domains towards humanitarian demining. Therefore the present study recommends an *Accompanying Measure* on ***Technology Watch***, along the lines detailed in the report. During the expected 5-6 year delay before the multisensor handheld systems currently emerging from R&D are deployed in the field, new technologies may well appear in other application domains which could usefully be adopted for mine detection. Moreover, the limited market for technology specifically developed for humanitarian demining, calls for technologies that can address wider application fields and that can be tuned or modified towards the needs of humanitarian demining.

As this is made clear in the present report, various new detection technologies are already emerging. It is proposed that, where justified, these should be supported by the European Commission using R&D procedures as at present. It is therefore likely that new demonstrators will be produced every year or two and these would be competed using the proposed Trials Site then, if appropriate, taken through to extensive evaluation in the field as proposed above.

From the review of the IST R&D projects, it appears that at the current size of funding/project the timeframe of 2 years is very short for R&D projects including a requirements phase, a specification phase, development and integration, demonstrator building, laboratory testing and initial field tests by end users. Currently the timeframe for R&D is not sufficiently synchronised with the timeframe of the Balkan operation. Solving the problem of carrying R&D results to the stage of production and deployment needs synchronisation between the R&D phase and subsequent measures for extensive testing and productionisation to avoid gaps during the transition. Creating coherence between (1) the EU policy based on political decision, (2) R&D, testing and productionisation of equipment and (3) timely deployment, requires a new way of co-ordinated thinking: *end-to-end planning*, supported by a well organised and co-ordinated organisational structure involving different DGs and even extending beyond the EU.

There is a need for an increased use of *mechanical systems* because these offer the greatest prospect for substantial productivity gains in clearing mines. However, very little R&D support exists anywhere within the EU to assist industry in this regard. This deficiency should be addressed as a matter of priority.

A general recommendation concerning the role of fundamental research is made in the context of a recent note emanating from the EU Commissioner for Research, “Towards a European Research Area”. Humanitarian Demining is proposed as a theme for practical implementation of a specific European Research area to overcome the current fragmentation of R&D, which is impeding fast progress. This proposal is motivated by the urgency of getting results and supported by ethical and moral principles that are generally accepted. There is a large community of fundamental scientists that can contribute to new technology, and the goal-oriented process from fundamental research to applied research, and development, testing and application in the field needs a continuous interaction. Giving a strong co-ordinated incentive supported by all member states will undoubtedly create a research/users community dedicated to the common goal of finally getting rid of the world-wide mine problem.

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Table of contents

1 TERMS OF REFERENCE 1

2 INTRODUCTION 1

3 HUMANITARIAN DEMINING – EU OBJECTIVES, TIMEFRAMES AND FUNDING 2

3.1 PRIORITIES AND OBJECTIVES, AS EXPRESSED BY THE EU, AND THEIR IMPACT ON R&D 2
3.1.1 UN International Standards for Humanitarian Mine Clearance Operations 2
3.1.2 Stability pact 2
3.1.3 Sustainable versus post conflict (emergency) humanitarian demining 2
3.1.4 Information Systems: tools for better mine action, priority assessment and increased R&D productivity? 2
3.1.5 Shared military-civilian RT&D in the context of a European Defence Force and Post-conflict peace keeping - potential and limitations 3
3.1.6 The Action Line I.4.2 within the IST programme of the 5-th framework 3
3.1.7 Current funding: institutional (EU, UN) and private sources for demining action 3
3.2 TIMEFRAMES 4
3.2.1 Timeframe of progress in humanitarian demining action results 4
3.2.2 Timeframe for EU investments and donor funding 4
3.2.3 Timeframe for developing new technologies, technology transfer resulting from R&D towards deployment 5
3.2.4 A new way of thinking: "end-to-end planning" 5

4 HUMANITARIAN DEMINING – THE SIZE OF THE PROBLEM 5

4.1 UNCERTAINTY ABOUT THE EXACT NUMBER OF MINES 5
4.2 INFECTED AREA VERSUS NUMBER OF MINES VERSUS SOCIO-ECONOMIC IMPACT 6
4.3 MEASURING THE SOCIO-ECONOMIC IMPACT 6

5 NEED FOR BETTER TECHNOLOGIES 6

5.1 CURRENT PRACTICES 6
5.2 COST PER DEMINED AREA – AN IMPORTANT PARAMETER FOR MEASURING EFFICIENCY OF NEW TECHNOLOGY 7
5.3 DATA NEEDED FOR COST AND TIME ESTIMATION TO MEET EU OBJECTIVES WITH PRESENT TECHNOLOGIES 7

6 PROMISING NEW TECHNOLOGIES 8

6.1 REVIEW OF THE STATE-OF-THE-ART IN EU RELATED TO HUMANITARIAN DEMINING TECHNOLOGY 8
Sensor technology 8
6.2 TECHNOLOGIES ADDRESSING VARIOUS MARKETS 10
6.2.1 Overview of appropriate military R&D and its potential for transfer to humanitarian use 10
6.2.2 Technology Transfer from other Applications into Humanitarian Demining 10
6.2.2.1 Opportunities and Difficulties relating to close-in detection 10
6.2.2.2 Opportunities for exploitation of high resolution satellite imagery in humanitarian demining 11
6.2.3 Technology Watch 11

7 R&D PROGRAMMES FOR TECHNOLOGY DEVELOPMENT 11

7.1 OVERVIEW OF OTHER LEADING R&D PROGRAMMES (E.G., THE US/DOD INITIATIVE) 11
7.2 HAND-HELD, VEHICLE BASED AND AIRBORNE PLATFORMS 12
7.2.1 Costs and time scale to production for representative handheld and vehicle-borne systems 12
7.2.1.1 Hand-held System 12
7.2.1.2 Vehicle-borne System 13
7.2.1.3 Purchase Prices of Hand-Held and Vehicle-borne systems 13

7.2.1.4 Airborne systems....13

8 ECONOMIC MODELS OF THE BENEFITS OF IMPROVED DETECTION EQUIPMENT.....14

8.1 INTRODUCTION....14
8.2 REDUCTION IN RUNNING COSTS....14
8.3 REDUCTION IN OVERALL COSTS....15

9 LESSONS LEARNED FROM ESPRIT/IST RT&D PROJECTS....15

10 RECOMMENDATIONS....16

10.1 GENERAL....16
10.1.1 The role of fundamental research, research institutes and universities....16
10.1.2 Specific R&D on mechanical equipment....16
10.2 RT&D PROJECTS....17
10.3 ACCOMPANYING MEASURES....17
10.3.1 Technical-Economic Systems Study....17
10.3.1.1 Introduction....17
10.3.1.2 Funding and Timescale....17
10.3.2 Adjudicated Trials of Candidate Systems....18
10.3.2.1 Introduction....18
10.3.2.2 Size, Seeding and Funding of Trials Site....18
10.3.3 Conduct of Trials....18
10.3.3.1 Comment....19
10.3.4 Technology Watch....19
10.3.4.1 Introduction....19
10.3.4.2 The main objectives....19
10.3.4.3 Implementation....19
10.3.4.4 Expected results and measures of success....19
10.4 EVALUATION OF DEVELOPED SYSTEMS....19
10.4.1 Purchase of pre-production units (Proposal 1)....19
10.4.1.1 Introduction....19
10.4.1.2 Expected Candidates for Trial....19
10.4.1.3 Estimated Timescale and Cost....19
10.4.1.4 Comment....19
10.4.2 Purchase of Production Units (Proposal 2)....19
10.4.2.1 Introduction....19
10.4.2.2 Purchase of Production Units for Extensive Evaluation....19
10.4.2.3 Timescale and Cost....19
10.4.2.4 Comment....19

11 REFERENCES....19

ANNEXES....19

ANNEX 1 INFORMATION SYSTEMS: TOOLS FOR BETTER MINE ACTION, PRIORITY ASSESSMENT AND INCREASED R&D PRODUCIVITY?....19
ANNEX 2 SHARED MILITARY-CIVILIAN RT&D....19
ANNEX 3 COST/SQ.M OF DEMINED AREA ESTIMATED FROM ONGOING DEMINING PRACTICE....19
ANNEX 4 NEW DEVELOPMENTS IN INFRARED TECHNOLOGY....19
ANNEX 5 DENSITY OF FALSE ALARMS DETECTED BY A MODERN METAL DETECTOR (ALARMS/SQ.M) SOME PRACTICAL ESTIMATES TO SUPPORT MODELLING....19
ANNEX 6 REDUCTION IN RUNNING COSTS....19
ANNEX 7 REDUCTION IN OVERALL COSTS....19
ANNEX 8 ECONOMIC MODEL BUILDING AND DATA GATHERING....19
ANNEX 9 DESIGN OF PROPOSED TRIALS....19
ANNEX 10 HAND-HELD SYSTEMS CURRENTLY BEING SUPPORTED....19

1 TERMS OF REFERENCE

Experience to date has shown that large sectors of European industry are reluctant to invest in the research, development, certification and production of improved equipments for humanitarian demining under the present European Commission funding arrangements as the technological risks are high and the routes to successful exploitation are uncertain.

A Strategic Study will be undertaken to:

1) Quantify the size of the demining requirements in the relevant infected countries together with an estimate of the cost of clearing these areas using present methods
2) Review the European Commission programmes that have been funded to date and identify the gaps, lessons learned and results accomplished
3) Provide an analytic overview of the efficiency of tools currently in use (sq.km/day) and discuss what level of daily clearance should be achieved to match the requirements of the Ottawa Treaty
4) Produce outline specifications of equipments that could feasibly be in production in the period 2005 to 2015 and estimate the corresponding likely improvements in clearance capability and the costs of research, development and certification and the unit production cost for suitable batch sizes
5) Propose and analyse alternative funding mechanisms for research, technological developments, demonstrations and procurement by the European Commission, which will stimulate appropriate investment and commitment by European industry.

2 INTRODUCTION

The case for continuing the action against anti-personnel mines over the next 10-15 years is clearly stated in [1]. In particular, it calls for more attention to be given to the development of appropriate technology for improving the performance in all areas of mine survey and clearance. Over the period 2000-2006, the mine action should continue at a funding level of at least 180 Meuro [2].

In 1998, the European Commission initiated a number of ESPRIT RTD research projects aimed at developing technology for the close-in detection of anti-personnel mines. Contracts for 11 collaborative projects were placed, the European Commission having provided or committed totalling 15.1 Meuro [1]. The industrial partners have spent or committed a comparable sum. The JRC has also won ESPRIT Competitive Support contracts totalling 1.8 Meuro. From the few projects that have been completed to date, there is little evidence that the results are about to be exploited by industry. Indeed, there is evidence to suggest that some large companies are no longer interested in making the considerable investments for developing and productionising new close-in detection systems.

The reasons for the lack of interest by industry are not hard to find and are widely acknowledged. Without well-defined technical specifications and a reasonable assurance of an adequate sales volume, no industrial company can justify the considerable funding required to take a promising solution forward from the research phase through the ever-increasingly-costly phases of development, trials, productionisation and certification. Overshadowing these further phases is the very real risk that, during the increasingly thorough development trials, the solution adopted is shown not to meet the exceedingly demanding performance required in mine detection.

This reluctance to invest company funds by industry is paralleled by the widely-held view of the deminer community that funds should mostly be used firstly to support current clearance operations using current technology and secondly to incrementally improve the currently used demining equipment, rather than risking public money on developing new technology with all the attendant risks and delay.

A Task Force has recently addressed this problem and proposed what is effectively a procurement agency [3]. This proposal has been reviewed by the European Commission and its recommendations have not been accepted.

In the meantime, Action Line I.4.2 of the IST Workprogramme 2000 [4] has invited consortia to submit R&D proposals on new smart sensor technology and data fusion, primarily targeting the solution of the mine problem in the South Eastern Europe, i.e. the Stability Pact area.

It is against the above background that the present Study has been performed.

3 HUMANITARIAN DEMINING – EU OBJECTIVES, TIMEFRAMES AND FUNDING

3.1 Priorities and Objectives, as expressed by the EU, and their impact on R&D

The current section enumerates a few important priorities and objectives, as expressed by the EU, having a major impact on R&D in humanitarian demining as well as technology deployment in the field.

3.1.1 UN International Standards for Humanitarian Mine Clearance Operations

Definitions of various types of activities requiring the usage of appropriate technology are summarised. A more complete view is given in [5].

- *Level 1 (general) survey* aims at collecting information on the location and categorisation of suspected areas affected by mines or UXO and areas that are not affected. Analysis of the socio-economic impact due to the presence of minefields is part of the Level 1 survey
- *Level 2 (technical) survey* should partition the suspected area and accurately define and delineate the outer edge of areas containing mine hazards (*minefield delineation and marking*). At this stage, land may be released for productive use (*area reduction*)
- *Mine/UXO clearance operation* is usually composed of close-in mine detection, mine marking and mine lifting. Clearance should be achieved to a standard of 99.6 %
- *Level 3 (completion) survey* is carried out in conjunction with the mine clearance teams and accurately records the area cleared, sometimes with a technical post clearance *Quality Control*. The completion survey and Quality Assurance check forms the basis for the documentation needed for issuing an authorised acceptance certificate.

