Technology Transfer Bottlenecks and Lessons Learned in Humanitarian Demining EU-funded Research: Analysis & Results from the EC DELVE Project

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The EC DELVE Support Action (www.delve.vub.ac.be) [1] has analyzed the bottlenecks in the transfer of Humanitarian Demining (HD) technology from technology development to the use in the field, basing itself on the assessment of the European HD Research and Technology Development (RTD) situation from early 1990 until 2006. The developments in HD during the last 10 years underline the fact that in a number of cases demining related developments have been terminated or at least put on hold. A number of lessons learned were drawn, bottlenecks identified and broadly classified as either Confidence, Cost, or Communication related. The study also showed that the funding provided by the European Commission (EC) has led directly to the creation of an extensive portfolio of HD technology development projects. However, the range of instruments available to the EC to finance the necessary R&D was limited to pre-competitive research. The EC had no tools or programs to fund actual product development. The corresponding consequences are detailed in the study. The separation of the Mine Action and RTD funding streams in the EC did also negatively affect the take-up of new technologies. As a main conclusion, creating coherence between: (1) the EC policy based on political decisions, (2) RTD, testing and industrialization of equipment, and (3) timely deployment, requires a new way of coordinated thinking: "end-to-end planning" has to be supported by a well organized and coordinated organizational structure involving different DGs (Directorate General) and even extending beyond the EU. This was not the case for Mine Action.

I. INTRODUCTION AND OVERVIEW

The EC DELVE Support Action has analyzed the bottlenecks in the transfer of Humanitarian Demining (HD) technology from technology development to the use in the field, and drawn some lessons learned, basing itself on the assessment of the European Humanitarian Demining RTD (Research and Technology Development) situation from early 1990 until 2006. The situation at European level was analyzed with emphasis on activities sponsored by the EC (European Commission). Moreover, four European countries (B, D, NL and UK) were selected, together with Japan, with emphasis on national activities.

The original project objectives have been defined under the assumption that DELVE would be a project in parallel to a number of projects for the development of Humanitarian Demining technology under the 2004 call in the Information Society Technologies (IST) program, within the 6th EU Framework Program for Research and Technological Development (FP6) [2]. The overall goal was to generate synergy between these projects and national programs in the various countries in Europe. The unexpected outcome of the evaluation of the proposals for this call, was that there would be no projects in FP6 specifically aiming at technology for Humanitarian Demining. From the assessment of the European R&D situation conducted during the first year of the DELVE project, it also became clear that the national research activities on technology for Humanitarian Demining were strongly decreasing in size. For these reasons *the opportunities for synergy as anticipated in the original DELVE work plan did no longer exist* and the original goals could only be pursued to a very limited extent. From the new perspective the focus shifted towards the modified objectives detailed in Section II C.

II. WORK PERFORMED

A. Approach used

The study team have taken a number of approaches in assessing the analysis of the Humanitarian Demining R&D situation. The team started from the existing body of literature and contacts accumulated from the extensive participation to European and national R&D programs in the past decade [3], complemented where necessary with targeted literature surveys (documents, databases, and internet search). A number of direct contacts and where appropriate specific interviews were used for the selected countries, both to compile the detailed descriptions of the most important national activities and to complement our analysis. Representative events, organizations and projects were selected rather than seeking to be exhaustive.

