**REPORT DOCUMENTATION PAGE**

<table>
<thead>
<tr>
<th>1. AGENCY USE ONLY (Leave blank)</th>
<th>2. REPORT DATE</th>
<th>3. REPORT TYPE AND DATES COVERED</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>4. TITLE AND SUBTITLE</th>
<th>5. FUNDING NUMBERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost and Effectiveness Analysis Modeling for Demining Operations</td>
<td>C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6. AUTHOR(S)</th>
<th>6. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steven M. Buc</td>
<td>System Planning Corporation</td>
</tr>
<tr>
<td>George C. Tillery</td>
<td>1429 N. Quincy Street</td>
</tr>
<tr>
<td></td>
<td>Arlington, Virginia 22207</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</th>
<th>8. PERFORMING ORGANIZATION REPORT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>System Planning Corporation</td>
<td>9614651</td>
</tr>
<tr>
<td>1429 N. Quincy Street</td>
<td></td>
</tr>
<tr>
<td>Arlington, Virginia 22207</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</th>
<th>10. SPONSORING/MONITORING AGENCY REPORT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Advanced Research Projects Agency (ARPA)</td>
<td></td>
</tr>
<tr>
<td>3701 N. Fairfax Drive</td>
<td></td>
</tr>
<tr>
<td>Arlington, Virginia 22203-1714</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>11. SUPPLEMENTARY NOTES</th>
<th>12a. DISTRIBUTION/AVAILABILITY STATEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>contract No. MDA972-92-C-0016</td>
<td>Approved for public release; distribution is unlimited</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>12b. DISTRIBUTION CODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTIC QUALITY PROTECTED</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>13. ABSTRACT (Maximum 200 words)</th>
</tr>
</thead>
<tbody>
<tr>
<td>This study's objectives were to assess the cost and operational effectiveness of state-of-the-art and emerging demining technologies, and to quantify the remaining challenges and potential benefits of developing new technologies. Its goals were to: 1) understand current demining operations and techniques; 2) identify the key cost and operational parameters which affect demining; 3) model demining operations and quantify the current methods in terms of these parameters; and 4) using this modeling tool, identify shortcomings and project potential improvements which could be provided by various new systems and technologies. All study objectives were met. A detailed tradeoff analysis was performed on a Mozambique demining scenario, using a variety of demining techniques and processes. Computer modeling results were in close agreement with reported field experiences, in terms of mine clearance rates, costs, and casualties. The computer model source code listing is provided.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>14. SUBJECT TERMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>military counter-mine, humanitarian demining, landmines, detectors, probing, casualties, costs, tradeoff analysis, equipment, computer modeling, scenarios, bomb dogs, explosive detection</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>15. NUMBER OF PAGES</th>
<th>94</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>16. PRICE CODE</th>
<th>20. LIMITATION OF ABSTRACT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>unlimited</td>
</tr>
</tbody>
</table>

NSN 7540-01-280-5500
COST AND EFFECTIVENESS MODELING
FOR DEMINING OPERATIONS

DRAFT

JANUARY 1996

STEVEN M. BUC
GEORGE C. TILLERY

Prepared for:
The Advanced Research Projects Agency
3701 N. Fairfax Drive,
Arlington, Virginia 22203-1714

Prepared by:
System Planning Corporation
1429 N. Quincy Street,
Arlington, Virginia 22207

<table>
<thead>
<tr>
<th>Availability Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dist</td>
</tr>
<tr>
<td>A-1</td>
</tr>
</tbody>
</table>
# TABLE OF CONTENTS

I. Executive Summary ................................................................. 4

A. Objectives and Deliverables .................................................. 4
B. Approach ................................................................................. 4
C. The Problem ............................................................................ 4
D. Technologies and Processes .................................................. 6
E. Modeling .................................................................................. 8
F. Findings and Recommendations ............................................. 9

II. The Nature of the Problem .......................................................... 14

A. Definition .................................................................................. 14
B. Dimensions ............................................................................... 15

III. Demining Functions and Cost Distribution ............................... 24

A. Functions .................................................................................. 24
B. Costs ......................................................................................... 25

IV. Current Mineclearing Technologies, Techniques, and Costs .......... 27

A. Framework for Estimating the Cost of Mineclearing Operations 28
B. Developing the Demining Scenario ......................................... 29
C. Current and Postulated Demining Technologies and Processes 30
   1. Bounding or Surveying the Minefields ................................. 30
   2. Detection-Verification-Neutralization of Mines and UXOs ....... 31
      a. Probing ............................................................................. 31
      b. Metal Detectors ................................................................ 32
      c. Bomb Detection Dogs ...................................................... 32
      d. Automated Machinery ...................................................... 34
      e. Cost Data ......................................................................... 38
      f. Technology Overview ....................................................... 39
   3. Cost Effectiveness Estimates for a Baseline Scenario .............. 39
   4. Summary or Demining Costs ................................................. 50
V. Computer Modeling .................................................................53

1. Scenario Generation .......................................................... 54
2. Country Survey ................................................................. 55
3. Landmine Clearance ......................................................... 58
4. Survey and Clearance Costs ................................................ 60
5. Casualty Modeling ............................................................. 63
6. Cost and Operational Effectiveness Analysis Results .............. 65
7. Conclusions ....................................................................... 68
8. Recommendations .............................................................. 69
9. Summary ........................................................................... 69

Appendices

A. References and Points of Contact ...........................................71

B. Computer Model Source Code Listing, Sample Input/Output .......74
I. EXECUTIVE SUMMARY

A. Objectives and Deliverables

This study's objectives were to assess the cost and operational effectiveness of state-of-the-art and emerging demining technologies, and to quantify the remaining challenges and potential benefits of developing new technologies. Its goals were to: 1) understand current demining operations and techniques; 2) identify the key cost and operational parameters which affect demining; 3) model demining operations and quantify the current methods in terms of these parameters; and 4) using this modeling tool, identify shortcomings and project potential improvements which could be provided by various new systems and technologies.

B. Approach

SPC employed a four step approach to accomplish of the objectives: 1) We first sought to define demining by researching and interviewing those directly involved. 2) Based on these understandings, we develop systems models of generic demining processes. 3) These demining processes then formed the basis for a computer model, which could rapidly vary parameters and trade off cost and effectiveness considerations. 4) Using this model, we conducted a preliminary assessment of where are the greatest potential for cost savings and improved effectiveness, and what challenges remain to be addressed.

C. The Problem.

Figure 1 (from Landmines: A Deadly Legacy) shows a map of the world, which gives the overall global demining challenge and the various degrees of severity by country and region. It appears that the only regions which are totally immune from the landmine threat are North America and Australia. Western Europe still suffers from the legacy of World War II, although at perhaps a trivial level compared to other regions of the world.
Figure 1
The Global Demining Challenge
The thirty-eight countries with severe and the most severe landmine problems are also suffering from severe economic and internal refuge problems, in part stemming from residual land mines which continue to deny the use of land and natural resources and terrorize those who dare to venture out from the limited safe havens. Neighboring countries and regions are also suffering economically from refugees displaced by these residual land mines and economic chaos.

The economic, social, and post-war conditions within these countries presents several challenges to the demining effort. In summary, these countries are poor and do not have sufficient resources to undertake demining projects or to maintain the necessary infrastructure to support demining. Knowledge of the precise location and numbers of residual landmines is not available, as evidenced by the many people who are killed or maimed each day by booby traps, landmines, and unexploded ordnance. As a result the demining process is labor intensive, expensive, and protracted, as every square foot of land must be checked for hidden dangers. Under these circumstances, some countries are estimated to require at least a century to clear.

D. Demining Technologies and Processes.

It must be realized that one demines a community, not simply a piece of land. The implications of this philosophy are far reaching in terms of the costs, technologies, and the schedule of a demining program. Communities comprise many specific locations: farms, roads, bridges, pasture, orchards, buildings, houses, water sources, and utilities. Therefore, the environmental disturbance or damage as a result of the clearance process should match the intended use of the specific location. This may dictate the use of different clearing processes and equipment which are most cost effective for a specific location. As examples, one may consider rolling roads, plowing farms, probing cemeteries, or employing bomb dogs to clear homes and buildings.

Some demining technologies may have more or less universal application in many specific locations, such as probes, metal detectors, and dogs. However, it is important not to destroy the long term usefulness of the location in an effort to make it mine free. For example, one should not plow or flail an orchard and kill all the trees in the name of demining efficiency. As a result, the most successful demining approaches have involved the most universally applicable and basic equipment and processes.
This study does not include an in-depth assessment of the cost effectiveness of using automated machinery or existing and developmental combat engineering equipment, which may be useful in counter-mine military operations. Combat engineering and earth moving equipment do not normally give high enough proof rates for demining. Comments made include: rollers do not conform to irregularities in the surface and therefore miss some mines; flails sometimes break the mines or push them deeper into the soil without detonation; and plows often push the mines aside without detonating them. These observations are more or less valid criticisms from a demining perspective. Nevertheless, a discussion of how heavy machinery and automated mine clearing processes could be adapted to a demining scenario is presented in the body of this report.