3.1.2 Stability pact

The European Commission is developing an integrated strategy for humanitarian demining, including humanitarian demining actions, R&D on equipment and technology oriented towards the user needs. The initiative is given certain coherence by focusing this strategy towards a confined geographical region, namely South Eastern Europe. The *Stability Pact* is a political commitment to support a co-ordinated strategic approach for this region to achieve common objectives with respect to democratisation, human rights, economic development, reconstruction, internal and external security. The *South Eastern Regional Table* (SEERT) was established to review progress under the Stability Pact, carry it forward and provide guidance towards progress in its objectives. Specific responsibility for humanitarian mine action falls under *Working Table III*. The European Commission's package for mine action in South Eastern Europe included in the "*Quick Start Package of projects"* is composed of 5 projects: (1) analysis of capability shortfalls and user needs, (2) establishment of high definition maps, (3) secure GIS in collaboration with local scientists, (4) testing and evaluation of metal detectors, (5) field assessment of new technologies in mine affected areas.

3.1.3 Sustainable versus post conflict (emergency) humanitarian demining

Focusing the humanitarian demining strategy towards South Eastern Europe creates the risk that long term efforts for sustainable demining might be abandoned due to the funding shifting towards priority areas in the Balkan. Post conflict (emergency) humanitarian demining puts other constraints to technology than sustainable demining as carried out at several places in Asia and Africa (e.g. old minefields). It should be accepted that sustainable demining needs a certain security of funding, because it is a long-term process. Since humanitarian demining is largely a government created market, in which also the EU has an important share of the total funding, policy consistency is required. Therefore, also in R&D*, the focus should be on generic technology, but having a particular impact in the Stability Pact areas.*

3.1.4 Information Systems: tools for better mine action, priority assessment and increased R&D productivity?

Incremental *refinement of available information systems* can help in specifying the priority of scenarios, associated with a selected area and solicited in a particular call for R&D. Adapting the existing information systems to demining requirements should be feasible at low cost (see also ANNEX 1). *To our knowledge at present no information system is going as far as taking into account the technology properties.* A system including this latter aspect could gradually grow towards a simulation tool for improving planning of demining for the different demining scenarios (e.g. for the Stability Pact Area, 8 different basis scenarios have been identified [18]) and selecting equipment for various specific demining tasks, as specified in section 3.1.1. *Standardisation efforts* in the area of Information Systems for humanitarian demining should primarily go towards adopting standards for data representation, fully exploiting existing standards. Harmonisation of software tools used is also important, but should be seen as a secondary objective.

3.1.5 Shared military-civilian RT&D in the context of a European Defence Force and Post-conflict peace keeping - potential and limitations

In [1], the "synergy between military and civil capabilities in the demining field" is pointed out. Specific mention is made of high resolution images (WEU) provided by NATO, and military expertise in trials of technical solutions. *Note that no explicit mention is made of R&D*, although in practice many technology companies in humanitarian demining R&D are also main players in military markets. *Although the goals pursued in humanitarian versus military demining are very different [6], an overlapping military-civilian market exists.* Envisaging co-ordinated, shared military-civilian research should be viewed in the light of the following empirical observations:

- New sensing principles for mine detection are mainly emerging from civil applications; globally there is *no net transfer anymore from military towards civilian world* (1).
- To a large extent, *useful military information stays classified* and not available for civilian usage (2).
- *In depth knowledge of newer sensing principles, allows for easy modification of mine designs (3)*.

These are but three examples of objective bottlenecks acting as impediments to a structured, shared military-civilian research. In our opinion, a *code of conduct should be established agreeing mechanisms for transferring military R&D to humanitarian R&D.* The subject clearly needs an in-depth analysis. This section has as a goal to draw attention not only to the identified high potential but also to the important problems of lifting barriers between military and humanitarian R&D. More information is given in ANNEX 2.
Currently military efforts have been undertaken, such as ITEP, NATO group 'Dual Use Technology Study', UK and German Programmes. Participants of these groups are also involved in EU-RTD projects and no obvious feedback has been noted.

3.1.6 The Action Line I.4.2 within the IST programme of the 5-th framework

RT&D in humanitarian demining is currently supported by Action Line I.4.2 in the workprogramme 2000 [4] of IST. Probably the scope of *the IST programme is too limited to support all the various interesting technologies for humanitarian demining.* Various actors in mine clearance have pointed out the likely benefits of shared-cost funding of R&D for new mechanical systems which have so far been excluded from the IST programme.

3.1.7 Current funding: institutional (EU, UN) and private sources for demining action

Due to the reluctance of the relevant actors, including the EU, we were unable to obtain the reports of mine action projects within the limited time of the current study. However, the substance of some of the reports of EU-funded projects in 1998 (see Annex of [1]) was discussed informally at JRC. These reports appear to be very diverse in structure. They are often descriptive without mentioning numerical data, or vice versa numerical data are given without context. Often the incidents and accidents are not treated in sufficient depth. The European Commission has a reputation as being hard on financial reporting, but less rigorous on technical reporting. Adoption of IMSMA (Information Management System for Mine Action – already a UN standard) by the European Commission could trigger substantial benefits.
The new UN standards, which are currently being compiled, will include a new standard on reporting. This is intended to maximise the value of data which are placed into the IMSMA database. However, the new standard is unlikely to require the collection of all the data which is foreseen in this report to assist R&D. The standards will be a 'living document' so changes can be made at any time but, for simplicity and maximum impact, the necessary changes should be requested in the next few months and before publication of the new standards document. The GICHD (the Geneva International Centre for Humanitarian Demining) is co-ordinating the revision.

In an attempt to identify the share of technology-dependent costs in typical demining campaigns, several private demining companies and NGOs were asked to provide quantitative data on the cost breakdown. No conclusions on this aspect can be presented due to the very poor response. The financial breakdown of the cost is essential for the further development of the technical-economic *Systems Study* proposed in section 10.3.1.

3.2 Timeframes

During much of the 1990s many mine clearance organisations and especially the International Campaign to Ban Mines (ICBL) were stating that the clearance of mines would take hundreds of years. Such statements might have been helpful to mobilise support for the campaign to ban mines but are, in two important senses, rather misleading. It presumed that the very slow manual techniques for clearing mines used at that time – and still largely now – would be the only means available. It also implied that the international community would continue to actively support the clearance of mines for the indefinite future.
New techniques and equipment are being developed to speed up the clearance of land. An important fact is that a very large proportion of land considered to be suspect will, in the end, be found to have no mines at all. One technique now in active use is that of 'area reduction' (also sometimes called Level 2 Survey) where rapid tools, such as mine detecting dogs or machines like rollers and flails, traverse the ground until mines are found. At that stage, the smaller mined area is marked for subsequent full clearance. As these area clearance techniques are very much faster than manual clearance techniques, a great deal of time is saved compared to using manual techniques on the entire area. In some countries, and under certain circumstances, machines are being used to clear even the areas known to contain mines rather than using manual techniques. There are a number of other initiatives that will continue to reduce the time taken to clear suspect land.

The application of more effective technology to mine action programs in South Eastern Europe is expected to have an immediate impact on the effectiveness and productivity of humanitarian demining operations. The limitations as to the deployment of high tech systems in the field are certainly less stringent in areas with a high socio-economic development, a good organisation of infrastructure, and a lot of technically skilled local people.

3.2.1 Timeframe of progress in humanitarian demining action results

Level 2 Surveys of suspect areas are increasingly being used prior to actual demining operations, and there is every prospect that evolving technology will accelerate this process.

Close-in detection technology for pinpointing individual mines will demonstrate benefits to all phases of mine clearance for several of the 8 typical scenarios found in South Eastern Europe. Incremental improvements to currently used detection systems (e.g., even a small decrease of the false alarm rate yields a tremendous reduction in operational costs – see section 8.2), can have worthwhile benefits in the short term. Until new multi-sensor hand-held systems for close-in detection, emerging from current R&D projects, become available in 5-6 years from today (see sections 10.4.1.4 and 10.4.2.4), these modifications will be the major ways in which detection performance will be improved.

Quality control technology with performances at least equal to close-in detection for post clearance operation could also be used for Level 2 surveys. For close-in detection the main parameter influencing operational cost is the *reduction of the false alarm rate* (see section 8.2). For quality control, however the speed of survey is the most important parameter for reducing cost. New developments will continue to be important as long as clearance goes on.

Management tools and Information systems are essential at all levels of demining. The IMSMA system, which has been accepted for use in the Balkan area, might be a good choice as a starting point for an open system. Also at the level of planning of R&D, targetting to specific goals and/or areas, information systems might play an important role to speed-up policy making and respond in a faster way to the political priorities of the moment, as mentioned in section 3.1.4.

3.2.2 Timeframe for EU investments and donor funding

It is highly unlikely that international donors will continue to support the clearance of mines at the present level of funding. Some mine clearance organisations already claim that money is becoming harder to get but this is difficult to verify in overall terms. What is known is that donors are becoming increasingly concerned at the slow pace of clearance and are demanding greater productivity from those organisations they fund. The

US President set out what was called the “2010 Initiative” aimed at eliminating all landmines threatening civilians by 2010 [7]. It is believed that very few seriously think this is possible and it will take many years more to achieve that goal. The greater importance of the statement is that it might indicate the limit of major international attention to this subject. Again this cannot be verified but is a view, which is gaining currency. More certain is the reality that sooner or later international donors will find other priorities for funding and that the best use must be made of the time and funds still remaining.

The EU has committed to fund at least up to 180 MEURO for a period extending to 2006. The launching of a new call for R&D proposals is decided on a yearly basis within the framework programme, and published in the yearly renewed workprogramme. An extended planning cycle is urgently needed (see Figure 1 and Figure 2) to ensure continuity of the post-R&D phases, bringing the best results to the stage of productionisation so that deployment in the field is achieved at the earliest date. This will require a limited investment of the EU, while continuing to guarantee industrial competition.

3.2.3 Timeframe for developing new technologies, technology transfer resulting from R&D towards deployment

The socio-economic impact of Level 2 survey and area reduction is very important. Therefore, Level 2 survey equipment remains a priority for R&D for the foreseeable future.

New technology and sensing principles for close-in detection might yield more spectacular breakthroughs, certainly in the long term. Even for the deployment of results of the ongoing ESPRIT/IST R&D projects on handheld multisensor probes a time delay of 5 to 6 years is estimated in this report (sections 10.4.1.4 and 10.4.2.4). Therefore any new sensing or data fusion principle opening realistic prospects of deployment within 5 to 6 year is worth supporting.

3.2.4 A new way of thinking: “end-to-end planning”

- From the recent review of ESPRIT/IST R&D projects, it appears that at the current size of funding/project the timeframe of 2 years is very short for multi-sensor R&D (this typically holds for projects including a requirements phase, a specification phase, development and integration, demonstrator building, laboratory testing and initial field tests by end users).
- Solving the problem of carrying R&D results to the stage of industrialisation and finally deployment needs synchronisation between the R&D phase and subsequent measures for extensive testing and productionisation (overall requiring an expected 5-6 year timeframe, at least for the currently researched handheld multisensor systems). Both phases should be synchronised in order to avoid gaps during the transition, and special measures may have to be taken to minimise the burden of extensive contract negotiations.
- Creating coherence between (1) the EU policy based on political decision, (2) R&D, testing and industrialisation of equipment and (3) timely deployment, requires a new way of co-ordinated thinking: “end-to-end planning” will have to be supported by a well organised and co-ordinated organisational structure involving different DGs and even extending beyond the EU.

4 HUMANITARIAN DEMINING – THE SIZE OF THE PROBLEM

4.1 Uncertainty about the exact number of mines

The origin of the confusion on the total number of mines both regionally and globally is clearly analysed in [8]. The initial number of 120 million mines spread over the world, announced by the UN, is based on adding numbers provided by individual countries without control of their veracity. This amount was taken over in various publications and extensively used for attracting public attention to the problem. An analysis of about 10 years of Humanitarian Demining, cleared and marked areas and remaining suspected areas, reveals that the number is highly over-estimated (many websites are currently removing all numbers).
The true number of mines already in the ground throughout the world is not known. Quoted figures vary from 120 millions to 60-30 millions and, accepting that the truth cannot be verified, it is probable that the lower range figure is nearer the truth. There are occasional, but relatively formal, assessments undertaken attempting to create a useful estimate [9] but these have always been subject to doubt.

4.2 Infected Area versus number of mines versus socio-economic impact

It is now generally accepted that the number of mines is largely irrelevant and much greater attention is now paid to two other issues. Firstly, the areas of land – particularly productive land – affected by mines and thus not available for productive use. Secondly, the socio-economic impact of the mines. This can be in terms of casualties, the economic effect, and the impact on the sustainable repatriation of refugees.

It is important to recognise that although mines are stated as the problem, there are other explosive products of conflict that should not be ignored and, in some cases, provide a much greater problem than mines. The problem of sub-munitions (also known as 'bomblets') has become well recognised following the end of the NATO campaign in Kosovo. These items are extremely dangerous and their removal in Kosovo is seen as a higher priority than most mines. Such problems are far from unique to Kosovo and, for example, Laos continues to suffer from the effects of sub-munitions since the end of the Vietnam war. Other types of unexploded ordnance (UXO) like shells, mortars, grenades and even large bombs dropped by aircraft, are found within mined areas and elsewhere and cannot be discounted. These latter UXO are generally not as immediately dangerous as mines and sub-munitions and their clearance is normally not given as high a priority except when they are found within a mined area.