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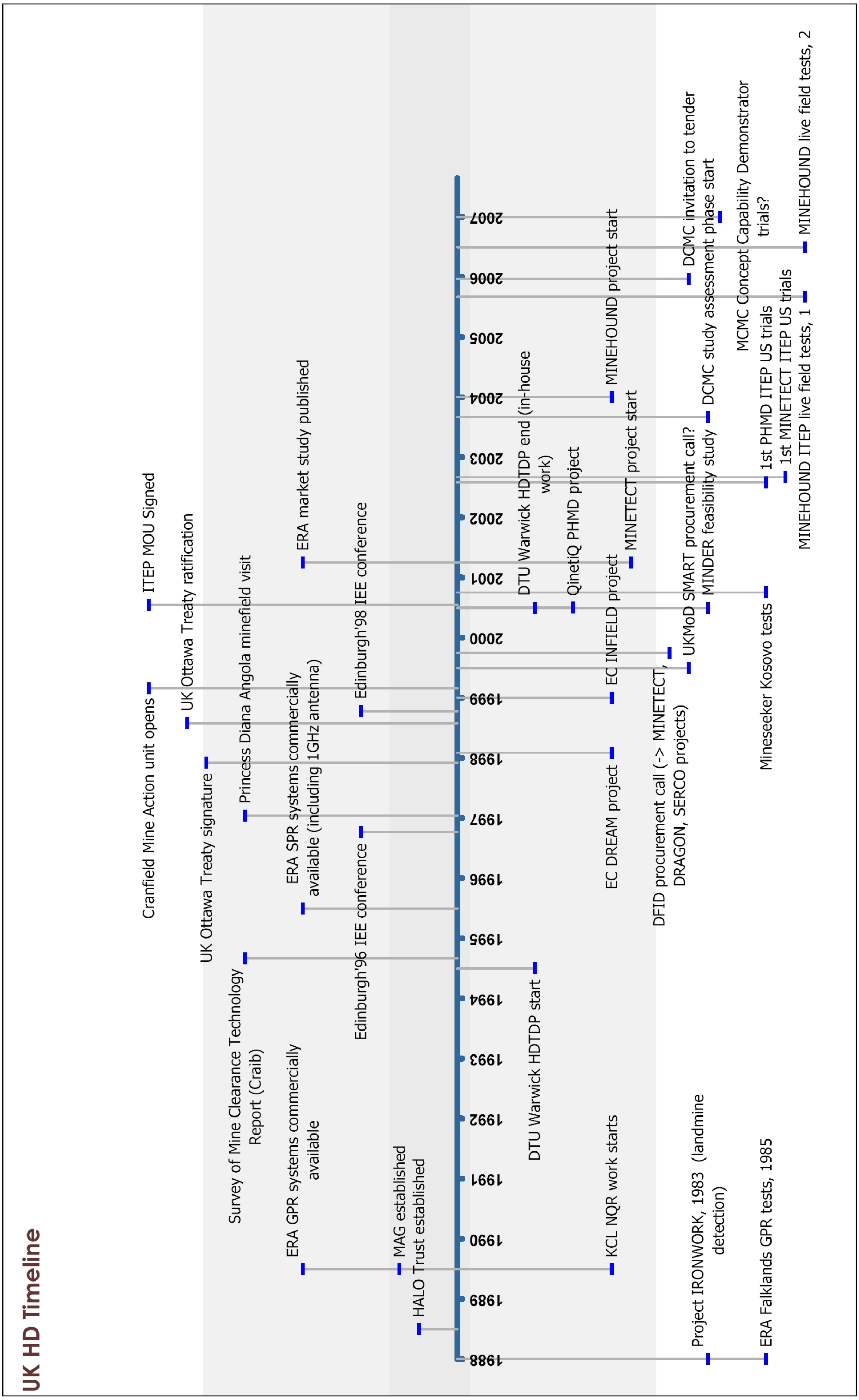

FIG. 1: United Kingdom RTD Activities Timeline

B. First phase

In the first phase of the project we identified the major stakeholders in Humanitarian Demining RTD. This allowed us to analyze country per country the actual R&D situation. Starting from the results of the EUDEM2 project [3] we reviewed the overview of the general Organizational aspects in some selected European countries as well as at the European Union (EU) level. This analysis led to the unexpected result that many of the R&D programs have ended in the period 2003–2005. The original project goal of generating synergy was therefore no longer achievable.

C. Second phase

The second phase of the project focused on a set of modified objectives. This paper will deal in particular with the results related to objectives 2 and 3 (see below), since the analysis of the decline of R&D project funding and the corresponding lessons learned are considered to be of interest for a broader audience outside Europe.

– *Objective 2) Detailed summary of the ending of the R&D project funding in Europe and a thorough analysis of the reasons why this has happened.*

  During the study a large set of data was collected on HD R&D projects in Europe both on EC level and on a national level for the selected countries (Belgium, Germany, Netherlands and the United Kingdom). The results of these HD R&D projects were also analyzed. Furthermore, a number of R&D projects and project clusters were selected for more detailed analysis. Data on HD R&D in Japan was collected for comparison. This objective resulted in DELVE Report T4.1-D4.1 "Humanitarian Demining R&D project funding in Europe" [4].

– *Objective 3) Analysis of the lessons learned which seeks to apply the results of the analysis prospectively to future R&D projects in the broad field of ICT for risk/crisis management, and provide useful support in defining the ToR (Terms of Reference) for Risk and Crisis management for FP7.*

  Based on the case studies on European R&D (including discussions with researchers and program and project managers, and including information from representatives from NGOs and Mine Action Centers) a number of lessons learned have been defined in support of future programs. These lessons learned cover the area of R&D for Humanitarian Demining in general. Some lessons learned are less specific to Humanitarian Demining but are more related to the structuring of R&D projects in the EC framework programs. This objective resulted in DELVE Report T4.2-D4.2 "Humanitarian Demining R&D - Lessons learned" [5].