The technologies and processes for demining a community should address all of the components of a demining program: Survey - Detect - Verify - Neutralize - Rehabilitate. Surveying is the process of identifying and marking suspected mined areas for eventual clearing. Detecting is the process of entering a suspected minefield and precisely locating individual mines. Since some detection systems only indicate a suspected target, which could be either a mine or false alarm, each target must be verified. Following verification, some technique neutralize the hazard is then employed. Once the minefield is cleared of all targets, the location is then rehabilitated for its intended use. Special consideration of technologies should be made not only on their cost effectiveness face to face with the mines and UXO, but also on their training and maintenance requirements within the country in question, and their long term suitability for that country's demining infrastructure.

This study concentrated on evaluating the following currently employed surveying systems: 1) human intelligence or HUMINT; and 2) a system called MEDDS (Mechan Explosive and Drug Detection System), which employs dogs and a mine resistant vehicle for rapid area coverage. One emerging survey system was considered called ASTAMIDS (Airborne Standoff Mine Detection System), which employs a radar and infrared sensor system to identify both buried and surface placed mines and unexploded ordnance. In the cost and effectiveness analysis, each of these three survey approaches were used alone and in combination. HUMINT, MEDDS, and ASTAMIDS were each evaluated as a primary survey process. The combinations of HUMINT-MEDDS, HUMINT-ASTAMIDS, and MEDDS-ASTAMIDS were employed as supplemental surveys to see if overall effectiveness improved compared to using the primary process alone.
Detection, Verification, and Neutralization techniques evaluated were those currently employed in demining operations. Aspects of each of these three components of demining were incorporated into four basic clearance processes, representative of current demining operations: 1) probing alone, 2) metal detectors, 3) metal detectors and dogs, and 4) dogs and probing. Each of the six survey processes (primary and supplemental) were evaluated along with each of the four clearance processes for a total of twenty-four demining process evaluations. The processes were evaluated against a ten year demining program within a Mozambique scenario. Mozambique was selected as a candidate scenario because of its reported severe landmine problems and the availability of relevant information. A ten year demining program was established as a baseline from which to scale cost and effectiveness tradeoffs because current and planned demining programs are projected at increments of approximately ten years. Demining programs also require large up-front investments in equipment and training, the life-cycle costs for which should be amortized over a long duration project, such as ten years.

E. Modeling.

The computer model developed to evaluate the cost effectiveness of different processes and parameters comprises four modules: 1) Scenario Development, 2) Survey, 3) Clearance, and 4) Cost Analysis. This organization to the model is consistent with the community oriented demining philosophy and incorporates the distinct elements involved in a demining program. Within the scenario development, a distribution of landmine concentrations can be postulated, which may represented the likely situation with a particular country or region. Using a flexible scenario approach in the modeling permits the survey process to be fully challenged and evaluated from a cost and effectiveness perspective. Survey outputs include the distribution mines which were identified by the survey technique, and the amount of un-mined area which will also end up being cleared, due to errors in the survey process. The results of the survey, which are now scenario dependent, are then passed on to the clearance module. Each candidate clearance process is evaluated against the survey results to determine the level of clearance achieved. Finally, the cost module calculates the total cost and duration of all survey and clearance processes considered for that scenario, based on cost and level-of-effort (LOE) input parameters.

This model is sufficiently flexible and robust to permit a multitude of survey and clearance processes -- either existing, emerging, or postulated -- to be evaluated against real world demining scenarios. For this reason, this model is useful not only for achieving the
stated objectives of this study, but also as a planning and evaluation tool for ongoing and upcoming demining efforts.

**F. Findings and Recommendations.**

Tables 1 and 2 present the detailed results of the twenty-four survey-clearance combinations considered in this study, for a real world Mozambique scenario. This specific scenario considers that 1 million mines are present within the 39,350 square kilometers of inhabited area of that country, and that all terrain will be cleared within a 10 year program. In addition, 8% of the landmines will be plastic or low-metallic and, therefore, un-detectable by currently employed mine detectors. This aspect of the scenario serves to highlight the unique challenge facing deminers and the need for effective plastic and low metallic mine detectors. The input parameters supporting the survey and clearance processes are a compilation of best estimates, based on the research conducted during this study. The chosen output format is based on those items of information of most interest to the demining community.
## TABLE 1A.
Demining Technology Analysis Results
for a Mozambique Scenario:
Process Costs

<table>
<thead>
<tr>
<th>Survey Type</th>
<th>Clearance Type</th>
<th>Detection</th>
<th>% Mines Surveyed</th>
<th>% Cleared</th>
<th>Uncleared Area (km²)</th>
<th>Survey Cost ($/km²)</th>
<th>Total Survey Costs ($/km²)</th>
<th>Total Cost/Area ($/km²)</th>
<th>Survey Cost/Mine ($)</th>
<th>Clearance Cost/Mine ($)</th>
<th>Total Cost/Mine ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humint</td>
<td>probing</td>
<td>0.998</td>
<td>94.9</td>
<td></td>
<td>13,000</td>
<td>71.3 billion</td>
<td>71.3 billion</td>
<td>1,81 million</td>
<td>1,81 million</td>
<td>75,132</td>
<td>4.32</td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>97.4</td>
<td></td>
<td></td>
<td>1.7 billion</td>
<td>1.7 billion</td>
<td>0.43 million</td>
<td>0.43 million</td>
<td>1,945</td>
<td>1.949</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>90.2</td>
<td></td>
<td></td>
<td>875 million</td>
<td>879 million</td>
<td>22,000</td>
<td>22,100</td>
<td>1,001</td>
<td>1.006</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>90.2</td>
<td></td>
<td></td>
<td>4,034 billion</td>
<td>4,04 billion</td>
<td>0.102 million</td>
<td>0.102 million</td>
<td>4,610</td>
<td>4,624</td>
</tr>
<tr>
<td>MEDDS</td>
<td>probing</td>
<td>0.999</td>
<td>99.0</td>
<td></td>
<td>6,215</td>
<td>75 million</td>
<td>34 billion</td>
<td>34.07 million</td>
<td>34.07 million</td>
<td>34,034</td>
<td>34,109</td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>92</td>
<td></td>
<td></td>
<td>859 million</td>
<td>934 million</td>
<td>22,000</td>
<td>24,000</td>
<td>924</td>
<td>1,015</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>95</td>
<td></td>
<td></td>
<td>453 million</td>
<td>529 million</td>
<td>12,000</td>
<td>14,000</td>
<td>477</td>
<td>556</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>95</td>
<td></td>
<td></td>
<td>2,64 billion</td>
<td>2,12 billion</td>
<td>54,040</td>
<td>56,212</td>
<td>2,148</td>
<td>2,232</td>
</tr>
<tr>
<td>Airborne</td>
<td>probing</td>
<td>0.999</td>
<td>99.5</td>
<td></td>
<td>1,391</td>
<td>3.6 million</td>
<td>77.6 million</td>
<td>77.64 million</td>
<td>77.64 million</td>
<td>7,807</td>
<td>7,811</td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>91.6</td>
<td></td>
<td></td>
<td>264 million</td>
<td>268 million</td>
<td>7,000</td>
<td>7,100</td>
<td>289</td>
<td>293</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>94.6</td>
<td></td>
<td></td>
<td>150 million</td>
<td>154 million</td>
<td>4,000</td>
<td>4,100</td>
<td>159</td>
<td>163</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>94.6</td>
<td></td>
<td></td>
<td>606 million</td>
<td>610 million</td>
<td>16,160</td>
<td>16,240</td>
<td>642</td>
<td>646</td>
</tr>
<tr>
<td>Humint-MEDDS</td>
<td>probing</td>
<td>0.999</td>
<td>94.9</td>
<td></td>
<td>5,904</td>
<td>28 million</td>
<td>32.6 billion</td>
<td>32.53 billion</td>
<td>32.53 million</td>
<td>34,247</td>
<td>34,278</td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>87</td>
<td></td>
<td></td>
<td>816 million</td>
<td>845 million</td>
<td>21,000</td>
<td>22,000</td>
<td>934</td>
<td>967</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>90.2</td>
<td></td>
<td></td>
<td>431 million</td>
<td>460 million</td>
<td>11,000</td>
<td>12,000</td>
<td>478</td>
<td>510</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>90.2</td>
<td></td>
<td></td>
<td>1,941 billion</td>
<td>1,97 billion</td>
<td>49,500</td>
<td>51,400</td>
<td>2,152</td>
<td>2,184</td>
</tr>
<tr>
<td>Humint-Airborne</td>
<td>probing</td>
<td>0.999</td>
<td>94.4</td>
<td></td>
<td>459</td>
<td>5.3 million</td>
<td>2.65 billion</td>
<td>2.655 billion</td>
<td>2,655 million</td>
<td>2,607</td>
<td>2,813</td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>87</td>
<td></td>
<td></td>
<td>145 million</td>
<td>150 million</td>
<td>4,000</td>
<td>4,100</td>
<td>167</td>
<td>172</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>89.8</td>
<td></td>
<td></td>
<td>88.6 million</td>
<td>93.9 million</td>
<td>2,300</td>
<td>2,400</td>
<td>99</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>89.8</td>
<td></td>
<td></td>
<td>320 million</td>
<td>325 million</td>
<td>8,132</td>
<td>8,259</td>
<td>358</td>
<td>363</td>
</tr>
<tr>
<td>MEDDS-Airborne</td>
<td>probing</td>
<td>0.999</td>
<td>99.4</td>
<td></td>
<td>220</td>
<td>75.8 million</td>
<td>1.35 billion</td>
<td>1.42 billion</td>
<td>1,420 million</td>
<td>1,358</td>
<td>1,428</td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>91.5</td>
<td></td>
<td></td>
<td>120 million</td>
<td>196 million</td>
<td>3,000</td>
<td>5,000</td>
<td>131</td>
<td>214</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>94.5</td>
<td></td>
<td></td>
<td>76.7 million</td>
<td>153 million</td>
<td>2,000</td>
<td>4,000</td>
<td>81</td>
<td>162</td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>94.5</td>
<td></td>
<td></td>
<td>559 million</td>
<td>335 million</td>
<td>6,600</td>
<td>8,800</td>
<td>274</td>
<td>355</td>
</tr>
</tbody>
</table>
# TABLE 1B.
Demining Technology Analysis Results
for a Mozambique Scenario:
Process Effectiveness