4.3 Measuring the socio-economic impact

Measuring the socio-economic impact of the mine problem in an area yields an objective input for political decision making, priority of action and funding policy. Rigour is needed to resolve conflicts about priority areas. Developing a scientific methodology would provide an objective tool to assist political decisions ([10]).

Apart from Kosovo, no databases exist on the socio-economic impact of landmines. These are however essential to understand the true impact of the mines, prioritising the work effort and making the process more efficient [11].

It is the socio-economic impact of mines in the ground, which is considered more important than the number of mines which remain to be cleared. That said, there have been few studies which have quantified the impact in real terms. One such study has been undertaken by the Mine Action Programme in Afghanistan (MAPA) based on actual experiences rather than theoretical. It is not perfect – nor does it claim to be – but it is an important piece of work [12]. The effect caused by mines in Afghanistan is a good indication of the effect in other countries. *The study suggests that even with the slow rate of manual clearance, the cost of clearance is substantially less than the cost of the mines remaining in the ground.* To substantially improve this cost-benefit is the great challenge for the next decade and a goal which should underpin the collective efforts of the international community.

5 NEED FOR BETTER TECHNOLOGIES

5.1 Current practices

Most mine clearance is undertaken using manual techniques, which are very slow, manpower intensive, dangerous and expensive. The most common and slowest manual technique is with a deminer probing the ground with a metal spike in a systematic manner making sure that there is only about 2 cm between each probe. The aim of the probe is to make contact with any mines that the deminer will then uncover for destruction. To ensure the mine is not detonated, the probe is inserted at an angle so it should not make contact with the top of the mine. This reduces the depth, which can be probed.

The fastest manual technique involves the use of a mine detector, which is carried by a deminer over the ground looking for mines. When a signal is detected the deminer will then probe the ground as explained above until the mine is found or until the signal is discredited. In suitable ground this is very much faster than probing alone. A mine detector is a metal detector, which is intended to detect any metal in mines. Unfortunately, many mines contain very little metal making them hard to find even in good ground. Most ground contains some scrap metal and even small amounts will be detected, all of which must be uncovered. Such 'false alarms' reduce the value of using mine detectors and can make their use of no value at all. In some parts of the world, the soil has a very high ferrous content, often characterised by a deep red colour. This causes a constant ringing tone in many mine detectors making them difficult to use.

An increasingly important component in the 'tool box' of equipment used to clear mines is that of machines. Many of the traditional machines owe their origin to the Second World War and before but in recent years these early designs have been improved, greatly increasing their utility. Machines for removing the often heavy vegetation covering minefields are now commonly seen in mine clearance projects and prepare the ground for clearance by manual means and can improve productivity by 100 % (NPA – Bosnia). More contentious is the use of machines, which are designed to destroy mines with little or no manual support. Potentially these have a very high productivity in relation to manual methods alone but have generally not been considered good enough to meet the quality output of 99.6% demanded by the UN standards [13]. Recently some machines have been used in specific circumstances with considerable success but their use is by no means widespread. It is quite probable that the greatest productivity gain in clearing mines will be through the use of such machines yet it remains a very under-investigated area.

5.2 Cost per demined area – an important parameter for measuring efficiency of new technology

The Price per cleared sq.m is one of the parameters for comparison of new versus existing technology. Although accurate information is difficult to get, partially due to the large variety of operational procedures, local circumstances, ways of calculating, scenarios, levels of salaries, etc., some examples of average figures over reasonably large areas have been assembled allowing for the establishment of an interval of realistic prices to be defined, subsequently used in the modelling study described in section 8. More information as to the origin of the numbers is given in ANNEX 3.

Afghanistan 0.65 Euro/sq.m
Croatia 1.02 –3.06 Euro/sq.m
International Trust Fund (Kosovo) 4DM/sq.m is the average price at which current contracts are awarded
Mechem 0.20- 5.50 US$/sq.m; See ANNEX 3 for table giving figures as a function of used technology and scenario
Fédération Suisse de Deminage (FSD) Informally communicated numbers: Croatia (CROMAC) - desired cost 3 DM/sq.m. This is too low for ensuring security (7DM/sqm is what FSD charges)
ABC Informally communicated numbers: "prices are pushed too low" (4-6 DM/sq.m)

5.3 Data needed for cost and time estimation to meet EU objectives with present technologies

When the number of mines is unknown and whilst there are so many variables involved in clearing them, it is impossible to predict with any certainty the resources needed to rid the world of mines. There are however two near certainties; firstly, mines will remain long after the 2010 target set by the United States and, secondly, donor funding will decline and may even end long before the task is complete. There is, therefore, a clear need to make best use of the available resources – namely money and time – to benefit the greatest number of people. This may involve some new and radical thinking, particularly by the demining community but it also puts pressure on the R&D community to bring forward their work to provide benefit within the next 5-6 years.

There is an obvious need to prioritise the mines which requiring clearing so that, at least, the most serious can be cleared. Many countries have undertaken some form of prioritisation and, although such lists may lack complete support for their objectivity, they provide a starting point. It may not be unreasonable to aim to clear these highest priority mines in, say, 10 years. Of course, as priority one tasks are cleared, priority two tasks become priority one so there is an unending list of high priority tasks.

It has been shown that mechanically cutting vegetation in a minefield before manual deminers are used can improve productivity by 50% to over 100%. These machines exist and are in use. This report will also suggest that even a small reduction in the number of false alarms when using a mine detector can have a considerable beneficial effect on operational costs and time. This is a subject which requires more R&D. In addition, but rather more contentious, is the prospect of a quantum leap in productivity if mechanical demining can meet the quality of clearance required by the UN. There are a few examples where this has happened but such machines have yet to win general support within the demining community. Nevertheless, it is an area of R&D which merits much greater support. These three concepts could substantially improve productivity and thus enable more areas to be cleared.

It has already been implied that, very likely, mine action will be limited by resources and many mines will remain long after the international funding has ceased, at least at its current level. This should not come as a great surprise since, with all their money and technology, many of the EU Member States are still dealing with explosive problems resulting from both the first and second world wars. In addition to making the best use of the available resources to benefit the greatest number of people, it is also important to leave in mine affected countries a national capability able to continue the clearance of mines.

6 PROMISING NEW TECHNOLOGIES

6.1 Review of the state-of-the-art in EU related to humanitarian demining technology

For a review of the state of the art, we refer to the recent study [6]. The EUDEM study has tried to make *some inferences about the maturity of the mine detection technologies, as well as their cost*. The resulting summarising table is undoubtedly subjective, and open for criticism, because (i) it relies on indirect evidence due to the absence of well established definitions of equipment performance, (ii) most of the results of independent performance tests are not publicly available, (iii) the conducted performance tests were not carried out by the authors themselves, and (iv) the authors do not share the practical experience of deminers working in the field.

Technological maturity, as used in the table, should be interpreted as a qualitative measure expressing a mixture of the:

- State of advancement of the R&D
- Demonstration of detection capabilities useful for humanitarian demining
- Demonstration of building a practical system.

Cost includes technological cost only; i.e. does not take into account the actual productivity in the field.

Needless to say, *innovation* can very well come from technologies other than the ones listed below, for example other trace explosive sensors, or acoustical/seismic detection systems, X-ray backscatter techniques, fluorescence imaging, bulk explosive detectors, etc.

Sensor technology	**Maturity**	**Cost**	Comments
Dogs	H	H-HH	Used in practice
Prodding/Excavation	H	LL	Used in practice
Magnetic devices	H	M	Used in practice (Magnetometers, Gradiometers)
Metal detectors	H	L	Used in practice EU projects: MACADAM, DREAM, INFIELD, HOPE, PICE, GEODE, MINESEYE
Metal detector Array	H	H-HH	Used in practice EU projects: GEODE, LOTUS
Passive mm. micro wave	L-M	HH	EU projects: INFIELD, HOPE,
mm wave radar	L	HH	Cost figure based on lab equipment
Passive infrared	M-H	H	Cost is decreasing EU projects: MACADAM, GEODE, LOTUS

Polarised infrared	M	HH	EU projects: DREAM
Multispectral	L	HH	
Ground Penetrating Radar (GPR)	H	M-H	EU projects: MACADAM, DREAM, INFIELD, DEMINE, HOPE, PICE, MINEREC, GEODE, LOTUS
Ultra-wideband radar (UWB)	L-M	H-HH	
GPR Array	M-H	HH	
Nuclear Quadrupole Resonance (NQR)	M	H	
Thermal Neutron Analysis (TNA)	M	HH	
Fast Neutron Analysis (FNA)	L-M	HH	EU project: MINESEYE
Ion Mobility Spectrometer (IMS)	M	M-H	
Biosensor	M-H	M	

(Qualitative) Maturity and Cost evaluation for various technologies. Maturity indication ranges from Low (L) to Medium (M) up to High (H); Cost indication uses L ≈ 4000 EURO (price of a high end metal detector), M ≈ 2 to 5 times L, H ≈ 5 to 10 times L, and HH >10 times L. [6]. The EU projects using certain detectors are listed in the "Comments" column (G. Basso / EU-IST)

The problem of mine and minefield detection continues to provide a significant challenge to sensor systems. Although various sensor technologies may excel in certain situations, there does not exist a single sensor technology that can adequately detect mines in all conditions such as time of day, weather, buried or surface laid, etc. A truly robust mine detection system will likely require the fusion of data from multiple sensor technologies. The performance of these systems, however, will ultimately depend on the performance of the individual sensors. *That is why new (smart) sensor technologies have to remain an important topic of research for at least 10 years.*

Although no systematic search for promising technology could be done after the end of the EUDEM project (July99), and although the limited size of the current strategic study does not allow for it, a few recent evolutions were found worth noting:

In **IR technology,** advancement is primarily characterised by the increasing amount of parameters measured in the near IR and the two thermal IR wavelength intervals (e.g. 3 to 4 polarisation image components, multispectral band splitting, fluorescence imaging induced by active illumination, reflectivity measurements under active illumination, combined IR imaging and range imaging based on laserscanning, various stimulus response methods based on microwave heating, halogen lamps, and even hot waterjets). By introducing this kind of multicomponent imaging, the well-known sources of uncontrollable variability of IR imaging might be overcome. A second research trend is the exploitation of temporal behaviour changes in the images when the platform moves or when the (natural) illumination changes. Combining both multitemporal and multiparemeter images looks like an interesting idea to investigate. More information on IR techniques related to humanitarian demining can be found in ANNEX 4. **Nuclear Quadrupole Resonance techniques** are absent in the current European Commission projects. The technique seems to be gaining popularity for being integrated in multisensor probes as confirmatory devices, although it appears to have limitations. The sensitivity has reached the point needed to be useful for explosive detection in the context of antipersonnel mine detection. Tests are currently being executed in Bosnia. **Neutron activation (TNA/FNA)** in humanitarian demining is a spin-off coming from safety/surveillance applications (e.g. in airports – the ESPRIT/IST project MINESEYE). Simulations indicate that the sensitivity is high enough for APL detection, at reasonable power consumption. Safety aspects have been shown to be acceptable. **X-ray spectroscopic backscatter** techniques have been studied with respect to detecting depleted Uranium polluting several post-conflict areas in Kosovo. The same kinds of techniques have been reported for explosive detection. Several spin-offs of **biotechnology research** are being mentioned lately: e.g. bacteria exhibiting fluorescence when confronted with certain molecules, … A new **X-ray/fluorescence** principle for detecting the presence of mines was reported in a recent SPIE newsletter. Although no convincing and thoroughly cross-checked results of **data fusion** have yet been demonstrated, the ESPRIT/IST project HOPE reports that data fusion at "pixel" level between GPR, MD and a passive microwave radiometer is within reach in the coming year.

The real potential impact of the new evolutions, spotted after the end of the EUDEM study [6], cannot be established without a systematic ***Technology Watch*** (see Section 6.2.3). It must also be clear that the limited scope of the current strategic study does not allow for any degree of exhaustiveness. The main benefits from a systematic *Technology Watch* will probably come from the identification of equipment that has reached maturity in other application domains than humanitarian demining, and the analysis of its capabilities to be adapted to the particular requirements of humanitarian demining.

6.2 <u>Technologies addressing various markets</u>

6.2.1 Overview of appropriate military R&D and its potential for transfer to humanitarian use

There is a great potential for co-operation between the *military and the humanitarian mine clearance communities.* Operations such as those in Bosnia and Kosovo demonstrate situations where both are working quite closely together and, although their objectives may be different, each can benefit from the support of the other.

Anecdotal evidence suggests that the military spends considerably more on mine clearance R&D than is possible by the humanitarian community. However, the latter has considerably more experience in the clearance of mines and the combination of these two elements – money and experience – is a potent mix and could provide value for both.