III. ACHIEVED RESULTS

A. Collection of data

During the study we did collect an enormous amount of data which has been organized in a database and made available for access via the DELVE website [1]. The data were collected among others through participation at conferences, participation in meetings of Humanitarian Demining co-ordination groups (ITEP, GICHD), as well as during actual participation in field test in Asia, Africa and South Eastern Europe. Moreover we did analyze historical data. Pulling together major events and research projects in one timeline illustrates the evolution over time and the relation between events and R&D.

An example is given in Fig. 1 for the situation in the UK: the top half contains in particular important political events, decisions and conferences, as well as key dates in the development of the commercial ERA GPR systems (relevant to the gap to market case study, Section VI). The bottom half contains in the centre indications on R&D projects, in particular those which eventually led to the MINEHOUND system (again of relevance for the gap to market case study), the DFID procurement call of 1999, indications on some military projects (from the early Falkland Islands work to MCMC and DCMC), and data collection and field trials (bottom, mainly the PHMD and MINETECT/ MINEHOUND dual sensor systems).

To support our findings, we have carried out a bibliometric study in order to analyze how the key R&D topics related to demining research evolved during the past 10 year, using as reference the yearly SPIE conference on "Detection and Remediation of Mines and Mine-like Targets". It is acknowledged that this conference is largely US oriented, heavily influenced by defense sponsored work, and partially suffering from a lack of end-user input. However, this event was the only one which ran (and still runs) yearly since 1995 consistently, greatly facilitating comparisons and the analysis of trends, with most results being applicable as well to demining R&D in Europe. Figure 2 provides an idea of the evolution of the total number of published papers (conference proceedings) over time, where one can notice the decline of the R&D activities on landmine detection and remediation starting in the year 2004. The number of papers in the program for 2008 is 57. Note that reporting at conferences usually has some delay after the finalization of the corresponding research activities. This means that the actual decay in HD R&D may have started some time before the decay in the number of publications.

Concerning the key R&D topics themselves, when plotting the number of papers subdivided by subject category (radar, IR, Trace, Bulk, etc.) and looking at the evolution of the single categories over time (see Ref. [4] for details), one can conclude that:

– There has always been an important data process-

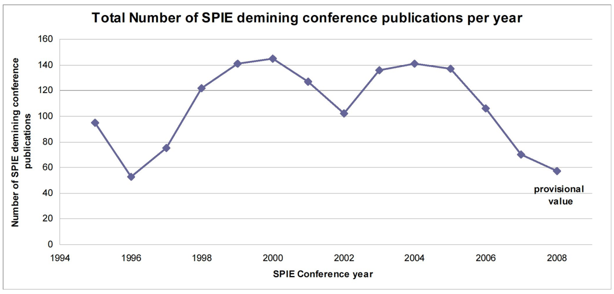

FIG. 2: Total number of SPIE conference publications per year.

ing, sensor fusion and radar component (the three together accounting in certain years for nearly half of all the publications);
- The interest in soil/environmental studies was small at the beginning and has clearly increased over the years;
- The amount of radar oriented publications decreased over the years;
- Infrared based detection showed several peaks over the years and then regressed strongly;
- Bulk detection is small compared to Trace detection throughout, with the latter becoming more important lately.

B. Identification of key stakeholders

Based on the material available the main stakeholders around Humanitarian Demining research have been identified. Figure 3 illustrates how we structured the key stakeholders and the interactions between them. In general this structure can be found at the European level but also at a national level with some minor modifications.

This political arena is probably the most difficult to deal with. Each stakeholder has his own individual motivations and driving factors. Progress in Humanitarian Demining is a common driver for all stakeholders, but certainly not the only one and sometimes not the most important one. For example when the ministry of education in a country sponsors a research project on Humanitarian Demining technology at a university, the core business for the ministry is still education and not Humanitarian Demining.

From the observation that there is not a single and uniform motivation shared between the stakeholders it is easy to understand that an overall coherent strategy, integrating RTD actors, mine action donors and field practitioners (deminers) [6], was never implemented. (This integration has been partly implemented in the case of already developed promising technologies, which still require extensive field testing, e.g., via ITEP.). *The lack of such an overall and coherent strategy has probably been the single most important bottleneck in Humanitarian Demining related R&D.*

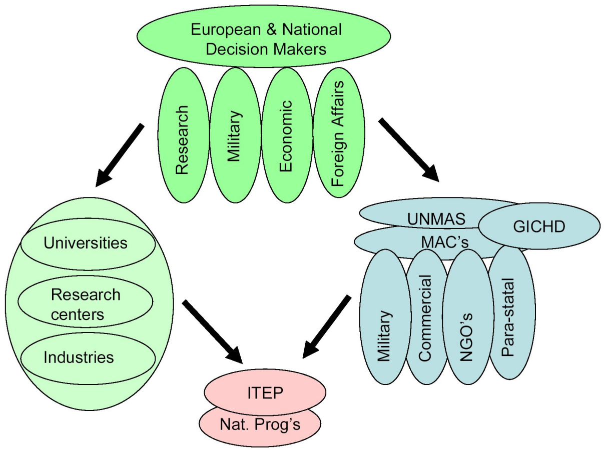

FIG. 3: Key Players Structure.