<table>
<thead>
<tr>
<th>survey type</th>
<th>clearance type</th>
<th>detection</th>
<th>% mines</th>
<th>% cleared</th>
<th># people</th>
<th># people</th>
<th># systems</th>
<th># systems</th>
<th>casualty</th>
<th>casualty</th>
<th>casualties</th>
<th>casualties</th>
<th>undetected mines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>probability</td>
<td>surveyed</td>
<td>by detection</td>
<td>continuous LOE</td>
<td>continuous LOE</td>
<td>continuous LOE</td>
<td>continuous LOE</td>
<td>probability</td>
<td>probability</td>
<td>people</td>
<td>systems</td>
<td>remaining</td>
<td></td>
</tr>
<tr>
<td>Humint</td>
<td>probing</td>
<td>0.999</td>
<td>94.9</td>
<td>1,011 million</td>
<td>0</td>
<td>0.001 prober</td>
<td>0.01</td>
<td>10,440</td>
<td>0</td>
<td>50,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>87.4</td>
<td>22,330</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,674</td>
<td>0</td>
<td>122,200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>90.2</td>
<td>11,024</td>
<td>648 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>4,654</td>
<td>48 dogs</td>
<td>94,152</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>90.2</td>
<td>54,080</td>
<td>2704 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>1,804</td>
<td>48 dogs</td>
<td>57,650</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDOS</td>
<td>probing</td>
<td>0.999</td>
<td>99.9</td>
<td>484,832</td>
<td>0</td>
<td>0.001 prober</td>
<td>0.01</td>
<td>10,990</td>
<td>0</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>92.0</td>
<td>11,209</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,920</td>
<td>0</td>
<td>76,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>95.5</td>
<td>6,538</td>
<td>426 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>4,900</td>
<td>50 dogs</td>
<td>46,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>95.5</td>
<td>27,040</td>
<td>1,352 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>1,900</td>
<td>50 dogs</td>
<td>24,900</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>airborne</td>
<td>probing</td>
<td>0.999</td>
<td>99.9</td>
<td>159,152</td>
<td>0</td>
<td>0.001 prober</td>
<td>0.01</td>
<td>10,935</td>
<td>0</td>
<td>5,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>91.5</td>
<td>3,212</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,895</td>
<td>0</td>
<td>81,020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>94.5</td>
<td>1,612</td>
<td>124 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>4,875</td>
<td>50 dogs</td>
<td>51,020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>94.5</td>
<td>7,800</td>
<td>1,000 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>1,900</td>
<td>50 dogs</td>
<td>53,955</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humint-MEDDS</td>
<td>probing</td>
<td>0.999</td>
<td>94.9</td>
<td>458,739</td>
<td>0</td>
<td>0.001 prober</td>
<td>0.01</td>
<td>10,440</td>
<td>0</td>
<td>50,100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>87.4</td>
<td>10,659</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,674</td>
<td>0</td>
<td>122,200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>90.2</td>
<td>5,226</td>
<td>420 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>4,654</td>
<td>47 dogs</td>
<td>94,200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>90.2</td>
<td>26,840</td>
<td>1,292 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>1,905</td>
<td>47 dogs</td>
<td>97,955</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humint-airborne</td>
<td>probing</td>
<td>0.999</td>
<td>94.4</td>
<td>37,296</td>
<td>0</td>
<td>0.001 prober</td>
<td>0.01</td>
<td>10,390</td>
<td>0</td>
<td>50,800</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>87.4</td>
<td>1,639</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,667</td>
<td>0</td>
<td>126,203</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>89.8</td>
<td>858</td>
<td>66 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>4,648</td>
<td>47 dogs</td>
<td>98,203</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>89.8</td>
<td>4,000</td>
<td>200 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>1,800</td>
<td>47 dogs</td>
<td>101,081</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDDS-airborne</td>
<td>probing</td>
<td>0.999</td>
<td>94.4</td>
<td>18,648</td>
<td>0</td>
<td>0.001 prober</td>
<td>0.01</td>
<td>10,935</td>
<td>0</td>
<td>5,100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>91.5</td>
<td>1,298</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,595</td>
<td>0</td>
<td>81,020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>94.5</td>
<td>676</td>
<td>52 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>4,575</td>
<td>50 dogs</td>
<td>51,020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>94.5</td>
<td>3,160</td>
<td>158 dogs</td>
<td>0.00005 dog</td>
<td>0.001</td>
<td>1,890</td>
<td>50 dogs</td>
<td>54,005</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sheet 1
Based on these analysis results, several conclusions and recommendations can be identified:

Conclusions:

1. Significant demining cost reductions are achievable by employing more advanced survey technologies. This results primarily from the great reduction in un-mined area which must be checked for mines, due to survey inaccuracies.

2. Survey inaccuracies, even with detection rates in the mid to high 90th percentile, result in large numbers of remaining undetected landmines. Short of sending bomb dogs (MEDDS) throughout the entire inhabited country, most survey technologies fail to ensure very high clearance rates.

3. Probing alone effectively clears every mine and minefield identified by the country survey (99.9% proof rate), and if dogs (MEDDS) is used as the survey process, 99.9% of all mines will be cleared. However, this is achieved at an enormous human and financial cost.

4. If all mines were detectable my metal detectors, the dog-detector clearance process is the most cost effective technology for achieving nearly a 95% proof rate.

5. In the presence of plastic and low-metallic mines, the reliance on metal detectors presents a serious casualty risk. Under these circumstances, probing must be employed, with the resulting decrease in efficiency and increase in clearance costs. The dogs-probing process more than doubles costs over dogs-detectors when using the most efficient survey process (MEDDS-airborne). For other survey processes, clearance costs increase dramatically.

6. Supplemental surveys will not increase the number of mines detected by the survey. However, large clearance cost reductions are obtainable by using a supplemental survey, if leaving slightly more undetected and uncleared mines is acceptable.
7. Although survey costs are relatively small compared to clearance costs, the accuracy of the survey process has the greatest impact on total clearance costs. This tradeoff highlights the need of the survey process to minimize the amount of un-mined area that must be cleared due to survey inaccuracies.

Recommendations:

1. Develop rapid remote sensing survey processes with effectiveness well beyond the limited capabilities of human intelligence. Multi-spectrum airborne detection systems may offer promising emerging technology. An effective near term survey process should include the use of bomb dogs.

2. Develop an effective plastic and low-metallic mine detector system, which also detects conventional metallic mines. The availability of such a device will greatly reduce demining casualties, while boosting clearance efficiency at greatly reduced cost. A near term approach to this problem may involve performing more in-depth characterization of the effectiveness of bomb dogs, and developing knowledge on when dogs cannot detect mines, and how to improve the pinpoint accuracy of a dog detection.

3. Develop improved protective clothing and greater standoff neutralization technologies for deminers. The clearance process still involves an individual excavating and neutralizing a mine in close proximity to his body. Regardless of high survey and detection system effectiveness, an injury is currently inevitable when constantly handling such large quantities of mines and unexploded ordnance at the neutralization phase of demining.
II.
THE NATURE OF THE PROBLEM

A. Definition

Demining is that set of related functions required to render mined areas safe for civil use. Demining operations can be accomplished by 1) expatriate contractors and or expatriate governmental and non-governmental entities, 2) indigenous governmental entities and or contractors, or by 3) some combination of these approaches. The difficulty with the second approach, which is preferred, is that, as a rule, societies with the most extensive mine problems have the least capacity, in terms of expertise and or resources, to deal with it. As a result, most demining operations employ variations of the third approach; usually employing expatriate resources to conduct time critical demining and to assist in development of an indigenous demining capability. Kuwait is the best noted exception to this rule.