Potentially, the greatest benefit of this co-operation will come from the work into improved detectors where the military and the humanitarian community have broadly similar needs. There are military airborne and vehicle-borne detection programmes that could provide wider benefits. Hand-held detectors are a common tool with very little difference in the military and non-military versions. Yet both suffer from the problems outlined above of locating mines – particularly minimum-metal mines – in a metallic soil. There may be other less visible military research projects where technology could be shared but the potential utility is not recognised.

Although mechanical demining requires more research, the military has less to offer, and the potential from this co-operation is much less.

6.2.2 Technology Transfer from other Applications into Humanitarian Demining

It is well recognised how ***military procedures and technology*** have influenced, through a relatively long process of adaptation, the field of humanitarian demining, but ***other domains are also providing new insights***, like non destructive testing, signal/image processing, remote sensing, Geographic Information Systems, medical imaging, etc. These other domains were included in the EUDEM study [6], containing the list of actors claiming to develop new technological applications, but admitting not to be active yet in humanitarian demining. In our opinion, it is useful to closely monitor these developments, so that specific humanitarian demining tests can be carried out once the technology has reached maturity in other application domains. This monitoring could be done in a ***Technology Watch*** *Accompanying Measure* which is described in more detail in the recommendations (Section 10.3.4)

6.2.2.1 Opportunities and Difficulties relating to close-in detection

An SME strategy is usually focused on one or a few well-defined target markets to ensure economic viability. In the case of mine detection many application areas are relying on the same type of generic “object detection” technology, e.g. pipe detection, detection of bodies in avalanches, thematic mapping of the underground, support for police investigations, forensic applications, and others. The majority of the market opportunities in these areas are usually created by governmental organisations with little consistency in their purchase strategy. Penetrating new segments of this fragmented market is not only a purely commercial problem, but depends heavily on unpredictable political priorities. Each of these applications require appropriate user interfacing and signal processing to turn the “generic object” detector into a “specific object” (bring down the False Alarm Rate) detector, which requires more than simple re-engineering. Seeing equipment as a combination of hardware and software, it is often the software complexity that causes the impossibility for SME’s to envisage market extension for their products.
This reasoning, collected in an interview within the current strategic study, might be different for techniques directly identifying the explosives. But also here, at least a substantial amount of re-engineering is needed for (1) achieving a sensitivity in accordance to the amount of explosive that has to be detected, (2) meeting the requirements of operation in the field, and (3) obtaining the needed specificity to cope with operational variability.

6.2.2.2 Opportunities for exploitation of high resolution satellite imagery in humanitarian demining

In this field there is an ongoing, interesting initiative that is worth mentioning. High-resolution satellite imagery has been, for a long a time, an area of military interest and activity. Most of the data are classified and inaccessible for civil applications. However, a generalised worldwide tendency exists to look for economic and humanitarian exploitation of these data in various applications.

This also opens interesting perspectives for humanitarian demining, and particularly in the context of the mine problem in the Balkan area. Analysis of the needs expressed by local demining organisations reveals that there is primarily a need for *good, detailed and reliable maps*. It is feasible to generate these maps, starting from high-resolution satellite image data. Although the original image data are classified, the maps can be released to representatives of the afflicted nations (e.g. Bosnia, Croatia, etc.) to be used by local experts. In this context, a “Clearing House” for information and data gathering and dissemination is being envisaged.

Also high-resolution data for civil applications are being produced and disseminated: the high-resolution IKONOS data are publicly available on payment. The viability of the IKONOS set-up seems to be largely dependent on NIMA (National Imagery and Mapping Agency – see www.nima.mil) who guarantees buying Ikonos data and who processes them for third parties, e.g. UNESCO. Although buying IKONOS data is extremely expensive for a nation wide coverage, the price of it is affordable when seen as part of the Level 2 Survey cost of a local area. At this stage, no estimates are available as to which degree these results can reduce costs of Level 1 and Level 2 surveys.

Although an extra economical validation of existing high resolution satellite image data would be welcome, the feasibility of application to humanitarian demining should be carefully investigated and R&D is needed to guarantee optimal exploitation. The initiative, is worth supporting, taking into account that it clearly goes beyond the limited European scale.

6.2.3 Technology Watch

Considering that the market for humanitarian demining equipment is very limited and identifying a lack of interest from large companies in making the considerable investments for developing and productionising the results of R&D, a pro-active measure is required for identifying transferable technologies from other application domains towards humanitarian demining. Analysis of the various ongoing initiatives aiming at increasing the overall efficiency of humanitarian demining, reveals that none of them includes a co-ordinated and continuous effort to address this issue. Therefore the current Strategic Study proposes, as a recommendation, to start an *Accompanying Measure* on *Technology Watch* (see Section 10.3.4), based on the following argumentation:

- The variety of tasks required in Mine Clearance Operations, and the structuring of their goals as expressed in UN international Standards for Humanitarian Mine Clearance Operations (see section 3.1.1) opens perspectives for brand new technology approaches.
- Current Information Systems (as described in Section 3.1.4) insufficiently take into account equipment and technology, while this is a prerequisite for bringing them up to a level where they also could be used as planning tools.
- The expected long timeframe (5-6 year) for bringing the multisensor hand-held systems currently emerging from R&D up to industrialisation and deployment in the field (see Sections 10.4.1.4 and 10.4.2.4) is a good motivation for investigating completely new approaches based on mature technology from other application domains.
- The limited market for technology specifically developed for humanitarian demining, calls for technologies that can address wider application fields and that can be tuned or modified towards the needs of humanitarian demining.

7 R&D PROGRAMMES FOR TECHNOLOGY DEVELOPMENT

7.1 Overview of other leading R&D programmes (e.g., the US/DoD initiative)

The tasks an information flow within the co-ordinating US Interdepartmental working group are given in [17]. A small-scale analysis of ongoing Government funded R&D projects in the US was carried out in the context of the EUDEM study in 1999. The results can be found in Annex 5 of the final report [6].

The Humanitarian Demining Technologies Program Office in the Countermine Division of the US Army Night Vision Electronic Sensor Directorate (NVESD) has sponsored more than 120 demining R&D projects since the programme began in 1995. These have been mechanical concepts and others on the technical applications of mine detection and clearance. 21 have been selected for development. In 1998, NVESD managed US$16.6 million in demining R&D. In May 1997, the Department of Defense (DoD) created the Unexploded Ordnance Center of Excellence at Fort Belvoir, Virginia, to co-ordinate the requirements and technologies for detecting and clearing UXO, including landmines. In October 1997, DoD established the Joint UXO Co-ordination Office, the action arm of the UXO Steering Committee, to share expertise and data in co-operative multinational exchange programmes.

The US has provided a significant amount of money for demining and mine awareness programmes. It provides demining assistance under the US Humanitarian Demining Program which was set up in 1993. According to its own calculations, the US has committed US$236 million to this programme since its inception. This includes US$63 million for Pentagon R&D programmes for ‘rapid prototyping and field testing of demining equipment’ (see [14], p 337). Although there has been some criticism that the US has focussed too much funding on research of futuristic technologies (see [14], p 341), the NVESD claims to have designed, developed, and demonstrated many short-term, low risk, and practical solutions for mine detection, mine clearance and neutralisation, individual tools, and mines awareness and training. The individual projects are made public each year and, for the projects in the fiscal year 1997, there is no evidence of futuristic R&D – it is largely down-to-earth and making use of commercial-off-the-shelf (COTS) technologies. This is well demonstrated in the latest brochure showing the R&D projects [15].

It is worth noting that an agreed mechanism for R&D co-operation between the European Union and the DoD of the United States exists, namely DTIF (Demining Technology Information Forum).

7.2 Hand-held, vehicle based and airborne platforms

It has to be emphasised that the cost figures reported in this section summarise the informed opinions of only two developers. They should be seen as no more than informal estimates. Crosschecking reveals that others mention numbers in the same order of magnitude within a factor of 2, both for the hand-held and the vehicle-borne systems.

7.2.1 Costs and time scale to production for representative handheld and vehicle-borne systems

To quantify the investment costs and time scale required to put a representative new detection system on the market, the developers of two dual-sensor systems have been consulted. Both systems are based on *the fusion of an advanced metal detector with an advanced GPR*. One system is hand-held and the other is configured to be fitted on to a range of suitable vehicles.
By basing these systems on a metal detector, much of the technical risk is reduced insofar as the detection probability of mines will probably be no lower than the performance accepted in present practice. The principal technical risk resides mainly in the extent to which the fused sensors will give a sufficiently lower false alarm rate to justify the purchase of the dual-sensor system in preference to the metal detector.

The justification for basing these two multi-sensor systems on a metal detector is that the majority of anti-personnel mines that need to be cleared at the present time contain enough metal to be detected by a modern metal detector. However, it is known that totally metal-free mines can be produced and it is to be expected that they will be deployed somewhere at some time in the future. If and when this occurs, the GPRs in these two representative systems will be required to detect these metal-free mines as well as rejecting false alarms.

7.2.1.1 Hand-held System

This dual-sensor system is based on an existing and proven metal detector and a GPR using current technology.
The cost to produce a system demonstrator for preliminary testing is estimated to be in the range 400–800 kEuro. This demonstrator would then need to be tested on a trial site. If these trials proved encouraging, then the system would be productionised including EMC testing, environmental proving, etc. To undergo these

further trials would entail the manufacture of some 6 pre-production units. The cost to manufacturing the first production units is estimated to be in the range 700-4,000 kEuro. The overall timescale to production is estimated to be 4-5 years and the unit production cost is 10 kEuro.

7.2.1.2 Vehicle-borne System

The vehicle-borne system, taken as representative, incorporates an IR camera – but this element has been subtracted from the contractor's estimates of cost.
The overall time to develop and test a pre-production model is estimated to be 2 years and to cost about 9 MEuro. The overall cost, including trials and productionisation is estimated to be 13-18 MEuro and the unit production price, including a vehicle, for batches of 10 units is given as 1-2 MEuro.

7.2.1.3 Purchase Prices of Hand-Held and Vehicle-borne systems

The following conclusions are based on the figures quoted above and reflect the cost to the purchaser if he limits his purchase (at least, in the first instance) to specific batch sizes and if the whole of the development and production costs are carried by these initial batches.

Hand-Held System

Number of units	Price in MEuro	Price/system in kEuro/unit
100	1.7 to 5	17.0 to 50
1000	10.7 to 14	10.7 to 14

Vehicle-Borne System

Number of units	Price in MEUR	Price/system in Meuro/unit
5	18 to 28	3.6 to 5.6
10	23 to 38	2.3 to 3.8

7.2.1.4 Airborne systems

Two well known demonstrator systems, among others, are: REMIDS - REmote MInefield Detection System (UK), ASTAMIDS - Airborne STAnd-off MInefield Detection System (US) that has been renamed LAMD – Light Airborne Mine Detector (more information can be found via [6]. At this stage the productionisation costs are not known. Performance has not yet been sufficiently demonstrated, and the cost/benefit potential is high but far from certain at this stage.

In a purely civilian Pilot Project supported by the EU: DG8 (Pilot project: Airborne Minefield Detection in Mozambique 1998-1999) a campaign was organised in Mozambique, after several test flights over a testfield in Belgium (Leopoldsburg). Although the final report of this project has not yet been made available, globally the following conclusion can be made:

(1) all minefields in the four Mozambique areas (selected on the basis of diversity in type of terrain) were identified and two unregistered extensions of minefield boundaries were identified,
(2) the system cannot guarantee reliable area reduction – i.e. it cannot be excluded that there are minefields in the areas where nothing abnormal was detected,
(3) the accuracy of the achieved minefield delineation has not been quantified,
(4) the results remain to be evaluated by an independent test (within the project the same group of people that collected the ground truth information was also involved in the image interpretation),
(5) the main off-line image analysis results were obtained by human operators, skilled in visual interpretation of remote sensing images,
(6) all results are based on the analysis of indirect minefield indicators (i.e. poles, fencings, trenches, roads, buildings, periodic patterns, terrain analysis, knowledge about the local armed conflicts, buildings, animal trails, etc..),
(7) automated image analysis has shown its usefulness in drawing attention to features which are not easily detectable by humans (e.g. hidden periodic patterns, very thin trails and paths, segmentation in zones of homogeneous texture)
(8) there is no indication yet that the operational system and methods can be extrapolated to other surroundings,
(9) the cost is prohibitively high (this is also partly explained by the high development and research component needed for this first civilian trial); the European Commission part funded the project with an

amount of 1.6Meuro and the participating countries together with the individual partners invested at least an equal amount

(10) locally operating NGOs have found the air photographs useful in getting a better insight of the overall topology of the area

(11) Although a lot of experience has been acquired in this isolated experiment, an R&D phase consolidating this know-how is needed to develop a *system* for minefield detection:

- image analysis aimed at designing computer support tools for human interpreters, mainly for local image enhancement, drawing attention to features which are not easily observed by the human visual system (e.g. global spatially distributed features, or detailed information at the level of a few pixels); the results have to be integrated in an interactive system involving the interaction between automated image analysis procedures and the image interpreter.
- further exploration of change detection before and after the conflict,
- campaigns, limited in size, should be carried out with new sensors that have not been investigated yet,
- improvements should be made in co-registration and time synchronisation of the acquired data to allow for data fusion,
- platforms other than aircrafts should be investigated
- the use of high resolution satellite data and change detection before the campaign should be studied.