This resulted at European level – apart from the large EC sponsored effort – in each country basically following a different approach towards Humanitarian Demining R&D (**fragmentation** of European research scenario). It also resulted in some research topics being quite well covered, such as GPR or multi-sensor data fusion, while others, such as R&D on mechanical equipment or on trace explosive detection, which appeared to be an area with potential for a breakthrough technology, being neglected.

In this political arena, full coherence would admittedly have been very difficult to implement in practice, and incoherence was partly unavoidable due to the very nature of R&D, the large number of stakeholders involved, and conflicting interests. However, understanding the motivations, driving factors and interactions in this arena will help decision makers in at least trying to avoid conflicting decisions. Eventually this should contribute to decreasing the effects of the bottlenecks for technology introduction which will be discussed in the following.

Still concerning the key stakeholders and their interactions, it would also have helped, in particular at European level, if new funding structures for Prototyping/T&E/ Production had been implemented. Such a process needs the key decision makers to be “on-board” and well informed, as well as the capability of convincing everybody that significant investments, a long term vision and the will to “carry through” are needed to get substantial rewards down the line.

Finally, Industrial/End Users partnership in particular has often been acknowledged to be essential to speed-up the integration of new developments into demining operations (“risk management” on both sides) [7].

C. HD vs. Military R&D Relationship

Due to the nature of the landmine problem, military approaches and R&D activities can obviously not be ignored even if the target scenario is strictly humanitarian. We will focus here on the effects of military R&D on the development of demining technology of interest to Humanitarian Demining ("spin-in" to HD). A more extensive discussion is reported in Ref. [4].

Based on the work performed for military countermine equipment, in the mid-90s there was widespread optimism that a breakthrough could be achieved in demining technology. For example, the general opinion was that the detection performance could be significantly improved by combining different detection techniques, while at the same time reducing the false alarm rate. Several nations started large research programs to develop this type of technology.

Around the year 2000 it became clear that these techniques, which might show success for the detection of large anti-tank mines, were less suitable for anti-personnel mines. This disappointment was in part due to fundamental physical limitations which blocked technological progress. May be even more important was the misperception of the main problems in demining operations, due to the lack of communication with the end users. For example, taking the military user as a starting point, one assumes well trained users, good logistics support, significant budgets, etc. These conditions are clearly different in Humanitarian Demining.

The research into landmine detection techniques did not completely stop at that point. More incremental improvements were instead pursued. The perception of the actual end users needs did also improve. This resulted for example in the development of hand-held mine detectors which combine metal detection and ground penetrating radar. In this case the perspective of military use (and sales) of these systems justified the funding.

Development for Humanitarian Demining only would not provide a solid business case, because the expected market is too small for an acceptable return on investment. This was well illustrated by a case study by Newnham and Daniels [8], where the authors argued that the cost of a relatively simple improvement of a metal detector could not be covered by the total market for Humanitarian Demining, because the sales numbers are so small that this would lead to unacceptable price increases.

D. Identification of bottlenecks in technology transfer

The bottlenecks in the transfer of technology from technology development to the use in the field were categorized as either (i) Confidence, (ii) Cost, or (iii) Communication related (see Fig. 4).

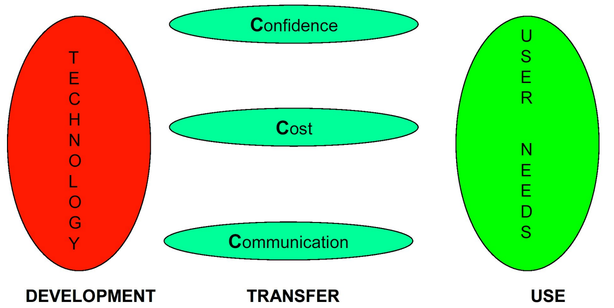

FIG. 4: "Confidence-Cost-Communication" Gap-to-market Model.

IV. TECHNOLOGY TRANSFER BOTTLENECKS AND POTENTIAL REMEDIES

Two of the main products of DELVE: (i) the collection of the lessons learned, and (ii) the analysis of the situation for Environmental Risk Management, have been prepared in terms of the analysis of the bottlenecks of the Humanitarian Demining RTD activities over the past years. The main outcome is summarized in the sections below, including possible remedies. The analysis of success factors in a number of case studies of technology development projects contributed to the definition of these potential remedies.