Demining operations are different from military countermine operations. The principal differences are: 1) countermine is conducted during hostilities while demining is conducted subsequent to hostilities; 2) countermine operations are often conducted under fire and at the least opportune times—at night and in adverse weather—to minimize casualties and or maximize surprise, demining operations are generally conducted under favorable conditions; 3) demining requires almost total clearance, countermine does not; and 4) keeping collateral damage to a minimum is more an imperative in demining than in countermine operations. The objective in countermine operations is generally to clear a relatively narrow lane of mines, on the order of 8 m in width and 100 m in length, as rapidly as possible. Additionally, countermine operations do not necessarily require mine neutralization, simply displacing them from the desired lane is sufficient. The objective of demining, on the other hand, is neutralizing all the mines within a generally large geographic area—usually measured in square kilometers—with a high degree of surety; 99 percent or better being desired.1 As demining’s core objective is returning mined areas to civil use, and because mines are principally found on or near infrastructure, it is imperative to keep collateral damage, consequent to demining, to a minimum.

---

1 Landmines: A Deadly Legacy, p. 236
B. Dimensions

As a consequence of both insurgency and conventional warfare, landmines pose a significant problem in a large part of the world. Based in large part on UN figures, the US Department of State estimates there may be as many as 85 - 90 million of these mines.\(^2\) This figure is probably high. The true extent of the landmine problem is unknown. For example, Human Rights Watch notes:

...the December 1992 United Nations estimate of 2 million mines ...has no scientific basis; ... The total number of landmines in Mozambique is certainly in the tens of thousands, and probably in the hundreds of thousands.\(^6\)

There are a number of reasons for this. First, mines are by design and nature of employment hard to detect. Additionally, while military organizations routinely record the location of their minefields, this practice is not always adhered to and data indicating minefield locations may be lost. Insurgents are normally concerned with such niceties.

Even if the true figure is only half as large as that cited by the State Department, mines would still pose a significant problem. Mines are assessed to cause some 150 civilian casualties per week,\(^3\) of which 15 may be fatalities.\(^4\) But injury and death resulting from direct encounters are only part of the cost inflicted by mines. By rendering transportation and economic infrastructure unusable, mines also exact an economic and political toll. In general, the most significant mine problem is found in Africa, the Middle East, and Southwest and Southeast Asia. Table 2 provides some sense of the scale of the problem.

Mines are generally emplaced in one of three ways. They may be buried from as little as 2 cm to more than 40 cm deep. The former being more likely in an environment in which manual as opposed to mechanical means of emplacement are employed. Mines may be also partially buried, such as the Italian Valmar 69, with fuze prongs exposed. Mines may also simply be laid on the surface of the ground or, in the case of the American M18 and Russian MON and POMZ series of mines, staked with the lethal mechanism elevated above the ground. Some mines, such as the Italian VS-50, may also be laid in shallow water, such as in fords. Given the opportunity, those emplacing mines will attempt to conceal them. Surface laid mines will normally have some neutral or even camouflage finish to help blend them into the background.

\(^2\) Hidden Killers: The Global Problem With Uncleared Landmines, p. 3
\(^6\) Landmines in Mozambique, p. 14
\(^3\) Ibid., p. 2
\(^4\) Landmines: A Deadly Legacy, p. 142
Table 2 implies that mines are uniformly distributed in a given geographic area. They are not. Mine density may vary by region and will vary depending on land use. For example, two provinces of Mozambique that together comprise roughly a fifth of its total area, Niassa and Cabo Delgado, have a comparatively minor mine problem.\textsuperscript{7} Mines, specifically those of most concern to demining, will for the most part be found where the population is. Mines are principally placed in such a manner as to terrorize or to deny use of terrain or, more correctly in scenarios of interest to demining, that which is on that terrain, such as infrastructure. Surveys conducted by the International Committee of the Red Cross (ICRC) and Africa Watch in Angola and Mozambique indicate the highest concentrations of mine incidents are found on or near unimproved roads and trails, followed by improved roads, inhabited areas, and finally fields and other areas. These findings are summarized in Table 3.

<table>
<thead>
<tr>
<th>Country</th>
<th>Area (km(^2))</th>
<th>Estimated Number of Mines</th>
<th>Mines per km(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sudan</td>
<td>2,500,000</td>
<td>500,000 - 2,000,000</td>
<td>0.5</td>
</tr>
<tr>
<td>Eritrea/Ethiopia</td>
<td>470,000</td>
<td>300,000 - 1,000,000</td>
<td>0.5</td>
</tr>
<tr>
<td>Nicaragua</td>
<td>130,000</td>
<td>130,000</td>
<td>1</td>
</tr>
<tr>
<td>Somalia</td>
<td>637,000</td>
<td>1,200,000 - 2,000,000</td>
<td>2.5</td>
</tr>
<tr>
<td>Mozambique</td>
<td>787,000</td>
<td>2,000,000</td>
<td>2.5</td>
</tr>
<tr>
<td>Angola</td>
<td>1,250,000</td>
<td>9,000,000</td>
<td>7.2</td>
</tr>
<tr>
<td>Former Yugoslavia</td>
<td>256,000</td>
<td>2,500,000 - 3,700,000</td>
<td>11.3</td>
</tr>
<tr>
<td>Iraq</td>
<td>435,000</td>
<td>5,000,000 - 7,000,000</td>
<td>11.5</td>
</tr>
<tr>
<td>Afghanistan</td>
<td>650,000</td>
<td>9,000,000 - 10,000,000</td>
<td>14.7</td>
</tr>
<tr>
<td>Cambodia</td>
<td>181,000</td>
<td>4,000,000 - 7,000,000</td>
<td>30.4</td>
</tr>
<tr>
<td>Kuwait</td>
<td>6,200</td>
<td>5,000,000 - 7,000,000</td>
<td>373.5</td>
</tr>
</tbody>
</table>

\textbf{Table 2. Scale of the Problem}\textsuperscript{5}

\textsuperscript{7} Landmines in Mozambique, p. 15
\textsuperscript{5} Derived from information found in HiddenKillers
Inhabited areas should not be construed to mean in urban areas, but rather small towns and villages and at points next to them likely to attract large groups, such as water sources. In his examination of the mine problem in *Hidden Killers*, David Gowdy notes that:

Our survey indicates that landmines are largely a rural, third world problem. ... Urban mining is the exception rather than the rule. Mines are most commonly found in rural border areas, around rural infrastructure such as electric lines, water plants, and bridges, around military installations in combat zones, and along roads. Terror mining of small towns and villages is common.\(^5\)

Fully two thirds of the mine incidents in Angola were found to have occurred within five kilometers of a village or town.\(^6\)

<table>
<thead>
<tr>
<th></th>
<th>Land Use</th>
<th>Unimproved Roads and Trails</th>
<th>Improved Roads</th>
<th>Inhabited Areas</th>
<th>Fields</th>
<th>Unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICRC (Angola)</td>
<td></td>
<td>69%</td>
<td>15%</td>
<td>16%</td>
<td>-</td>
<td>0%</td>
</tr>
<tr>
<td>Africa Watch (Angola)</td>
<td></td>
<td>61%</td>
<td>19%</td>
<td>9%</td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td>ICRC (Mozambique)</td>
<td></td>
<td>58%</td>
<td>23%</td>
<td>-</td>
<td>16%</td>
<td>3%</td>
</tr>
</tbody>
</table>

**Table 3. Distribution of Mine Incidents.**\(^8\)

Another point to be noted is that individual landmines do not appear to be the major problem so much as minefields, perhaps more appropriately clusters of four (4) or more mines. The example cited in *Landmines in Mozambique* of 500 mines in 34 clusters appears more the norm than the individual mine.\(^9\)

While these data are specific to Mozambique and Angola, this pattern can reasonably be expected to apply to other regions where the mine problem is primarily the result of insurgencies, rather than conventional warfare.

This should not be construed to imply that minefield configurations more typical of conventional conflicts will not be found in the aftermath of insurgencies. In Somalia it is

---

5. *Hidden Killers*, p. 7
estimated that some 70% of the mines are to be found in barrier minefields along the
Ethiopian border laid by the Somali government to hinder insurgent forces crossing the
border from Ethiopia into Somalia. Large barrier minefields are, however, an intrinsically
easier problem to deal with, from the perspective of location and avoidance, than randomly
placed clusters of mines.

If one approaches the demining problem from the perspective of where mines are most
likely found and do the most harm, the real extent of the problem in a given area becomes
clear. Dense human habitation as well as the vast majority of a society's economic and
transportation infrastructure is found on its arable land. In Mozambique this is roughly one
third of the total land area, about 236,100 km². Actual land under actual cultivation will be
less than total arable land. It may be much less. The World Bank, for instance, estimates
that only about 30,000 km² are under cultivation in Mozambique, slightly less than four
(4) percent of total land area. Mozambique's transportation infrastructure—improved,
unimproved roads, and railroads—accounts for another 238 km², if one assumes a
uniform 8 meter clearance requirement. There are no good figures for total area occupied by
towns and villages. However, based on the extent of land under cultivation and
transportation infrastructure, one could reasonably argue that the area of Mozambique of
principal concern to a demining operation is about five (5) percent of the total land area or
39,350 km². This decreases the total land area to be demined by 95% but increases mine
density. If one assumed 1,000,000 mines, by all accounts a more reasonable figure than
the UN's initial estimate of 2,000,000, this reduction in area would increase mine density
from 1.3 per km² to 25.4 per km².