An R&D phase consolidating the acquired know-how is needed to develop a *system* for minefield detection.

8 ECONOMIC MODELS OF THE BENEFITS OF IMPROVED DETECTION EQUIPMENT

8.1 Introduction

Two simple analyses have been made to estimate the reduction in the cost of detecting and lifting mines using improved detection systems. Both analyses use data and evidence culled from mine clearance organisations (ANNEX 5). These figures vary from operation to operation but due cognisance has been taken of these spreads. Both analyses produce results which are referenced to the corresponding figures for modern metal detectors as used at present.

- ***Reference Scenario***

The model is based on the following scenario. Any overlying vegetation has been cleared and trip-wires removed. The problem, therefore, is to detect and clear the remaining mines, many of which will be buried.

At the present time, most mines contain enough metal to be detected with adequate reliability in suitable soils by the current range of hand-held metal detectors. But the problem with metal detectors is the fact that with every mine there are often many pieces of metal detritus that are also detected which have to be lifted with the same care as if they were real mines. This can slow down the clearance process considerably.

8.2 Reduction in running costs

This analysis is applicable to any type of new detection system and estimates the reduction in running costs for detection and lifting as a function of the technical performance of the new system. The analysis is presented in ANNEX 6. Although the analysis is very simple, it does not appear to have been done before and produces the following important conclusions.

- ***Conclusions***

1) Speeding-up the search phase yields only small reductions in running costs.

2) Relatively modest reductions in the false alarm rate, however, yield valuable reductions in running cost. This reduction in false alarm rate is obtained by improving the discrimination by the sensors against a larger proportion of detritus.

3) Conclusion (1) above throws into question the justification of vehicle-borne systems for close-in detection and clearance. However, it is likely that this type of system will prove useful for Quality Control and for clearance in some specific scenarios, like roads.

Conclusion (2) is consistent with the tacit assumptions used to justify the programmes on multi-sensor hand-held systems. The integration of a GPR with a metal detector, for example, can be expected to enable the operator to use the GPR to reject small objects which alarm the metal detector – and with little reduction in search speed. Detritus that would otherwise alarm the metal detector alone but which would be excluded by the GPR include objects such as bullets, pieces of shrapnel, coins, etc.

It is clear that all proposals for work on new detection systems should be based on a convincing economic model – preferably more realistic than the one presented in ANNEX 6.

8.3 Reduction in overall costs

This analysis extends the one above (Section 8.2) to include considerations of the purchase price and service lifetime of the equipments and the wages of the detection and lifting operators.

The analysis is presented in ANNEX 7. In order to provide a realistic estimate of the purchase price of a new detection system, the model was constructed on the basis that the new equipment was the hand-held dual-sensor system for which a developer has provided estimates (Section 7.2.1.3). However, as is shown in ANNEX 7, the actual purchase price has little impact on the cost/sq.m of clearance and the following conclusions are broadly applicable to any type of new system.

- ***Conclusions***

1) The purchase price of the present metal detector and of the dual-sensor system have very little impact on the cost of detection and lifting when amortised over the 4 year lifetime assumed.

2) Allowing for the purchase price and lifetime of a modern hand-held metal detector, in central Europe, detection and lifting costs lie between 1 and 28 Euro/sq.m, depending on the particular scenario being cleared. (Note that the higher of these two figures relates to particularly difficult and small areas in central Europe and is not an average over the large areas which form the basis for the lower figures cited in Section 5.2).

3) Provided that the hand-held dual sensor system reduces the false alarm rate by a factor of 2 or more without reducing the search rate by more than about 4 times, the cost/sq.m will be less than about 60% of that when using the metal detector alone, both systems operating in the most onerous conditions.

4) This conclusion applies even when the dual-sensor system is one of the first batch produced and costs as much as 50 kEuro per unit (compared with 4 kEuro per unit for the metal detector, also cited in Section 7.1).

5) Even if the dual-sensor system searches at a rather lower rate than the metal detector, it has relatively little effect on the cost/sq.m, particularly under the most onerous conditions.

6) In summary, under all operational conditions, reducing the false alarm leads to a significant reduction in the cost/sq.m of detection and lifting.

9 LESSONS LEARNED FROM ESPRIT/IST RT&D PROJECTS

The following is a commentary on the experience to date; proactive proposals arising from this experience are presented as recommendations in Section 10.2.

1) Consortia have been very reluctant to present comprehensive trials results. This may be to protect their IPR but is more likely to be due to the poor results obtained to date.

2) Attempts by the JRC to establish target signature databases have not proved useful. The databases for metal detectors record only the outputs of the detectors. Data derived for other classes of sensors are at a more fundamental level but remain specific to the parameters of the instrumentation equipment used to gather the data. To transform data from a sensor with one set of design parameters to a hypothetical sensor of the same class but with different parameters is likely to be extremely difficult and little progress has yet been made in this area.

3) For systems based on new detection principles, it has been shown that the sizes of trials that can be afforded during the research and early development phases cannot establish the detection performance with confidence [16]. Industry is therefore confronted with the difficult decision as to whether to continue to fund the ever-increasing cost of development and certification when it can have only limited conviction of the true performance of the system.

4) For systems based on new technologies, it has been shown in [16] that, before acceptance, they should undergo acceptance trials against a considerable number of mines and pieces of detritus. This acceptance phase will be expensive in time and money. At the worst, it could show that the extremely-demanding performance required has not been met and that the system must be abandoned.

5) The concept of the Network of Excellence (ARIS) should be developed and maintained in order to distribute data on the threat, the threat magnitude, the results of trials and market surveys, initiatives by NGOs and governments, working papers on relevant issues, announcements of workshops and conferences and details of principal organisations and experts working in the area. In its implementation the project was too slow at start-up. It is only recently that an active attitude has demonstrated the usefulness of the Network for the community.

6) In the embryonic field of new close-in detection systems, attempts at equipment standardisation in general are likely to be more of an impediment than a help. An important exception, however, is in the area of acceptance trials where a suite of standards would be extremely helpful to the customers when purchasing equipment and to the sources of funds for the development of new systems.

7) End Users are required to be part of RT&D project, but they need to be given a greater responsibility in all the phases of project development to ensure continuing realism. The active participation of the end users in projects should be required to be reflected in dedicated sections of progress reports.

10 RECOMMENDATIONS

10.1 <u>General</u>

10.1.1 The role of fundamental research, research institutes and universities

Recently, a note emanating from EU Commissioner for Research, Ph. Busquin, was spread around for triggering a large debate on the subject “Towards a European Research Area (ERA)”. Key elements for discussion are: co-ordination of the research of the member states, the creation of distributed (virtual) centres of excellence, common values behind science and technology, the importance of fundamental research. Although globally the acknowledgement of the importance of fundamental research was welcomed, it was felt that its role was insufficiently worked out. Also severe criticism was formulated on the co-ordination of national research, because the danger exists that this would create an extra layer of bureaucracy.
As a reply to the demand for positive response to the above mentioned note we recommend for the specific case of humanitarian demining the implementation of a specific European Research Area, because at present:

- the fragmentation of the research is a severe bottleneck for further progress
- there is a clear well-specified common goal, namely “Progress in Humanitarian/ Sustainable Demining”
- the urgency of getting results is motivated by ethical and moral reasons that are generally accepted
- there is a large community of fundamental scientists that can contribute to new technology
- the goal oriented process from fundamental research, applied research, development, testing and application in the field needs a continuous interaction
- dialogue will create a research/users community closely collaborating towards the commonly established goal

10.1.2 Specific R&D on mechanical equipment

As a matter of urgency, the European Commission should identify a mechanism by which the R&D of a range of mechanical equipment concepts can be funded and implemented. The considerable potential of such concepts to provide a quantum leap in productivity should not be ignored.

10.2 RT&D projects

1) Sensor Fusion has not progressed beyond the elementary stage of combining the outputs of various sensors. Better results would be expected by using signals (features) available in the pre-detection processing of the individual sensors. This proper approach should be required in all proposals for future multi-sensor programmes.

2) In consortia where sensors are provided by sub-contractors, it follows that the pre-detection signals will not be made available so that proper sensor fusion work cannot be undertaken. In all consortia proposing multi-sensor solutions, it should be required that the sensors should be provided by partners in the consortium and not by sub-contractors.

3) For vehicle-borne systems, Human Factors has received very little attention to date. If no proper attention is given to this aspect in future proposals, the risk exists that vehicle-borne systems for close-in detection will be slowed-down by the human operator to a level comparable to that of a hand-held system. Proper attention to the human factors aspects should be required in all future proposals.

4) When proposing a new project, the consortium should be required to present the design of the trials to be undertaken and to specify the criteria against which the success of the work will be judged.

5) Before agreeing to support any future projects, the European Commission should require the consortium to present a proper justification of their proposal, including a realistic assessment of the development and trials costs, risks, timescales and return on investment. These justifications should be evaluated by relevant experts in much more depth than current practice allows. As the result of such evaluation there will often be the need for the proposal to be revised - and the current practices need to be amended to permit such iteration.

6) The monitoring of progress on projects funded in part by the European Commission should be done using proper management tools. In particular, the use of Critical Path Analysis should be insisted upon.

10.3 Accompanying measures

10.3.1 Technical-Economic Systems Study

10.3.1.1 Introduction

Despite the relatively large funds that have been spent on research into new methods for detecting anti-personnel mines, there is a dearth of knowledge of the impact upon the design requirements by many economic issues.

It is proposed that, as a matter of urgency, a suitable systems analysis organisation, or a consortium of such organisations, should be contracted to undertake such a Study, some of the details of which are outlined below.

The results of these analyses and the identification of the principal factors are essential knowledge for prospective customers and manufacturers contemplating the research, development, certification, productionisation and manufacture of new detection systems. The preliminary results should therefore be made available to all interested parties as soon as they are reported. This Study should also draw up the Certification procedures and standards required for new systems, as mentioned in ANNEX 8.

An outline of the topics to be covered by this study is given in ANNEX 8.

10.3.1.2 Funding and Timescale

The quantitative results of this study are central to advising the manufacturers and customers of the rewards and benefits for producing and using more effective equipments. The results should be published widely and so the study should receive 100% funding from the European Commission.

It is expected that an indication of the key results should be available 12 months after commencement – and this figure will be assumed below. However, there is little doubt that as the technology of mine clearance evolves, new issues will emerge so that the economic model will require amendment and refinement over a longer period.

It is roughly estimated that the work comprising the first 12 months will engage some 8 professional staff and so cost in the order of 1 MEuro. Subsequent work would be conducted at a much lower level of effort and cost about 200 kEuro/annum.

10.3.2 Adjudicated Trials of Candidate Systems

10.3.2.1 Introduction

As has been made clear above, relatively large trials are required in order to establish the technical performance of a new detection system, the cost of which is another factor inhibiting investment by industry. It is proposed that the European Commission should establish a suitable trials site and procedures in order that it can evaluate candidate systems and then act accordingly. This facility could be justified on this basis alone but would be essential if either of the two further recommendations is adopted (See Sections 10.4.1and 10.4.2).

Insofar as this site would be used solely for quantifying the performance of detectors at the demonstrator stage or beyond, there would be no need for concrete tracks, overhanging gantries or facilities for monitoring the environmental conditions.

The candidate systems that would be tested on this site would range from advanced metal detectors and novel sensors through to multi-sensor systems using data fusion.

10.3.2.2 Size, Seeding and Funding of Trials Site

The requirements for a suitable trials site are given in some detail in ANNEX 9.

It is concluded there that the site should occupy about 10,000 sq.m and be divided into a number of equal areas to permit a number of systems to be tested in parallel. The site would be seeded with about 1,000 surrogate mines and some 20,000 pieces of metallic detritus. These pieces of detritus would preferably be things that have actually caused false alarms in metal detectors in the field and will have been collected from the clearance operators for this purpose. It is proposed that Trials Site should be designed and constructed within 1 year.
This will involve some intensive work in a variety of areas. Preferably, the Trials Site should be within one facility although the sub-sites could be funded separately by participating nations. The funding required from the European Commission is therefore difficult to estimate at this stage but is believed to be in the order of 1-2MEuro.

10.3.3 Conduct of Trials

It is proposed that each candidate system should survey the whole area on 3 separate occasions using different but trained operators on each survey.

If 5 systems are to be tested, for instance, it is estimated that the duration of the whole programme would be about 18 weeks. As each candidate system requires 1 operator and each operator would be monitored by 1 invigilator throughout the process, the testing of 5 systems would engage 10 people for the duration of the programme. The 5 invigilators would then require some further 4 weeks to complete their report. Prior to the commencement of the trials, one or more modern metal detectors would be used to confirm that they detected every surrogate mine. Allowing for contingencies, therefore, the total duration of these trials would be about 6 months. Some 5 invigilators would be required throughout at a cost to the European Commission of about 500 kEuro. The cost of the equipment operators should be shared on a 50:50 basis with the manufacturers so that the total cost to the European Commission would be about 700 kEuro.

10.3.3.1 Comment

Irrespective of the remainder of this proposal, the construction of the mid-size trials site would be of great benefit to the R&D projects supported by the EU and to European industry as a whole provided it were made available for them to use at a reasonable charge. Although not adequate to provide all the environmental scenarios in which detection equipments are to operate, it will be the first one which provides enough mines and pieces of detritus to give reasonably convincing statistical results.