A. Confidence related issues

Building end-user confidence in technology

Confidence in new technology has to be built up. Technology demonstrated only in controlled test environments is not very convincing, although tests under such conditions are necessary and can be part of the confidence building process.

Confidence is however not always based on scientifically proven data. During the EUDEM2-SCOT 2003 conference [9] first results were presented on rigorous testing of well accepted HD techniques – metal detectors and prodders – which showed much less than 100% detection rates. New technologies with similar non-perfect test results will not be accepted for field use, and perhaps not even fully tried out in practice, which illustrates that confidence is essential for the end user.

Possible remedy: Rather than trying to replace technology currently in use one should try to operate in parallel and show the benefits of the new technology to the user. This is for example done by several developers of hand-held multi-sensor systems (MINEHOUND and HSTAMIDS).

B. Cost related issues

Cost of product development/Lack of financial continuity

Many of the projects aimed at the development of demining technology resulted in a demonstration of a proof of concept or a demonstration system (some did not even reach this level). Further product development, which is well-known to often cost much more than the initial demonstration or proof of concept stage, was hardly ever sponsored.

This finance gap ("death valley") between R&D and field-ready technologies has been well-known over the years, and was already specifically discussed at EC level in 1997, and possibly even earlier. However, due to the EC R&D funding constraints (pre-competitive R&D only as a consequence of the laws on competition – support cannot be given to turn a working prototype into a commercial production item), it was in practice impossible to overcome this at EC level.

Possible remedies: In retrospective it might have helped to find ways to select a few systems and carry them through the full development cycle, similarly to what is done in certain military procurement processes. The concept of a supra-national Equipment Procurement Agency, acquiring, organizing and maintaining a central pool of equipment (technical toolbox), which could be called upon by the deminers following e.g., a leasing formula, was also discussed as the basis of a solution to meet the market requirements. This type of agency did however never see the light.

Absence of a commercial market

It has become clear in the past years that the market for Humanitarian Demining sensing technologies and systems is nowhere as large as initially assumed. This is coupled to "the uncertainty of the prospective sales volume" [8] (which can depend heavily on unpredictable political priorities) and to "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".

Possible remedies: Some possible strategies have already been presented in the previous section. "Spin-offs" from HD to other markets (i.e., search for non-demining applications for the technologies being developed) were also considered. The most important ones seem nowadays to be security and military demining.

Level of cost trade-off

The level at which financial decisions are made is of key importance. At local level the decisions will be different than at national or even international level. For example, contracts for demining operations tend to be too small, and possibly non-renewable, to justify significant investment in technical equipment by a demining organization.

Possible remedies: One possible strategy consists in combining budgets at a sufficiently high level (international) to allow the development and fielding of technology. The trade-off should then be made between the cost of the technology and the savings made in operations due to higher demining productivity. In other words, the cost of research on demining in technology should be compared to the potential cost reduction of the use of this technology worldwide. Donors for technology research and donors for actual demining are usually not the same; this cost-benefit analysis is therefore hardly ever made.

At end user level, larger demining projects should be supported or, if not possible, other methods devised to ensure continuity of operations, in order to enable long term investment in technology.

C. Communication related issues

Basic understanding of the problem and clear problem overview

It might seem obvious that a problem has to be well described and understood before it can be tackled, but this was not the case at the beginning for Humanitarian Demining. Reasons are the lack of communication between the end users and the technology developers, the fact that the demining one is still a relatively young industry, and the initial difficulty of the demining community in coming up with clear scenario definitions.

Parameters such as equipment robustness, ease of use, acceptable system cost and operating costs, and operator training level, have not always been considered in the R&D projects from the very beginning.

Possible remedy: To increase the understanding of the requirements it is sometimes very useful to have a set of scenarios. These scenarios should be defined with strong input from demining organizations and also agreed by them. The scenarios should provide a description of the operational concept of the application of the technique or technology by the user. Based on the scenarios and operational concept description the actual requirements can be derived taking into account both the problems and the boundary conditions imposed by the use in the field and the technical limitations for the specific technological solution. It is therefore obvious that the definition of technical requirements requires adequate communication between end-users and technology developers.

Exchange on technical topics at the right level between researchers and deminers

A critical factor in the process of defining the product goal in a technology development process is that the technical representative of the Humanitarian Demining organization is able to understand the potential of the technique and that at the same time the researcher can understand the operational requirements.

Possible remedy: Visits to demining operations and discussions with technical representatives from Humanitarian Demining organizations during conferences like EUDEM2-SCOT [9], or field visits, or courses reserved for scientists and technicians will facilitate this process.