Actual area to be cleared is even less than this, as Figure 2 indicates. Based principally
on the pilot road clearing project conducted by Gurkha Security Guards, Ltd., in Sofala
province Mozambique in 1993, it is reasonable to expect that information derived from
local inhabitants, former combatants and local authorities can reduce the actual area to be
searched and cleared by as much as two thirds. In Mozambique this translates to some
12,986 km², which would increase mine density of 77 mines per km², again assuming
1,000,000 total mines.

---

10 Landmines: A Deadly Legacy, p. 223
11 Landmines in Mozambique, 80-83
Figure 2. Actual Area Requiring Clearance

Applying what is known about mine employment, the distribution of these 77 mines should be reasonably similar to that proposed in Figure 3. Mines would be placed in clusters on paths and trails leading to fields, to sources of water, and on roads and trails between towns and villages to disrupt communication.
Figure 3. Anticipated Mine Distribution

The mine problem is compounded by the fact that there are a variety of different mines requiring different technologies and techniques to detect and neutralize. There are two basic types of mines that are considered in this study—antipersonnel (AP) and anti-vehicular or tank (AT) mines. Of these two, AP mines are by far the most prevalent in demining scenarios. For example, an Africa Watch Study conducted in 1992, determined that only 4 percent of the mine incidents in Angola were attributable to AT mines. A comparable study by the ICRC attributed 16 percent of the mine incidents in Angola to AT mines.\(^\text{12}\)

Complicating the problem of mine clearance are that AP and AT mines are often combined a given mine cluster, and that unexploded ordnance (UXO) may be intermingled with mines, more often as the result of conventional conflict than insurgency, and that UXO's are in some instances modified for employment as mines.

The metal content and arming mechanisms of mines vary, compounding the problem even further from the perspective of detection and neutralization. UXOs by their nature are

---

\(^{12}\) *Landmines: A Deadly Legacy*, p 155
invariably of high metal content, and consequently readily detectable by metallic mine detectors. Some mines, such as the US M14 and the Italian VS-50, have such a low metal content as to render current metallic mine detectors all but useless.

There are essentially three types of arming mechanisms: 1) influence-activated by some type of signature, e.g., electromagnetic to include emanations from metallic mine detectors; 2) contact, including pressure, disturbance and tripwire activation; and, reportedly, 3) photonic—activated by exposure to the sun. Of these three categories of arming mechanisms, the ones of most concern in demining scenarios are those activated by contact. Mechanisms activated by pressure and tripwires are of concern.

Command detonation as an arming mechanism is of no concern in demining because such mines are assumed to be unmanned. They are therefore characterized according to the arming mechanism of the anti-handling device, if any, affixed to them. Mines, and UXOs for that matter, are often equipped with anti-handling devices or booby traps to make disarming them difficult if not impossible. Mines such as the Italian VS-50 have integral anti-handling devices.

It must be noted that many, if not most, command detonated mines, such as the US M18, may also be activated by tripwires. The Russian MOM series command detonated mines may also be activated by a seismic sensor.

While trip wires improve the likelihood that a mine will be detected, they also increase the chance that it will be encountered. For example while the fuze prongs on the Yugoslav PROM-1 cover an area on the order of .01 m², this mine's 16 m trip wire extends the area over which it may be encountered and detonated to 1,607 m². The hazardous area of the Russian MON series mines may be even greater, if the UMK seismic sensor is employed.

Table 4 lists the characteristics of some of the most widely proliferated mines. In general, AP mines have diameters on the order of 100 mm or less—note exceptions being the Russian MON-100 and -200—while AT mines are normally three times that size. Explosive loading in AP mines is normally less than .5 kg—the MON series again being exceptions—while the explosive loading of AT mines is ten times greater. Artillery and or air delivered scatterable mines are generally smaller with less explosive, but are not as widely proliferated and, hence, representative as the mines presented in Table 4.
<table>
<thead>
<tr>
<th>Type</th>
<th>Emplacement</th>
<th>Explosive Charge</th>
<th>Materials</th>
<th>Size</th>
<th>Fuze</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>AP</strong></td>
<td><strong>Mines</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M-14 (US)</td>
<td>buried</td>
<td>.029 kg</td>
<td>plastic</td>
<td>height 40 mm</td>
<td>pressure</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>diameter: 56 mm</td>
<td></td>
</tr>
<tr>
<td>M-16 (US)</td>
<td>partially buried</td>
<td>.454 kg</td>
<td>metallic</td>
<td>height 199 mm</td>
<td>pressure or trip wire</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>diameter: 103 mm</td>
<td></td>
</tr>
<tr>
<td>M18A1 (US)</td>
<td>surface emplaced</td>
<td>.680 kg</td>
<td>plastic</td>
<td>height: 83 mm length: 216 mm</td>
<td>trip wire or command</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>width: 35 mm</td>
<td></td>
</tr>
<tr>
<td>MON (Russia)</td>
<td>surface emplaced</td>
<td>MON-50 - 6.80 kg</td>
<td>plastic</td>
<td>MON-50 - height ~ 83 mm; length ~216 mm; width ~35 mm</td>
<td>trip wire, command or seismic influence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MON-100 - 5 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>MON-200 - 12 kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZM (Russia)</td>
<td>partially buried</td>
<td>.075 kg</td>
<td>metallic</td>
<td>height: 120 mm diameter 75 mm</td>
<td>pressure, trip wire or command</td>
</tr>
<tr>
<td>PMD-6 (Russia)</td>
<td>Buried</td>
<td>.200 kg</td>
<td>wooden</td>
<td>height: 64 mm length 200 mm width 89 mm</td>
<td>pressure or trip wire</td>
</tr>
<tr>
<td>PMN (Russia)</td>
<td>buried</td>
<td>.240 kg</td>
<td>plastic</td>
<td>height: 56 mm diameter 112 mm</td>
<td>pressure</td>
</tr>
<tr>
<td>POMZ-2 (Russia)</td>
<td>surface emplaced</td>
<td>.075 kg</td>
<td>metallic</td>
<td>height: 135 mm diameter 64 mm</td>
<td>trip wire</td>
</tr>
<tr>
<td></td>
<td>(staked)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type 72 (China)</td>
<td>surface laid or buried</td>
<td>.034 kg</td>
<td>plastic</td>
<td>height: diameter:</td>
<td>pressure</td>
</tr>
<tr>
<td>Valmara 69 (Italy)</td>
<td>partially buried</td>
<td>.420 kg</td>
<td>plastic</td>
<td>height: 205 mm diameter 130 mm</td>
<td>pressure or trip wire</td>
</tr>
<tr>
<td>VS-50 (Italy)</td>
<td>surface laid or buried</td>
<td>.043 kg</td>
<td>plastic</td>
<td>height: 45 mm diameter 90 mm</td>
<td>pressure</td>
</tr>
<tr>
<td><strong>AT</strong></td>
<td><strong>Mines</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TM/TMN-46 (Russia)</td>
<td>surface laid or buried</td>
<td>5.95 kg</td>
<td>metallic</td>
<td>height: 91 - 110 mm diameter 304 mm</td>
<td>pressure</td>
</tr>
<tr>
<td>TM-62 (Russia)</td>
<td>surface laid or buried</td>
<td>7.00 kg</td>
<td>metallic, plastic, wooden, cardboard</td>
<td>height: 115 mm diameter 315 mm</td>
<td>pressure or magnetic influence</td>
</tr>
<tr>
<td>Type 72 (China)</td>
<td>surface laid or buried</td>
<td>5.40 kg</td>
<td>plastic</td>
<td>height: 100 mm diameter 270 mm</td>
<td>pressure</td>
</tr>
</tbody>
</table>

Table 4. Common Mines
If one were to attempt to capture all the potential demining scenarios that might be encountered, based on the environment and the nature of the mine threat, it would result in a matrix similar to that depicted in Table 5.

Potential demining scenarios are defined principally by the environment, primarily terrain and vegetation because weather is a factor that can usually be controlled for, and the nature of the mine threat. There are four basic types of terrain. Improved roads and inhabited areas are unique in that contour, soil type and water are not significant complicating factors. An unimproved road or trail, on the other hand, may differ little from the surrounding terrain except in its comparative lack of vegetation.

The effects of contour, texture — according to Webster’s New World Dictionary "...the arrangement of the particles or constituent parts of any material as it affects the appearance or feel of the surface; structure, composition, grain, etc."— vegetation, soil type, and water are considerations that must be addressed but will vary with the technologies and techniques employed in demining. They affect both mobility, and hence may limit mechanical means of mine detection and neutralization, and the ability of different technologies to detect mines. Texture, with respect to the electromagnetic spectrum, is principally of concern with respect to reflectivity and absorption.

Another environmental factor, in addition to weather that will be assumed away for purposes of this study is the condition of the local transportation and communications infrastructure. While infrastructure damage will affect the pace of demining, infrastructure repair, besides reclamation consequent to mine clearance itself, is not a demining function.