10.3.4 Technology Watch

10.3.4.1 Introduction

As has been made clear in Section 6.2.3, many technologies that are currently emerging from R&D and new equipment that has reached a certain stage of maturity in other application domains have not yet been brought into relation with humanitarian demining, although they are potentially capable of triggering major breakthroughs.

The existence of this potential has been widely acknowledged by the R&D community on humanitarian demining. Workshops are being organised to bring actors of diverse domains together, but their results stay superficial due to lack of continued effort and co-ordination. Rarely the identified technologies, are analysed in sufficient depth, up to a point where a realistic project plan can be made for the transfer of know how and the study of the adaptations needed to meet the requirements of humanitarian demining. No analysis is made on the actual amount of effort required, no solid workplans are prepared, no physical feasibilty tests are organised, no systematic analysis of the possible operational procedures is made , etc.
The *Technology Watch Accompanying Measure* should help bridging the gap between identified potentials and feasibility tests as well as R&D projects.

10.3.4.2 The main objectives

The main objectives are

- ***Identifying*** and ***analysing*** technologies that are currently not directly related to landmine detection, with the aim of ***identifying the most promising ones for humanitarian demining***.
- Proposing ***workplans*** and ***identifying associated time frames*** for the transfer of the most promising technologies towards humanitarian demining.
- Concentrating on technologies that could yield ***significant breakthroughs*** in both industrial and societal terms, by ***actively involving new players from industry and academia.***

10.3.4.3 Implementation

The technology watch and assessment process should be based on an active and targeted information collection and analysis. For this process to be structured, two types of actions should be envisaged:

- a continuous, wide spectrum "background" survey,
- Successive focused analyses of specific technology areas, concentrating on each of them for a longer time frame of several months (e.g. six months per area),

To be more precise, the work carried out should consist of

- Identification of the technology areas, the main actors and information sources (existing reports, databases), by carrying out selected interviews. In-depth knowledge should be gained by expert opinions when needed for certain areas.
- Wide but controlled information dissemination to foster trust and confidence to R&D developers and possible users.
- Actions for establishing close collaboration and information exchange with other European and supranational organisations, initiated during EUDEM99, need continuation (UN, Geneva Centre, JMU, JRC, NIMA NVESD, JUXOCO, etc.). The Technology Watch study should not ignore work done in the past in related fields (consolidation of existing material, collection of references, etc.)
- Confrontation of the findings with the opinions of representatives of the end-user community

10.3.4.4 Expected results and measures of success

- ***The definition of at least one appropriate technology*** (demonstrator) for humanitarian de-mining that can undergo ***some physical feasibility testing and/or become eligible for R&D***
- Identification of technologies that are currently being mentioned with respect to their usefulness in humanitarian demining, and that turn out to be ***of limited utility or NOT applicable*** at all within the field of humanitarian demining
- Proposals for ***new combinations of physical principles with certain technologies*** for humanitarian demining
- Identification of ***new technology providers*** from the studied application domains, who are considering technology transfer into the field of humanitarian de-mining
- ***A comprehensive and technically motivated overview of the potentials*** of each technology studied.

10.4 Evaluation of developed Systems

The following *two proposals* are alternatives.

Neither proposes any shared funding by the European Commission. The competitive element is fully retained by requiring all manufacturers of candidate systems to submit them for initial trials, the results of which will determine which manufacturers will be given contracts to produce sizeable quantities for field evaluation under contracts from the European Commission.

In both of these proposals, the European Commission would carry the technical risk.

The contracts for equipments to be produced for field evaluation would be fixed-price ones with penalty clauses for late delivery.

10.4.1 Purchase of pre-production units (Proposal 1)

10.4.1.1 Introduction

The objective of this recommendation is to encourage manufacturers with promising detection systems to submit them to a competitive evaluation (as outlined above) and then for the European Commission to purchase 6 pre-production copies from the two most successful for further evaluation by clearance operators in the field. The evaluation would be undertaken using the trials area outlined above in conjunction with the model generated by the Technical-Economic Study.

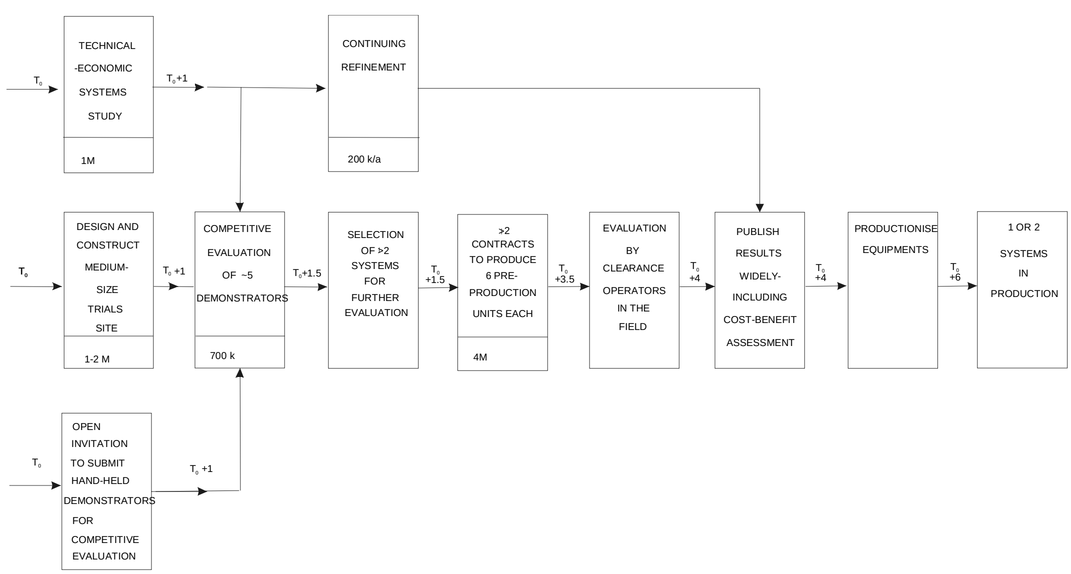

Figure 1: Flow-diagram associated to the *First Proposal*

10.4.1.2 Expected Candidates for Trial

As listed in ANNEX 10, six hand-held detection systems are being supported by the European Commission at present. All these projects are due to be completed by June 2001 and all are due to produce demonstrators.

In addition to these, it is reasonable to suppose that the manufacturers of advanced metal detectors would also wish to take the opportunity to compete using their latest models.

10.4.1.3 Estimated Timescale and Cost

Provided that the number of candidates submitted, in the event, were about 5, the duration of the trials would be the 6 months estimated in Section 10.3.3.

Prior to the start of the trials, the developers of each candidate system would be required to give a firm quotation of what they would charge the European Commission for the provision of, say, 6 pre-production prototypes for subsequent wider evaluation by mine clearance organisations.

At the conclusion of the trials, the Technical-Economic model developed during the study outlined in Section 10.3.1 would be used to rank the candidates in order of cost/benefit. Hopefully, several candidate systems would show a significant cost-benefit compared with current practice.

It is proposed, therefore, that the European Commission should place contracts with the developers of the two most promising systems for pre-production prototypes for intensive evaluation in the field.

Based on the limited information in Section 7.2.1, the cost to the European Commission for 6 pre-production models of each of two hand-held detection systems is believed to be in the order of 4 MEuro and the time taken to manufacture them would be about 2 years.

10.4.1.4 Comment

The essence of this proposal is that the European Commission should bear the risk that the pre-production models fail to perform adequately when used by mine clearance organisations working in a wide range of environmental scenarios in the field.

Providing these field trials confirm the cost-benefit and hence the marketability of the systems selected, there is little doubt that the manufacturers would fund the productionisation phase themselves.

If this proposed route were adopted, one or two fully-productionised and field-proven systems could be on the market at an economical price about 6 years after commencement.

10.4.2 Purchase of Production Units (Proposal 2)

10.4.2.1 Introduction

This proposal is a variant of that outlined in Section 10.4.1 and promises an earlier date in service.

It proposes postponing the user trials and assessments until after productionisation and then to purchase a much larger number of units which will enable a comprehensive evaluation to be made over the total spectrum of relevant operational scenarios by a variety of mine clearance organisations.

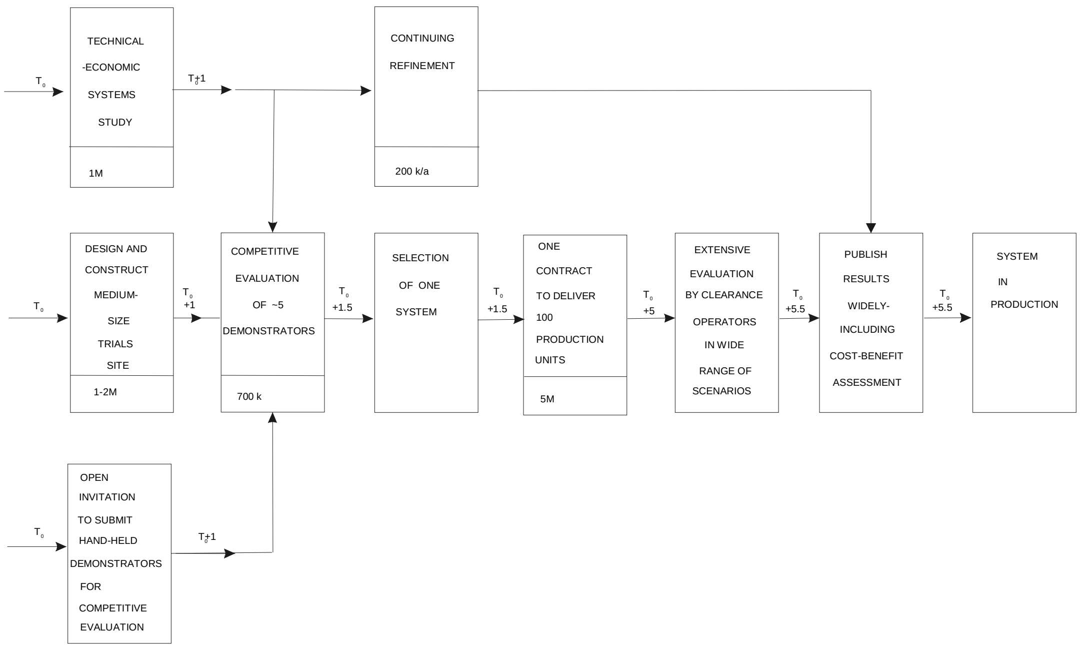

Figure 2: Flow-diagram associated to the *Second Proposal*

10.4.2.2 Purchase of Production Units for Extensive Evaluation

In order to accelerate the introduction of the most promising demonstrator candidate into useful service in the field, it is proposed that the European Commission should accept the risk of proceeding in one step and to order 100 productionised units of that system for comprehensive evaluation.

By this means, many units of the fully-developed system could be evaluated in parallel by clearance operators under a wide range of scenarios. The evaluation reports would need to be rigorous and, to this end, the clearance organisations should preferably undertake this work under contract. As the results of these extensive evaluations would be published, this proposal would comprise a very attractive incentive to the developers of the candidate demonstrators.

10.4.2.3 Timescale and Cost

Using data reported in Section 7.2.1, it is estimated that the cost of these 100 production units would be in the region of 1.7 to 5 MEuro and the time to start manufacturing them after the demonstrator trial would be about 3 to 4 years.

10.4.2.4 Comment

The advantage of this proposal is that it promises that a fully-proven and economic system will be on the market as soon as possible, probably about 5.5 years after commencement.

The risk to the European Commission is greater than in the proposal outlined in 10.4.1 insofar as only one system is selected after the mid-size trials. The principal advantage, however, is that sufficient production units will be produced for a realistic scale of testing and evaluation by clearance operators working over the whole range of environmental scenarios in the field.

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ANNEXES

ANNEX 1 <u>Information Systems: tools for better mine action, priority assessment and increased R&D producivity?</u>

In the JRC Workshop of 14 April 2000 on "Operational Needs and Equipment Requirements for Mine Action in South Eastern Europe", I. Shepherd presented the ***landcover map of EU, and the EU soil information system made in the context of agriculture and soil erosion problems (1)***. In the same workshop an information system developed by the UN Geneva International Centre for Humanitarian Demining (GICHD) was presented [18]. It was presented as ***a global planning tool for campaigns in a broad area (2)***, e.g. the Balkan (taking into account landscape, soil, seasonal climate changes, socio/political/economic context, the parameters describing the demining tasks,…). At present the system seems to have limited capabilities, and there is an ongoing debate about its release to potential users. To our opinion it should be released for testing to a limited user community as a documented tool together with the necessary warnings about misuse due to the tool limitations. ***An extended combination of the geographical information tools developed at JRC (1) and the global planning tool (2) could become a good instrument to better specify call for proposals in R&D, adapted to the political priorities of the EU***. The IMSMA (Information Management System for Mine Action) database might also be useful in the context of planning (Source: Workshop, 7-8 March 2000 "Towards harmonised Information Systems and GIS for Demining S-E Europe"). A strong recommendation was made at the Global Mine Action Information Coordination Workshop, April 19-21, 2000 at James Madison University to ***foresee a "Technology Section"*** within IMSMA.