Communication to stakeholders

Competing projects: The presence of similar projects is part of a natural process in R&D, at least during the initial development stages, but can be difficult to explain to the end users and the general public in high visibility domains such as Humanitarian Demining, and therefore be subject to public pressure and criticism.

Basic research versus Product development: It is a fact that the lead times of some R&D sensing technologies can be very long (GPR, trace explosive detection, smart metal detector). It might be tempting to announce technical breakthroughs, but this should be done with great care. Overexposure of immature technology and unrealistic claims and promises for future effectiveness based on initial experiments have done a lot of harm in the communication between the research community and the end users.

Possible remedy: The maturity of the development should always be clearly stated. A common method for indicating the maturity of technology is the Technology Readiness Level (TRL) scale [10].

Communication between R&D projects (past and present)

Competing projects: It is acknowledged that increasing the communication between competing projects is difficult, and not only when there are clear commercial interests. Ways should nevertheless be found to make a project's results more visible. Lack of communication between projects in high visibility domains such as Humanitarian Demining can be difficult to understand for the end users and the general public.

Possible remedy: Mandatory publishing of short summaries (and possibly of the main results), or well structured and content-rich websites. Encourage participation and organization at selected events, e.g., "cluster" meetings, or networking opportunities such as the Nordic Demining Research Forum. Ideally there should also be a clear and effective knowledge transfer between a starting project and those in the same domain having already completed.

V. LESSONS LEARNED

In addition to the lessons learned related to the specific bottlenecks analyzed so far, some more general lessons learned have also been extracted, as listed below. Although they are written as an advice to the EC, they have a more general validity.

A. Cost

Realistic assessment of all costs

Development and trials costs, risks, timescales and return on investment are not always taken into analysis by consortia bidding for EC co-funded R&D projects. It was suggested (Ref. [5] and references therein) that any consortium should "present a proper justification of their proposal", including a realistic assessment of the previously mentioned factors, before receiving EC support. "These justifications should then 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."

Relative benefits of new technology

Assessing the real benefits of a new technology should be done by means of appropriate tools, such as cost-effectiveness analysis. Such an assessment would involve an evaluation on how Humanitarian Demining contributes to higher economic or political goals in terms of (growth of) economic activities or political stability in a region. Expressing the results of this evaluation in financial terms would then help to judge the justification of investment on demining technology.

B. Test & Evaluation

Test and Evaluation is discusses in detail in Ref. [5]. Here we will only emphasize that testing requires significant engineering competence and advance planning; it should not be considered as something to be done quickly towards the end of a project. There is a need to test the fundamental principles of new technologies as well as their implementation and suitability to form part of a Humanitarian Demining system for use in the field. Particular attention needs also to be paid to the careful design of realistic and meaningful assessment of equipment, especially when it uses new principles. Finally, the independence of testing must be guaranteed when the end-user is a member of the project consortium.

ITEP, the International Test and Evaluation Program, played an important role in supporting Test and Evaluation activities. Over the lifetime of ITEP since the year 2000 many common projects have been successfully completed. The corresponding results (and reports) are published on the website (www.itep.ws). Although not all the projects have been reported in the same level of detail, the ITEP website contains a large set of good quality test reports. Notable ITEP results include *Standardization activities (e.g., of the evaluation of Metal Detectors), mechanical demining tests, and the evaluation of hand held GPR-MD sensors.*

C. Contributions at European Level - Direct results and Spin-offs to other domains

The full analysis of the situation at the European level as a whole, with particular attention to the EC sponsored projects, is reported in Ref. [5]. In fairness to the efforts made during the last 10 years we summarize in Table I a few examples of the main "spin-offs" which have resulted from the EC co-funded projects. The most important ones seem to be in **security, military demining and environmental risk management**.

VI. GAP TO MARKET - SUCCESS CASE STUDIES

Notwithstanding the previously illustrated bottlenecks, in some cases it has indeed been possible to bridge, at least partially, the gap to market, bringing new or improved technology all the way to the end users. Four selected case studies were analyzed in order to identify the enabling factors and the circumstances which actually made this happen [4]. We will here illustrate just one case, the UK – **MINEHOUND dual sensor system**.

A. Description

The MINEHOUND dual sensor detector combines ground penetrating radar (GPR) and a pulsed metal detector to reduce the false alarm rate normally encountered by metal detectors. This is expected to result in improved productivity of mine clearing operations. The output to the operator from both the metal detector and GPR is by means of audio signals.

MINEHOUND is based on a custom-designed GPR from ERA Technology Ltd (UK) and on the pulse induction MD-Type VMH3 from Vallon GmbH (Germany); it is now in production and available from Vallon (MINEHOUND VMR2). The original development (called MINETECT) was developed under the sponsorship of the UK Department for International Development (DFID) and MINEHOUND was additionally supported by the German Foreign Ministry [11].