A final point is that a single region to be demined may span the entire spectrum of scenarios. In Mozambique, for example, natural ground cover varies from tropical rain forest to savanna with elevations from near sea level to almost 1,600 meters. The only types of mines not encountered in Mozambique, generically, were influence and photonic. Further, UXOs do not appear to have been a significant threat.
III.
DEMINING FUNCTIONS AND COST DISTRIBUTION

A. Functions

While expatriate entities may be employed to perform emergency demining to clear lines of communications (LOCs) and perhaps staging areas until an indigenous capability is established, the preferred approach is providing indigenous authorities the capability, in terms of resources and training, to conduct demining themselves. This is both official UN and US policy. There are seven basic functions that must be performed to provide such a capability. These are: 1) planning and 2) resource collection; 3) survey of the country to be assisted to determine resource and training requirements; 4) securing staging areas and including LOCs, to include limited mine clearance if necessary and 5) preparing staging areas as logistics and operations centers and training sites for indigenous personnel; 6) training indigenous personnel to conduct mine clearance and providing mine awareness training for the population at large; and 7) the actual conduct of large scale mine clearance operations by indigenous personnel. The relation of these functions is depicted in Figure 4.

Figure 4. Demining Functional Systems Model

Planning and resource collection are common to all other functions. For example, one assesses training requirements, plans training and then collects the resources necessary to
execute that plan. If on completion of training it is determined that the requisite degree of learning was not achieved, then a new plan is developed to correct deficiencies and additional resources are gathered, if required. A key output of the planning function is the prioritization of mine clearance operations, based on mine and population density and the political, economic and humanitarian cost of deferring clearance of specific areas.

B. Costs

Assessing cost distribution is difficult. UN costs' estimates are based on a rule of thumb per mine removed of $300 to $1,000. Contractors are reluctant to share cost models. Sufficient open source information, however, does exist to permit a rough estimate to be made for the allocation of funding within an overall demining program.

Conducting an initial country survey can take as little as a few weeks or at most months. It principally consists of small teams of experts going to a country to determine its needs based principally on discussions with local authorities combined with some amount of direct observation. The United States Special Operations Command's (USSOCOM) country survey and follow-up discussions with authorities in Eritrea, for example, consisted of an initial ten (10) day evaluation by two (2) men with a ten (10) day follow-up with a seven (7) man team. The Mine Advisory Group's (MAGs) initial assessment of the mine problem in Angola also took less than a month.

Table 5. compares the percentage of initial year costs allocated to the seven demining functions in the: 1) MAG Emergency Proposal for Landmine-Related Project in Angola, January 28, 1994; 2) the Cost Estimates for FY94 DoD Humanitarian Demining Assistance provided by USSOCOM/CENTCOM to Eritrea and PACOM to Cambodia, including an estimated $2,000,000 in mine detection/clearance equipment to be provided the Cambodian government; and 3) UNOMOZ1 for initial year demining costs in Mozambique, supplemented by information extracted form Landmines A Deadly Legacy. Figure 5. shows this comparison in graphic form. For each function area, the initial year and subsequent year allocations are shown side-by-side. While direct comparison of these efforts is difficult, for example the FY94 DoD Humanitarian Demining Assistance does not include salary costs and none of these sources breaks costs out exactly in the functional categories proposed in this paper, it is readily apparent that by far the largest portion of resources is allocated to actual mine clearance followed by training.

The MAG Emergency Proposal for Landmine-Related Project in Angola provides somewhat more insight in actual cost breakdown. With respect to training costs, 6% are associated with mine field bounding and mine location, 4% with neutralization, and 10%
with mine awareness. With respect to mine clearance, 30% of the costs are associated with minefield bounding and mine location and 20% with neutralization.

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>ORGANIZATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MAG</td>
</tr>
<tr>
<td>Planning and Direction</td>
<td>10%</td>
</tr>
<tr>
<td>Resource Collection</td>
<td>4%</td>
</tr>
<tr>
<td>Country Survey</td>
<td>6%</td>
</tr>
<tr>
<td>Secure Staging Areas and LOCs</td>
<td>0%</td>
</tr>
<tr>
<td>Prepare Staging Areas</td>
<td>10%</td>
</tr>
<tr>
<td>Train</td>
<td>20%</td>
</tr>
<tr>
<td>Conduct Large Scale Mine Clearance</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 5. Resource Requirements as Percentage of Initial Year Budget

![Legend](image)

Notes:
* As % of budget
** Captured in large scale mine clearance.
*** Salary only. Set-up and travel costs included in staging area preparation. 40% of total training costs are the salaries of the mine awareness personnel for the entire year, not just the period of their training. Mine awareness training of the population is a key training task.
**** 50% of total is salary. 40% of total is military salaries. 5% of total is salary and equipment-o.g., trauma kits—for auxiliary personnel, medical drivers, translators, etc.
***** 31% of total budget is salary.

Figure 5. Resource Requirements as Percentage of Initial Year Budget

The remainder of this study will focus on mine clearance operations. Of the seven demining functions, it is the most time intensive and costly; consuming over half of a demining operation budget.

26
IV. CURRENT MINECLEARING TECHNOLOGIES, TECHNIQUES, AND COSTS

Mine clearance itself consists of five sub functions. These are: 1) minefield bounding or surveying, which involves locating the areas to be cleared; 2) precise location of mines and UXOs, this requires both detection and verification that the object detected is a mine or UXO; 3) neutralization of mines and UXOs; 4) proofing, or quality assurance, a high degree of surety in the location and neutralization processes may preclude the need to proof; and 5) reclamation or rehabilitation of the terrain for use as intended by the local population. The relationship of these functions is depicted in Figure 6.

![Figure 6. Mine Clearance Functions](image)

Current mine clearance technologies and techniques are manpower intensive and dangerous. Handheld metallic mine detectors, manual probing and dogs trained to detect mines are the most common methods of mine detection. Even when dogs are employed, metal detectors and probes are normally required to pinpoint mine location, while neutralization involves either manual excavation and then either removal for remote destruction or destruction in situ, employing explosives.

Mine neutralization technologies developed for military countermine operations, while inherently safer and more rapid, such as explosive line charges and flails, are terrain limited, too destructive and or have a surety level too low for demining. Mine plows, rather than neutralizing mines, simply move them out of the way, and in that process may cause the to detonate or arm. Further, a number of mines, such as the Italian VS-50, are
constructed to resist the over pressure, that is the principal operating mechanism of systems like explosive line charges. Consequently UNOMOZ1, A Mine Clearance Plan for Mozambique, notes:

...the clearance rate for these (mechanical) devices will probably be 80 percent, considerably lower that the 99.9 percent clearance needed for the re-introduction of refugees or displaced persons into the area.\textsuperscript{13}

In the end the most efficient means of mine neutralization today remains the individual deminer.

Because these technologies and techniques are manpower intensive they are time consuming and costly, as well as dangerous. The UN estimates it will take from $50 to $120 million and from five to ten years to clear Cambodia and $30 to $40 million over seven to ten years to clear Mozambique,\textsuperscript{14} based on a cost of between $300 to $1,000 for each mine neutralized.\textsuperscript{15}

A. Framework for Estimating the Cost of Mineclearing Operations

Estimating the financial costs associated with demining a former war zone, be it the result of a guerrilla or conventional war, is of great interest to governments and humanitarian organizations. Off hand estimates place the cost of demining at anywhere from $300 to $1000 per mine removed. Such estimates, however, are completely inadequate for competent cost analysis and planning. Basically, the cost per mine removed is entirely the wrong measure of effectiveness of a demining program. The real issue is the cost per area of land certified as mine free. Therefore, there is always a significant cost incurred whether any mines at all are discovered and removed.

The number of mines to be removed, however, does have a secondary effect on the rate of mine clearing and ultimate costs, depending on terrain conditions and the demining technologies employed. As a result, developing more advanced demining technologies has become an additional interest within the many governments involved. Nevertheless, choosing which technologies to employ or develop in response to any one demining scenario must result from a rational cost and effectiveness model.

\textsuperscript{13} UNOMOZ1, p. 2
\textsuperscript{14} Landmines: A Deadly Legacy, p. 252 and Landmines in Mozambique, p. 46
\textsuperscript{15} Ibid., p. 251
The framework for this model is presented here. It begins with a discussion of
considerations surrounding the demining scenario to be costed. Following this is a
presentation of the cost effectiveness of known and postulated demining technologies. A
first order cost effectiveness and tradeoff analysis is made comparing the three most
common demining processes and technologies. Finally, a more complete computer model
has been developed to permit rapid tradeoffs between competing demining system
parameters and costs.

B. Developing the Demining Scenario

It cannot be over stated that one demines a community, not simply a piece of land.
The implications of this philosophy are far reaching in terms of the costs, technologies, and
schedule of a demining program. The community comprises many specific locations:
farms, roads, bridges, pasture orchards, paddies, buildings, houses, water sources,
utilities, etc. Therefore, the environmental disturbance/damage of the clearance process
should match the intended use of the specific location. This may dictate the use of different
clearing processes and equipment which are most cost effective for a specific location. For
example: roll roads, plow farms, probe cemeteries, sniff (dogs) houses, etc.