ANNEX 2 Shared military-civilian RT&D

In [1] mention is made of Military/Civilian cooperation in the Chapter “Reinforcing EU contribution”, subparagraph “Principles”, article 30 on Military Cooperation: “synergy between military and civil capabilities in the demining field” is potentially existing. In subparagraph “Means”, article 35, specific mention is made of high resolution images (WEU), provided by NATO, and military expertise in trials of technical solutions. ***Note that no explicit mention is made of R&D***, although in practice many of the companies involved in humanitarian demining are also main players in military markets. ***Although the goals pursued in humanitarian versus military demining are very different [6], an overlapping military-civilian market exists.***

It is important to understand the extent to which the differences in humanitarian (sustainable and post conflict demining) and military objectives affect the design and requirements of mine detection and minefield delineation technology***. For the former the needs of real time operation and testing following military practice are not so relevant***. Hence *acceptance* and *ergonomy* adapted to usage by indigenous deminers and NGOs, as well as *increased performance in sensitivity at a reasonable False Alarm Rate* should be emphasised (Extracted from [6]).

ANNEX 3 Cost/sq.m of demined area estimated from ongoing demining practice

The numbers given in this ANNEX have to be seen as averages over large areas.

- **Afghanistan: 0.65 Euro/sqm**

Source: United Nations Mine Action Programme for Afghanistan; Socio Economic Impact Study of Landmines and Mine Action Operations in Afghanistan. December 1999, 35 pages.
Mine clearance operations cost 20-25 million US$ per year in Afghanistan. Between 1990-1997 the United Nations have spent on mine operation programmes in Afghanistan alone over 114 million US$. MAPA returns more than 30SqKm of cleared land to local communities per year, at a cost of 60 US cents or 0.65 € per sq.m.

- **Croatia 1.02Euro/sqm (times 2 to 3)**

Source: EUDEM interviews – not published yet; Meeting with UN MAAP personnel (Richard Todd, Head, Belinda Goslin, Project Officer, and colleagues) and CROMAC personnel (Josip Tulicic, Deputy Head), CROMAC Scientific Council personnel (Milan Bajic, Deputy President, Davor Antonic, Ministry of Interior) and CROMAC GIS personnel Zagreb, 24-28/5/1999.
The Croatian government itself invested about 10M$ in humanitarian demining during 1998, with the total investment including external sources being estimated at 15M$. About 900 trained and licensed deminers are available in Croatia, but apparently only a maximum of 300 are active at the same time. The lowest prize that has ever been obtained for demining in Croatia and Bosnia is 2 DM or 1.02 €, but usually this prize lies about 2 to 3 times higher than this.

- **Mechem**

Approximate costs (US$/sq.m) of detecting mines for MECHEM for different terrain:

Clearance type	Road	Open field	Short vegetation	Bush	Rocky
Manual MD+prodding	1.15	0.40	0.75	1.50	1.15
Heavy Flail + manual + Dogs	3	4	4	4.50	5.50
Light flail + manual	1.65	1.65	1.65		
Tiller machine + manual	4	4	4	5	5.50
Steel wheels + manual + dogs	0.40	0.40	0.40	0.50	
Sniffer Dogs (only survey)	0.55	0.20	0.40		0.60
Vapour detection survey				0.08	
Light Flail + Vehicle Mounted Detector and Mine Marker	1.50	1.50	1.50		
Steels Wheels + Vehicle Mounted Detector and Mine Marker	0.25	0.25	0.5	0.40	

- **Fédération Suisse de Déminage FSD (informally communicated numbers)**

Croatia (CROMAC): desired cost 3 DM/sq.m. This is too low for ensuring security (7DM/sqm is what FSD charged)

- **ABC (informally communicated numbers)**

Prices are pushed too low (4-6 DM/sq.m).

ANNEX 4 New developments in infrared technology

IR systems are used for the *detection of mines and minefields* (mostly AT mines) primarily on *airborne platforms*, and *stand-off detection from vehicles*, typically on roads and tracks.

Infrared (IR) cameras are normally operating in the 3-5 µm (MWIR) and/or 8-12 µm (LWIR) atmospheric windows. They are capable of detecting *mines on the surface as well as buried mines that produce a thermal contrast between the perturbed soil above the buried mine and the surroundings.* The maximum burial depth still allowing detection is estimated around 10-30 cm. ***One of the main problems associated with the use of passive IR imagery is its heavy dependency on the environmental conditions, the mines history, the soil types, moisture, material type and weather conditions***. There are even crossover periods (typically in the evening and in the morning) when the thermal contrast is negligible and the mine practically undetectable. Moreover there exist a large diversity of usually highly textured backgrounds. Due to all these reasons spatial contrast in one static IR image.

The main challenge of IR equipment is to overcome the heavy dependency on external conditions in practical applications. Two major approaches have been followed to enhance detection efficiency:

- The analysis of ***IR image sequences, showing the dynamic scene behaviour*** after or during time variant heating (e.g. solar illumination, as studied in [Schachne98]).

- The exploitation of ***extra image components*** representing various physical parameters,

    - the 3 or 4 parameters describing the ***polarisation*** (e.g. [Barbour98], [Larive99]) of the IR radiation emitted by man-made objects, as e.g. studied at DERA in the UK,

    - ***hyperspectral measurements*** obtained by splitting of the wavelength intervals.

Even a combination of both can be exploited at Frame rates of 10 frames/s (e.g. [Barnes99]). A periodical image sequence can be obtained by continuously rotating the polarisation orientation, yielding - in an ideal situation - periodically blinking man-made objects versus time-independent background.
Besides image sequence analysis and multiparameter imaging, also experiments with ***active IR systems*** are made to overcome the problem of low clutter rejection, low and variable contrasts and high dependency on uncontrollable environmental factors. The experiment, described in [Johnson98] is based on active illumination (visible up to near IR laser) combined with hyperspectral imaging (7 wavelength bands). The measured parameters are spectral reflectance, fluorescence signature, degree of polarisation, and range to target information (via range gating). It has to be noted that the results do not include thermal imaging at this stage. In the context of an airborne system [Simard98] a combination of (1) passive LWR apparent temperature measurement, (2) active LWIR reflectivity imaging and (3) 3D profiling with cm accuracy is reported A direct pixel to pixel correspondence is established.
Also microwave heating (e.g. 2.45 GHz, 5-50kW) allows for creating contrasts even for buried mines. Two mechanisms can be exploited: (1) during heating, an immediate change of the heating pattern is observed due to presence of mine; (2) after heating, an image with shape info staying there for many minutes is observed [Di Marzio99].
Various other stimuli have been investigated, but all of them are still in the domain of preliminary testing: Butane burners, Light Panels with halogen lamps [Strom98], Waterjet arrays - water temperature is 20 degrees higher than soil [Mitchell98].

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[Simard98] An airborne Far-IR minefield Imaging System (AFIRMIS): Description and Preliminary Results, J.-R. Simard, P. Mathieu, V. Larochelle, D. Bonnier (Active Systems for Surveillance and Target Acquisition Defence Research Establishment Valcartier), SPIE Conference on Detection and Remediation Technologies for Mines and Minelike Targets III, Orlando, Florida, April 1998, SPIE Vol. 3392. April 1998

[Strom98] Detection of buried land mines facilitated by actively provoked IR signature, J. Strom, B. Haugsted (Danish Defence Res. Establishment) SPIE Conference on Detection and Remediation Technologies for Mines and Minelike Targets IV, Orlando, Florida, April 1998, SPIE Vol. 3710. April 1999, pp. 167 –172

ANNEX 5 Density of false alarms detected by a modern metal detector (alarms/sq.m) Some practical estimates to support modelling

Density of False-alarms

The density of false alarms detected by a modern metal detector is very difficult to clearly specify as it depends upon many variables. The two main of which are:

1. the capability of the detector
2. the amount of metal in the ground

A detector can be made extremely sensitive so that even an invisible item of metal can be found. At times, increased sensitivity can be a disadvantage as it increases the potential for false alarms. However, if the equipment is desensitised it could miss minimum metal mines. This is the major conundrum on the use of mine detectors.

The real unknown is the amount of metal in the ground. On one hand, the ground might be laterite (oxidised soil) which creates a constant ringing in a detector. This can be overcome to some extent but at the risk of missing minimum metal mines. The most common problem is scrap metal which, because it is not a natural phenomenom - unlike laterite - it is not homogenous and varies greatly even within a small area. The realistic range which may have to be expected in general is likely to be 0.5 - 5 false alarms/sq.m. Clearly, there will be some areas where it is zero and some areas where it is much higher but as a realistic range, the above should be reasonably accurate.

Rate of search by a metal detector operator (sq.m/hour).
If there are no false alarms, then an operator could check about 100-300sq.m/hour depending upon terrain and vegetation.

Rate of digging up mines and false alarms by an operator (digs/hour).
The main consideration is that each false alarm must be treated as a potential mine until that is disproved. Each false alarm can therefore take between 5 and 15 minutes to check depending upon depth, size and hardness of the ground. Digs/hour are therefore likely to be in the range of, say, 10 - 4. In the case of an actual mine being found, this rate will reduce to 4 - 2 depending upon the procedure employed.

Are the costs/hour of these operators comparable? What are they, including all overheads?
The cost per (manual demining) operator is not necessarily the easiest method of comparison, as some agencies use two men and some only one (the second, if there are two, usually supervises the first). However, it is proving very difficult to compare costs across the range of agencies involved because they all offer something different to each other. As an example, one agency costs about Euro 28,000 per operator per annum (central Europe) if all the overheads and ancillary costs are included (vehicles, airfares etc). A very simple operation might cost Euro 8-12,000 per annum (in the Developing World) on a similar basis. To give a more meaningful comparison requires clearly defined parameters.

The price of a modern mine (metal) detector.
This can range from very cheap 'treasure hunting' devices to between Euro 4,000 and 7,000 depending upon the level of sophistication. Magnetometers can be very much more expensive, in the order of Euro 8,000 – 16,000.

The annual total of mine detectors bought world-wide.
This is not known but an estimate is between 5,000 and 10,000 (not including the military).

Lifetime of a detector.
The average lifetime of a detector can be between 3-5 years.

ANNEX 6 <u>Reduction in running costs</u>

6.1 Cost of Using Current Detectors
It will be assumed that the cost/hour of the search and lifting operators are the same at C/hour, where C includes all the relevant overheads.

It will also be assumed that the density of mines is M/sqm and that every mine is detected and that the density of false alarms is F/sqm (F is clearly a function of the types of detritus and the ability of the metal detector to reject them).

If the search operator searches at the rate of A sqm/hour, then the cost/sqm /hour will be C/A. If the lifting operator investigates and lifts mines and detected detritus at the rate of L/hour, then the cost/sqm for lifting will be $C(M+F)/L$. The total cost/sqm will thus be

$$P=C[1/A+(M+F)/L]$$

6.2 Cost of Using a New System
Suppose that the search operator uses an equipment based on new technology that enables him to search at an enhanced rate of aA sqm/hour with a false alarm rate reduced to F/f per sqm. The lifting operator will still operate at the rate of L/hour so that the total cost/sqm will be

$$N=C[1/(aA)+(M+F/f)/L]$$

6.3 Reduction in Cost of Using New System
The cost/sqm using the new equipment will be N/P times that using the current equipment.

The values for the parameters used above are very dependent upon the scenario of the area being cleared. Representative values and ranges experienced in practice are:-

A = 100-300 sqm/hour in the absence of false alarms
L = 4-10/hour for false alarms and 2-4/hour for actual mines
M = 0 to possibly 1/sqm
F = 0.5-5/sqm

From the equations developed above and inserting the extreme values listed above,

$$P/C = 1/(100\text{->}300) + (0\text{->}1)/(4\text{->}10) + (0.5\text{->}5)/(4\text{->}10)$$

The minimum and maximum values of P are therefore $P(\min) = 0.053C$ and
$P(\max) = 1.51C$, respectively.