According to the manufacturer, trials in live minefields show that the FAR can be reduced by a factor of between two and seven times with respect to a standalone MD, and the GPR also detects zero or minimum metal mines that are difficult for the MD. Full details are reported for example in Ref. [11], and references contained therein.

A number of trials have been completed over the years, including field trials in real minefields in collaboration with several NGOs, alongside the currently used MD and under ITEP invigilation [12].

B. Success factors

- A number of funding sources have been exploited over the years (including related GPR developments), both civil and military (European Commission within the DREAM and INFIELD projects for ERA and the HOPE project for Vallon, DFID, UK MoD, the German Foreign Ministry, etc.).
- Constant focus and dedication (continuity).
- Early GPR experience (both as ERA in the Falkland Islands project, 1984-1986, and separately on commercial applications).
- ERA kept visible and continued to communicate and disseminate information throughout.
- Operational experience with GPR products (parallel commercial developments and application line[15], e.g., for civil engineering applications – see also the UK timeline).
- Clear vision of end user requirements and acceptance and potential market (maybe not from the beginning but earlier than others).
- Abandoned an imaging-based approach, targeting the development of a "simple" acoustic interface.
- Commercial awareness (internal ERA investments) and focus on delivering a commercial product.

VII. CONCLUSION

In summary, this project has analyzed the evolution of research and development efforts in the field of technology for Humanitarian Demining in Europe both at the EC level and at national levels. Based on this analysis a number of bottlenecks for the transfer of technology from the research to the end user were identified and potential remedies were suggested. Lessons learned and recommendations were established for the benefit of similar future research programs, primarily as an advice to the EC but with a wider application range.

A. Detailed findings

What emerged from the HD R&D analysis is that:

TABLE I: Spin-offs of EC co-funded RTD projects to other domains.

R&D, support activity	**Project** (example)	**Direct results**	**Spin-offs**
Airborne surveys	DG DEV Airborne Minefield Detection Pilot Project, ARC, SMART	Demonstrator systems, flight campaigns Demonstration of their cost/benefit potential	Environmental risk management applications (STREAM project). Enhanced Camcopter UAV (enhanced product). Coupling of airborne monitoring to GIS (border patrol applications)
Bulk explosive detection	MINESEYE		Explosive detection system (airport security, prototype)
Data fusion	GEODE, DREAM, LOTUS, DEMAND	Improved data fusion systems	Improved data fusion systems for other applications
Data taking	MINETEST, MINESIGN, MSMS	Signature DBs New test facilities Surrogate mines	Fundamental Research
GIS	DG DEV MINEDEMON, ISIS, JRC activities	GIS for SE Europe	Environmental risk management applications
GPR	INFIELD, HOPE, DEMINE, DEMAND	Improved GPR (and GPR array) design	Enhanced understanding of multi-sensor probes. Enhanced understanding of GPR physics. Improved GPR (for civil engineering). Through-the-wall UWB radar.
Metal detection (EMI)	PICE, HOPE, MINESEYE	Improved MD (Schiebel AT-MID, product)	Enhanced metal detectors in the field. Enhanced understanding of EMI physics (e.g., for NdT applications). Inversion models (for imaging applications).
MD array	LOTUS	Förster MD array (product)	Enhanced understanding of EMI physics (e.g., for NdT applications). Inversion models (for imaging applications).
MD+GPR	INFIELD, HOPE	Demonstrators	Handheld multi-sensor systems currently field tested (MINEHOUND)
Other ICT	TELEDIMOS		Environmental risk management applications
Trace explosive detection	BIOSENS	BIOSENS system Test campaigns	Environmental risk management applications. Explosive and drug detection system (BIOSENS, product). Counterterrorism. Enhanced understanding of explosive fate & transport.

– Humanitarian Demining activities started in earnest during the late 80s-early 90s and soon made the headlines thereafter. As one of the consequences important RTD efforts were started, including a strong EC R&D civilian program.

– Different countries replied in very different ways (research fragmentation at the European and national level – fragmentation aspects are discussed in Ref. [5]).