Some demining technologies may have more or less universal application in many
specific locations. However, it is important to not destroy the long term usefulness of the
location in an effort to make it mine free. For example, don’t plow or flail an orchard and
kill all the trees in the name of demining efficiency. As a result, the most successful
demining approaches have involved the most universally applicable and basic equipment
and processes.

For cost and time efficiency, the proof or level of clearance should also match the
intended use of the specific location. Locations with high levels and diverse forms of
human disturbance require 100% clearance to great depth of all mine and UXO threats --
rroads for example. Locations with unique or low levels of human disturbance can
accommodate less than 100% clearance of certain types of threats. For example, orchards,
pasture, and non-mechanical farms may not require total identification and removal of
heavy AT mines and large, deep UXOs, since the level of human disturbance to set these
off will not be present.
However, in the long term, land use may change and the freeze-thaw cycle or erosion may cause buried objects to migrate to the surface. Under these circumstances, the local population and land owners must be educated to the residual threat, and the community must have an EOD infrastructure to deal with it. A good example is what is in place in Germany, Belgium, Holland, and Great Britain. 50 years after WWII, residual ordnance is occasionally found when land is converted to new uses, but the ordnance is successfully removed with little risk.

The development of the demining scenario should consider the entire geographical makeup of the community in question; its history and future. The technologies and processes for demining this community should as a whole address all of the components of the demining program: Survey - Detect - Verify - Neutralize - Rehabilitate. Special consideration of technologies should be made not only on their cost effectiveness face to face with the mines and UXO, but also on their training and maintenance requirements within the country in question, and their long term suitability for that country's demining infrastructure.

C. Current and Postulated Demining Technologies and Processes

1. Bounding or Surveying the Minefields

The process of surveying a country for mine and minefield locations is laborious, since precise locations have been forgotten, if ever recorded, only later to be rediscovered by accidental death or serious injury. The technologies supporting minefield surveying are the same as used in current mine clearing processes. Teams of deminers are trained in the use of metal detectors, probes, and dogs and go into the field and directly verify known or suspected mined sites.

Various levels of automation have been achieved in the use of dogs as a survey technology. One proven technique employs a vehicle, which drives along while periodically sampling the air. The air is passed through a filter which is changed at fixed intervals, the location of which is recorded on the route map. At the end of the mission, all the filters are brought back to a dog site. The dogs are presented the filters and they will cue on any one containing traces of explosives. A demining team can then more efficiently return to that specific location rather than concern themselves with the other miles of terrain.
the vehicle crossed. Surveying in this manner can quickly focus demining efforts over very large areas.

For most parts of the world, however, surveying is important for posting warnings and informing locals not to go into that particular area, if they do not already know. One could say that the current known reserves of minefields is sufficient to keep everyone busy clearing these for many decades. Therefore, simply identifying more minefields does not necessarily speed up the clearance process, given the current state of the demining problem.

If, however, an overfly or ground based remote sensing survey could be linked into a differential GPS register for cataloging of specific mine locations, that may be useful in speeding up demining. During the clearing process, the deminer could, hypothetically, use his own differential GPS system and walk directly up to the precise location of the mine in the data base, provided he was also sweeping for targets which the survey missed. One sees that the cost-benefit is still not so clear, since the survey may still miss some very deadly targets and the deminer must deal with these in a conventional, time consuming manner. Nevertheless, some nations are working on developing survey technologies using radar or infrared imagery to not only identify large minefields, but to also aid in pinpointed precise mine locations for more efficient clearing.

2. Detection - Verification - Neutralization of Mines and UXOs

a. Probe - Excavate - Neutralize

With proper training and experienced prodders, this is the single most safe and effective means of 100% detection and verification of a buried mine or UXO. However, it is incredibly slow and labor intensive. A prodder crouches down and pushes a probe into the ground at a shallow angle to feel if anything is buried there. If something is identified, it is then carefully uncovered or excavated. Depending on what is found, a neutralization technique is then employed. Performance parameters may be summarized as follows7:

7 FM 5-34 pg 2-4; Landmines A Deadly Legacy pg. 181, pg. 235, 241; and discussions with Hap Hambric.
1 probe every 2 seconds, with 30 minutes every excavation-neutralization.
1 probe every 2x2 inches to get all AP mines.
1 probe every 6x6 inches to get all AT mines.
One person can clear 20-50 square meters per day.
(estimate average of 4.4 square meters per man-hour)

Using this technique alone, the 200 square kilometers of estimated minefields in Cambodia could be cleared this way with current force levels (2200 prodders) in 10 years (2080 man-hrs per year).

b. Metal Detector - Probe - Excavate - Neutralize

Much faster than prodding alone, but may miss plastic and low-metallic mines.

Experienced deminers have averaged 3 to 5 km per day on poor condition gravel roads in Mozambique. These roads were cleared into the shoulder vegetation to a width of 4 meters. The deminers consisted of six 5 man teams. On an average, this works out to 66 square meters per man-hour, or about 15 times faster than prodding alone.8

c. Bomb Detection Dog - Metal Detector - Probe - Excavate - Neutralize

Using the dogs has the advantage of getting the low-metallic mines and speeding up verification of metal detector targets. Dogs are fallible and cannot be calibrated as can a metal detector. Dogs, on an average, experience a very high success rate (95%), when the conditions are controlled. However, one cannot easily quantify their failure rate in the field (it's not simply 5%), since it is a dog and cannot tell its handler if it does not smell something and why not. This is a calibration problem. The handler can most often know if the conditions are right, but he cannot absolutely know when the conditions are wrong.

8 Landmines in Mozambique, pg 80-83; BRDEC PAM 350-4, pg. 97.
Under the circumstances in Mozambique for example, the risk of a dog non-detection on a valid target is less than the percentage of low-metallic mines, which the metal detector is certainly going to miss out right. The area survey, however, should identify the level of threats which may be missed by whatever clearance process is selected, so that a valid risk assessment and mitigation procedure can be developed.

The dog team approach is also labor intensive, since every dog requires a dedicated handler, who only works the dog's hours. If we consider the dog-handler team to be one person, however, then the clearing rate increases to 78.6 m² per man-hour, but with an increased man-hour cost due to the dogs. Perhaps in a cost effectiveness model, the dog should be considered an item of equipment with its associated logistics burden.

Although very effective, this process may still be too slow for many countries affected by landmines. Using this same technique in Afghanistan, a 992 man UN group of deminers, supported by 90 dogs and 2 mechanical flails is estimated to be able to clear 10 square kilometers per year. This averages as 4.8 m² per man-hour, or about the same rate as prodding alone. The UN reports this to be a highly successful program. Nevertheless, at current UN demining team levels, Afghanistan will still take 1000 years to demine.

It is difficult to assess the efficiency discrepancies between the UN team and Ronco. It's possible the UN is going to find 16 times more mines in Afghanistan, which have to be destroyed in the same slow process. Terrain differences may have significant effects -- clearing roads versus rough, hilly land. Maybe they are going to work less than 2080 hours per year (assumed baseline). Maybe larger organizations lose efficiency. In any event, many variables not considered above can greatly affect the efficiency of any candidate demining technique.\(^9\)

d. Automated Machinery

Combat engineering and earth moving equipment do not normally give high enough proof rates for demining. Comments made include: rollers do not conform to irregularities

\(^{9}\) Landmines a Deadly Legacy pg. 147, pg. 243; FM 7-41, Mine and Tunnel Dog Training and Employment; discussions with Ronco Consulting Corp.; discussions with Rae McGrah, Mines Advisory Group; discussions with Chip Hurlock, Washington, D.C. Bomb Squad.
Plowing and Grubbing

Some terrain, soil, and land use conditions (such as farms and sandy deserts or beaches) may permit plowing or grubbing to remove mines and UXOs. If a plowing operation using a mine plow or a grubbing operation using an armored bulldozer to clear the top few inches of soil is used, additional follow-on mechanical operations are required to increase the proof rate and to rehabilitate the terrain. During the plowing and grubbing operations, the disturbed soil should be scooped up and loaded into a machine which sifts for remaining mines and UXOs which did not go off during the initial displacement.

This additional machine could be a conveyor-type which passes the soil through various levels of sieves. Remaining ordnance is then mechanically picked out and placed into a holding container or mass destruction pit. At the end of the conveyor or sieving mechanism, the clean soil or sand is loaded into scrapers or dump trucks, which then place it back where it came from.

One sees that several existing and yet to be developed armored earth movers and machines are required to support this type of clearing process. Not knowing exactly what the sifting conveyor would look like does not necessarily stop us from estimating its processing speed and cost, however.

A plowing operation may involve the following pieces of equipment and processing rates:

Plow -- 3 meters width at 3 mph = 14400 m² per hr

6 inch depth = 2900 cubic yards per hr

Load and Sift
5 yard bucket loader -- processes 2900 cubic yards in 4 hrs

Replace soil
18 yard scraper -- places 2900 cubic yards in six inch lifts in 10 hrs

Grade surface
Grader -- grades 14,400 m² in 2 hours
Replacing and grading sifted soil or sand could probably begin 1 hour into the plowing and sifting phase so the longest time line is 11 hours. This reduces the effective plowing rate to 1300 m2 per hour. Although it requires at least four major items of machinery and equipment, this process is 16 times faster than dogs and detectors alone.