Using the corresponding extreme values, the minimum value for N, $N(\min)$ is given by

$$N(\min)/C = 1/300a + 1/20f$$

While the maximum value, $N(\max)$, is given by

$$N(\max)/C = 1/100a + 1/4 + 5/4f$$

Graphs showing the reduction in running costs corresponding to the extreme conditions are given in the figures below:

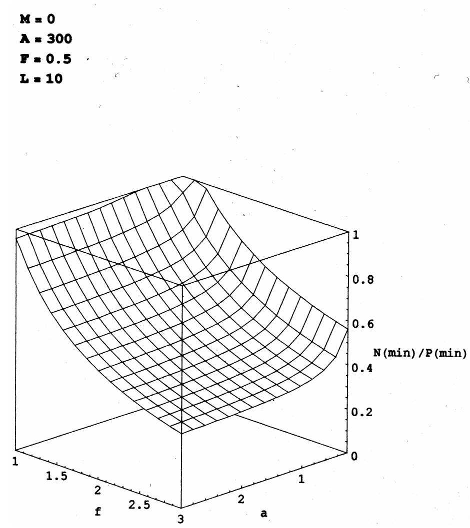

Figure 3: reduction of running cost for *N*(min)/*P*(min)

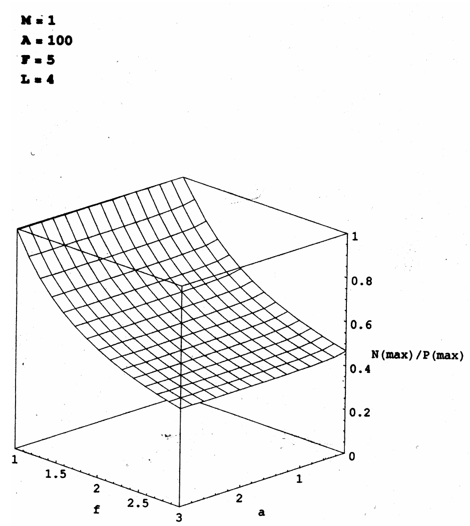

Figure 4: reduction of running cost for *N*(max)/*P*(max)

Over the range of parameters quoted above, a rough summary is that *N/P* is very insensitive to an increase in the search rate but falls rapidly with a reduction in the false alarm rate offered by the new system.

ANNEX 7 <u>Reduction in overall costs</u>

7.1 Metal Detector
This justification will be referenced to the modern hand-held metal detector costing *S*. The service lifetime will be denoted as *Y* years. It will be assumed that the cost/ann of a search operator and a lifting operator are the same at *K*, including overheads. The search operator will be assumed to search at the rate of *A* sq.m/hour and the lifting operator will lift mines and false alarms at the rate of *L*/hour and it will be assumed that both operators work 1500 hours/ann.

If there are *M* mines/sq.m and *F* false alarms/sq.m, then the cost/sq.m amortised over the lifetime of the equipment will be

$p = \{S/AY + K[1/A + (M+F)/L]\}/1500$

7.2 Dual-sensor System
The system to be considered here is one using a modern metal detector fused with an advanced GPR. If it costs *D* and increases the search rate by the factor *a* and reduces the false alarm rate by the factor *f*, and if the service lifetime is the same as for the metal detector, then , over the lifetime of the equipment, the amortised cost/sq.m will be

$d = \{D/aAY + K[1/aA + (M+F/f)/L]\}/1500$

7.3 Representative Figures
The average unit price of a modern metal detector is S = 4 kEuro. The estimate of the production prices of the dual-sensor system, *D*, has been given as between 17 kEuro and 50 kEuro for an initial batch of 100 units and between 10.7 kEuro and 14 kEuro for an initial batch of 1000 units. The service lifetime of both systems will be taken as Y = 4 years while the agency costs of a clearance operator in central Europe is quoted as K = 28 kEuro/ann.

Representative values and ranges experienced in practice are quoted as :-

A = 100-300 sq.m/hour
L = 4-10 lifts/hour
M = 0-1/sq.m
F = 0.5-5/sq.m

Inserting these figures into the above equations shows that

p = 0.67/(100->300) + 18/(100->300) + 18[(0->1) + (0.5->5)]/(4->10)

- which shows that the first term, corresponding to the capital cost is dominated by the third term on the RHS. Over these combinations, the smallest value of *p*, *p*(min) = 1.0 while the largest, *p*(max) = 28.2 Eur/sq.m.

For the dual-sensor system,

d = (1.8->8.3)/(100->300) + 18/a(100->300) + 18[(0->1) + (0.5->5)/f]/(4->10)

The first term on the RHS, corresponding to the capital cost, is dominated by the other two terms. To bring out the conclusions most visibly, therefore, *D* will be taken to be always at the most expensive end of its range, ie, 50 kEuro. Over the corresponding range of extremes of the other parameters the largest, *d*(max), and minimum, *d*(min), values of *d* corresponding to a number of combinations of performance, ie, *a* and *f*, are:-

a	*f*	d(min) Euro/sq.m	d(max) Euro/sq.m	d(min) / p(min)	d(max) / p(max)
1	1	1.02	28.3	1.03	1.00
1	1.5	0.71	20.5	0.71	0.73
1	2	0.56	16.6	0.56	0.59
1	4	0.32	10.8	0.32	0.38
0.5	1.5	0.80	20.8	0.80	0.74
0.5	2	0.65	16.9	0.65	0.60
0.5	4	0.41	11.0	0.41	0.39
0.25	1.5	0.98	21.3	0.98	0.76
0.25	2	0.83	17.4	0.83	0.62
0.25	4	0.59	11.6	0.59	0.41

The corresponding graphs are depicted below:

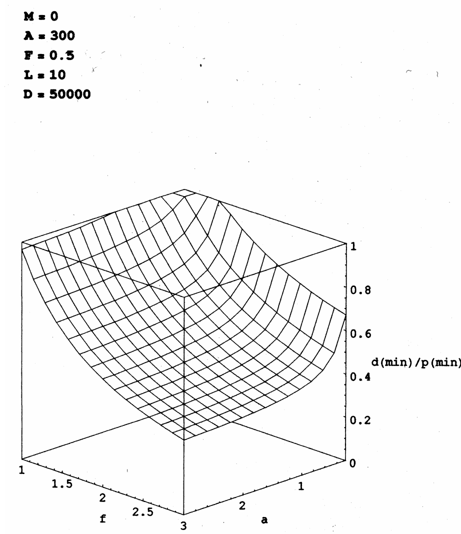

Figure 5: reduction in overall cost for *d*(min)/*p*(min)

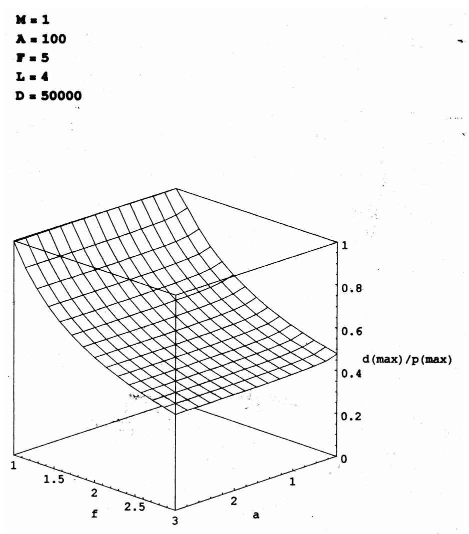

Figure 6: reduction in overall cost for *d*(max)/*p*(max)

ANNEX 8 Economic model building and data gathering

8.1 Data Gathering on Sources of False Alarms
The principal factor which slows down the process of detecting and lifting mines is the time it takes to investigate false alarms. Insofar as the only electronic detectors in use at the present time are metal detectors, it follows that all these false alarms arise from metallic detritus.

When designing more-advanced metal detectors or systems using multiple sensors, it is important to know the population of items of detritus that have been recovered during actual clearance operations. Although the population of items of detritus will vary from site to site, a knowledge of the representative population is essential when estimating the efficacy of a new type of system in rejecting such sources of alarm.

What is required, therefore, is a knowledge of the various categories of detritus and the corresponding area density when using specific metal detectors. It would also be helpful to know the range of depths at which these items were found.

For the purposes of development and proving trials, it would be most desirable for a large number of these recovered pieces of detritus to be collected and used to "seed" trials areas.

It is understood that some organisations have already been keeping records of the items recovered but the rigour and detail of these procedures needs to be confirmed.

When collecting this data and the items of detritus, it would be desirable to record the type of soil in which they were found. Ideally, a small sample of the soil in which each item was falsely detected could usefully be preserved along with the corresponding item.

8.2 Economic Data Gathering
In order to justify the purchase of a new sensor, it is clearly essential for the customer to estimate the benefit it will give him. Basically, the customer needs to balance the cost of the new equipment against the savings he will make by using it.

Clearly, the technical performance of the new equipment is a key issue. But so also are the costs of using the new equipment. Central to these manning costs are the rates of pay of the operators using the detection equipment and the associated operators investigating and removing the mines and the detritus that has caused false alarms. These rates of pay should include all the relevant overheads.

Also central to the economic justification is an understanding of the "cost of ownership" of existing metal detectors. This will include the initial price of the equipment, the maintenance costs and the average lifetime.

8.3 Specification and Price
Assuming that the detection performance of a candidate new system is at least as good as that of a modern metal detector, a cost-benefit relationship should be derived relating all the above data. One of the principal results of this analysis will be the relationship between the reduction of the false alarm rate, the rate of search and the unit price. The rate of search and the false alarm rate are the parameters that should be measured in trials while the unit price and through-life costs establish the target unit cost for the manufacturer.

8.4 Certification
During the course of this Study, the principal factors defining the overall performance of detection systems will be identified and quantified. It is proposed, therefore, that one of the tasks to be undertaken towards the end of the first year of this Study will be to draw-up a draft Certification procedure in collaboration with other interested bodies.

ANNEX 9 <u>Design of proposed trials</u>

The sole objective of the proposed trials is to identify demonstrators that have sufficient promise to warrant further development.

It will clearly be essential to confirm that the demonstrators identified should have a detection performance at least as good as that of current metal detectors. In order to measure the detection performance to the level required of 99.6% with 95% confidence, it will be necessary to seed the trials area with some 800 surrogate mines, see [16] reproduced also in ANNEX 11. For a demonstrator to be considered suitable for further development, it must miss no more than 1 or 2 of these surrogate mines.

Assuming that the detection performance is adequate, the next key measure is the rate at which the demonstrator declares false alarms. The objective here is to determine how much better the new system is than the current metal detectors. If a demonstrator falsely detects N pieces of detritus in the trial, the rms error in the estimate of performance inferred from that measurement will be in the order of N^(-1/2). In order to discriminate between competing demonstrators having comparable performances, then the percentage error in the inferred false alarm rate should be no more than about 1% (say). For N^(-1/2) = 0.01, it follows that N will need to be in the order of 10,000. If the demonstrators are capable of reducing the false alarm rate by the factor of 2, say, compared with current metal detectors, than the number of pieces of detritus that need to be "sown" is 20,000.

The density of false alarms detected by current metal detectors is reported to be in the range 0.5 to 5/sq.m. Taking a representative value of 2/sq.m, it follows that the 20,000 pieces of detritus should be sown randomly over an area of about 10,000 sq.m. If 1,000 surrogate mines were also sown randomly over this same area, the density would be 0.1/sq.m – which is at the lower end of the densities reported in practice.

In order to achieve convincing results, each detection system should be taken over the trial area a number of times with different, but trained operators on each occasion. If 3 such surveys are deemed adequate, and if the searches proceed at about one-quarter of the typical speed when using a metal detector of 200 sq.m/hour, then each demonstrator will need to be used for 3x10,000/(200x4) = 600 hours.

Insofar as the "competing" demonstrator systems need to be compared on the same basis, they should be operated simultaneously over different parts of the trial area. If there were 5 demonstrators in the trial, for instance, then the trials area could be divided into 5 separate areas each of 2,000 sq.m. To survey each sub-area once at the rate of 50 sq.m/hour would take 40 hours, ie, about one week. The procedure would be for the 5 demonstrators to be cycled around the 5 sub-areas after the slowest had finished so that, at the end of about 6 weeks, one pass over the whole area would have been completed using the first set of operators. If the exercise were to be repeated twice (using a new set of operators for each repeat) then the total trials duration would be in the order of 18 weeks.

By arranging the soil conditions in the sub-areas to be as similar as possible and by commencing and finishing the trials of all the demonstrators simultaneously, the evaluations will be done under identical weather conditions. This procedure will also expose any relative deteriorations in performance due to operator fatigue. If any demonstrators relied upon differential environmental effects (as do IR and MMW sensors) then special provisions would need to be made in their evaluation. Otherwise, this approach would seem to be as fair as is practicable.

In order to bring as much realism into the competition as practicable, consideration should be given to arranging for half of each sub-area to be covered with a thin layer of turf and for the other half to be covered with gravel.

Each sub-area should be physically-secured for the duration of each phase of the trial in order to limit access solely to the trial invigilators and suitable separation or screening should be used to prevent competitors from observing their opponents' procedures and progress.

During the setting-up of the trial site, modern metal detectors would be used to confirm that all the surrogate mines were detectable. There would clearly be no need to check that every piece of detritus gave a false alarm in these detectors, since it is only the total number of false alarms produced by these metal detectors that would be used to establish the reference baseline against which the performance of each detector was compared.

The weightings for deriving the "figure-of-merit" for each demonstrator from the figures obtained during the trials would need to be established after more detailed analysis than can be undertaken during this short study. However, the results that make the principal contributions to the figure-of-merit are clearly :-

the number of surrogate mines missed (even 1 would be very serious),
the number of false alarms and
the total time to conduct the survey.

ANNEX 10 Hand-held systems currently being supported

Six hand-held systems have been or are being supported by the EC at present:-

		No. of collab	Completion due
DEMINE	GPR	4	Jan 2001
HOPE	MD+GPR+MMW	14	Dec 2000
INFIELD	MD+GPR+MMW	4	June 2000
MINEREC	GPR	2	Completed
MINESEYE	GPR+FNA	5	June 2001
PICE	MD+GPR	9	Dec 2000

All of these projects will therefore be completed with a demonstrator by June 2001 at the latest.

ANNEX 11