- In a number of cases there has been little interaction between decision makers, R&D organizations and/or end users.
- As with many other "new" topics all involved actors had to climb their share of the learning curve, new structures and ways of collaborating had to be invented (e.g., International Test and Evaluation Program, ITEP), with mixed success.
- Examples of coordinated *end-to-end planning* by creating coherence between (1) policy, based on political decision, (2) RTD, testing and production of equipment, and (3) timely deployment, supported by a well organized and coordinated organizational structure, showed effectiveness in bridging the gap between R&D and Deployment.
- From the review of the EC R&D projects it appeared that, at the current funding/project size, the typical timeframe of 2-3 years is very short for R&D projects, which include a requirements phase, a specification phase, development and integration, demonstrator building, laboratory testing and initial field tests by end users, to be effective. Currently the timeframe for R&D is not sufficiently synchronized with the timeframe of the Humanitarian Action funding/operation.
- At the Humanitarian Demining sensing related R&D level, the most notable developments which have taken place during the past 10 years are: "(i) an increased understanding of the problem, (ii) a shift from a focus on the individual sensor as a solution towards the individual sensor as part of a set of tools, (iii) an increased emphasis on area reduction and the detection of minefield indicators rather than individual mines, (iv) an increased emphasis on trace explosive detection, (v) the gaining of importance of systematic test and evaluation (in particular via the International Test and Evaluation Program, ITEP) [11]."
- Although a host of physical principles have been investigated to detect landmines, only electromagnetic-based technologies, in particular enhanced metal detectors and ground penetrating radars, have seen significant advances and are being introduced into the field. Test results consistently confirm that some of these technologies can indeed increase the productivity of Humanitarian Demining, while at least maintaining the current high levels of safety. Several development groups have shown this is the case for the combination of a metal detector with ground penetrating radar.
- Well known demonstrator systems developed using Earth Observation techniques (e.g., the DG Development Pilot project: Airborne Minefield Detection in Mozambique, the DG IST ARC & SMART projects) have been sufficiently demonstrated, together with their cost/benefit potential; however, their take-up by end users has not been successful.
- Information Technology, including GIS, has been demonstrated in several European projects (e.g., the DG IST ISIS "Intelligent Systems for Humanitarian Geo-Infrastructure" project, and the DG Development MINEDEMON "Mine Database Demonstrator" project), as well as national projects (RMA-Belgium Paradis). However, the deployment of such systems for field use has been achieved by the GICHD with its Information Management System for Mine Action (IMSMA), and by the Swedish EOD and Demining Centre (SWEDEC) with its EOD IS system, using the end-to-end planning approach mentioned above.
- At the R&D level the subject of Humanitarian Demining started to lose importance as from around 2004, being mostly taken over by security related issues and environmental risk management as a whole. The current reduction of the EU Humanitarian Demining research program and its incorporation into the wider "Improving Risk Management" strategic objective, which was foreseen as a way of generating synergies with other types of responses to humanitarian crises management, where technologies such as Information Management, Geographical Information Management and Earth Observation are more likely to be used in a "System Approach", did not generate the expected synergies.
- Military R&D efforts are still ongoing, although refocused around specific topics, and likely to continue for the foreseeable future.
- On the civilian front some individual, mostly academic efforts are still ongoing at national level (with a notable exception such as the IAEA TMs), whereas large concerted projects are ending – like for European projects – and might not be continued.
- Mine Action funding is mostly leveling off (also at the EC level), but not decreasing and still substantial (Ref. [13], pp. 64-72).

B. Main Conclusions

The study showed that the funding provided by the European Commission has led directly to the creation of an extensive portfolio of HD technology development projects. However, the range of *instruments* available to the EC to finance the necessary R&D was limited, until the FP7 program, to pre-competitive research. The EC had no tools or programs to fund actual product development. The corresponding consequences have been sketched above and are fully detailed in the study [4, 5]. The separation of the Mine Action and RTD funding streams in the EC did also negatively affect the take-up of new technologies (see also Ref. [14]).

Notwithstanding the previously illustrated limitations, in some cases it has indeed been possible to bridge, at least partially, the gap to market. Four selected case studies, of which only one was illustrated here, were analyzed in order to identify the enabling factors and the circumstances which actually made this happen [4]. Much could be obtained from putting the corresponding lessons learned in practice, in particular looking in-depth at the case studies that came closer to the field and eventually to the market.

As a main conclusion, creating coherence between: (1) the EC policy based on political decisions, (2) RTD, testing and industrialization of equipment, and (3) timely deployment, requires a new way of coordinated thinking: "end-to-end planning" has to be supported by a well organized and coordinated organizational structure involving different DGs (Directorate General) and even extending beyond the EU. This was not the case for Mine Action.

C. Final remark

We would like to wrap up this paper with the final paragraph from Ref. [11], which we believe still retains all its validity: "The landmine problem is far from solved and landmine detection and area reduction are still the most important elements in the Humanitarian Demining equation. Research and development of practical detection technologies and systems that are appropriate for Humanitarian Demining, duly taking into account the lessons learned and the developments outlined in this section [Section 12 of Ref [11]], continues therefore to represent one of the most significant contributions to the solution of the landmine problem."

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Disclaimer

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