Grubbing -- Armored bulldozer -- 1000 m2 per hour
6 inch depth = 200 cubic yards per hr

Load and Sift
5 yard bucket loader -- 200 cubic yards in .27 hours

Replace soil
18 yard scraper -- 200 cubic yards in .7 hours

Grade surface -- 1000 m2 in .12 hours.

Sifting and replacing can begin after the first bucket load is processed, so the longest time line is the total grubbing effort. This process is about 1000 m2 per hour.¹⁰

Summary of Clearing Rates for Current Technologies

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe - Excavate</td>
<td>4.4 m² / man-hr</td>
</tr>
<tr>
<td>Detector - Probe - Excavate</td>
<td>66</td>
</tr>
<tr>
<td>Dog - Detector - Probe - Excavate</td>
<td>78.6</td>
</tr>
</tbody>
</table>

Summary of Hypothetical Mechanical Technologies

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Roller</td>
<td>24000 m² / hour</td>
</tr>
<tr>
<td>Walker</td>
<td>3200</td>
</tr>
<tr>
<td>Plow - Sift - Replace</td>
<td>1300</td>
</tr>
<tr>
<td>Grub - Sift - Replace</td>
<td>1000</td>
</tr>
</tbody>
</table>

¹⁰ FM 5-333 pg 6-5; FM 5-34 pg 2-4.
<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expatriate western deminer</td>
<td>$75 / hr</td>
</tr>
<tr>
<td>(includes insurance, travel, subsistence)</td>
<td></td>
</tr>
<tr>
<td>Local Deminer</td>
<td>$2 / hr</td>
</tr>
<tr>
<td>Metal Detector</td>
<td>$3,500 each</td>
</tr>
<tr>
<td>Batteries</td>
<td>$35 each</td>
</tr>
<tr>
<td>Battery Charger</td>
<td>$200 each</td>
</tr>
<tr>
<td>Tool Kit (for marking lane)</td>
<td>$150 each</td>
</tr>
<tr>
<td>Probe</td>
<td>$33 each</td>
</tr>
<tr>
<td>Grapnel with 50 meters of cord</td>
<td>$20 each</td>
</tr>
<tr>
<td>Explosives (shipped to site)</td>
<td>$3.00 / pound</td>
</tr>
<tr>
<td>Explosive primer cord</td>
<td>$0.16 / foot</td>
</tr>
<tr>
<td>Electric blasting cap (with 24 foot wire)</td>
<td>$3.50 each</td>
</tr>
<tr>
<td>Electric detonator firing unit</td>
<td>$500 each</td>
</tr>
<tr>
<td>Protective clothing</td>
<td>$150 each</td>
</tr>
<tr>
<td>Trucks (delivered to country)</td>
<td>$35,000 each</td>
</tr>
</tbody>
</table>

---

11 Emergency Proposal for Landmine-Related Project in Angola, Mines Advisory Group; Mines a Deadly Legacy pg. 252.
Mechanical Devices\textsuperscript{12}

road grader \hspace{1cm} $215,000
D-9 bulldozer \hspace{1cm} 625,000
5 yard bucket loader \hspace{1cm} 315,000
12 yard scraper \hspace{1cm} 225,000

f. Technology Overview

Those involved in the development and application of countermine technologies may look at the demining problem slightly differently than those who have been demining in the Third World. The Third World has a tremendous resource available for demining -- people. The most cost effective approaches, all things consider, may simply involve extensive training and education in the use of the most rudimentary equipment and its associated hazards. Given enough probes, all the mines may eventually be found and cleared, although not necessarily in these people's lifetimes.

Some have stated that the number one demining problem is detecting plastic or low-metallic mines. Close investigation, however, gives the impression that those with this problem have found a workable solution. That is to use dogs. There may still be a better way, but convincing the deminers may be the biggest challenge. The reality is that the deminers must ultimately select their equipment. They select the equipment based on their experiences. The lesson here is that the technology developers have to get close with the deminers in the field if a new piece of equipment is to be successful, regardless of how well it really works.


To illustrate the interaction of many process parameters on the actual cost effectiveness of demining technologies, a simple baseline scenario is developed. Given a hypothetical mined location, the following assumptions are made:

\textsuperscript{12} commercial cost, Caterpillar Sales, Baltimore, Maryland.
Assumptions:

1. no false alarms or false alarms consistent for each process.
2. all salaries are based on local personnel ($16 per day).
3. average mine density of 4 mines per 100 square meters.
4. contour, texture, water, weather is appropriate for process.
5. closure is reached every day on all detections.

The first four assumptions are made to simplify this first order tradeoff analysis, and are self explanatory. At this point they establish a level field for evaluating various demining technologies. The assumption of closure is important to discuss in detail, however. A serious problem in the Third World is the black and gray markets in mines, ordnance, and explosives. Often, mines and ordnance which have been detected or cleared are later pilfered. The demining community seeks to avoid aggravating this trade in dangerous materials.

To this end, the demining process they employ attempts to physically destroy every dangerous item cleared or unearthed on a daily basis. Therefore, the size of each demining team, the hours they work, and their demining locations are tailored toward reaching this closure at the end of the day. In other words, every mine detected will be unearthed and will be destroyed by that evening. Clearly, within this practice, it is not useful to emphasize detection rates which are faster than neutralization rates. This consideration can greatly affect any cost analysis and the selection of appropriate demining technologies.

Process #1   Probing

Probe - Verify - Neutralize

Assumptions:

All detections are verified and neutralized when found, since the danger of accidental contact is too great to permit continued probing around a suspected target. Therefore, all suspected targets are immediately excavated and activity stops when a mine is being neutralized (grapnel pull).
each prober sweeps a 1 meter lane -- 36 m² in 6 hours
expect 1.4 mines per lane -- 12 minutes to excavate/verify
-- 5.25 minutes to neutralize

1.4 * 17.25 = 24 minutes
total daily working time = 6.4 hours
3 lanes will clear 108 m² per day

Staffing:
6 probers who also excavate
1 neutralizer
1 medic
1 supervisor

total 9 personnel at $ 16 per day = $ 144

Equipment:
Tools, grapnels, probes -- $0.73 per day
Backup Explosives -- $6.60 per day

Total Daily Cost: $ 151.33
Total Cost to Clear: $ 1.40 per square meter

A significant cost to any demining operation is the use of explosives as the means of destroying landmines and ordnance. Although $3.00 per pound for a one pound block of explosives and 16 cents per foot of primer cord may not seem like much, there are an estimated 100 million landmines which need to be cleaned up world-wide. The approved procedure when using explosives is to use a one pound block per mine, and if possible connect using explosive primer cord up to five mines, provided they were all within 50 feet of each other. This speeds up the destruction process and uses only one electrical blasting cap. If all of these 100 million mines were each destroyed in situ by a block of explosives, with five blocks connected by primer cord to one electrical detonator, the cost for these explosives, the detonators, and primer cord would exceed $ 1.2 billion. Figure 7 illustrates this generic mineclearing process.
Current Techniques Elaborated (Probing Alone)

Sequence:
1. A prober detects an object
2. Prober verifies (uncovers mine) 12 minutes
3. If mine is verified, neutralizer advances to mine and other personnel mark their positions and withdraw 50 m. If false alarm sweep continues (Other probes continue to advance 1.2 m until mine is verified.)
4. Neutralizer places grapnel or explosives 2 minutes
5. Neutralizer withdraws 50 m and detonates explosive if grapnel is not employed 1 minute
6. Neutralizer pulls grapnel and waits 5 minutes
7. Mine is removed for later disposal and personnel return to positions and resume probing 1 minute

*BRDEC Pam 350 - 4 indicates a 300 m safe distance when using explosives to destroy mines in situ

Legend
- Supervisor
- Neutralizer
- Medic
- Prober

Figure 7. Probing Alone Mineclearing Process
Process #2  Metal Detector  
Detect - Probe - Excavate

Assumptions:

All metal detections are immediately marked for follow-up verification by probing and excavating. Valid targets are neutralized en masse at the end of the day, since the danger of accidental contact is less when using a metal detector, which has a larger standoff than a probe. Using the grapnel pull method to dislodge the mine, 5 targets can be dealt with simultaneously. If a mine does not detonate, wait 5 minutes and then carry it to a mass destruction pit.

two detectors and markers sweep a 2.75 meter lane  
-- 1700 m2 in 5 hours  
during this time  
-- 12 minutes to excavate/verify each target  
68 mines are expected to be found  
normalize 5 at a time -- 13.6 pulls at 5.25 minutes each  
= 1.19 hours to neutralize  
total daily working time = 6.19 hours

Staffing:

4 detector operators  
2 target markers  
2 probers who also excavate  
1 neutralizer  
1 medic  
1 supervisor  
total 11 personnel at $ 16 per day = $ 176

Equipment:

Tools  
-- $ 11.50 per day  
Backup Explosives  
-- $ 104.00  
4 metal detectors at $ 2.30 per day each  
-- $ 9.20

Total Daily Cost -- $ 300.70  
Total Cost to Clear -- $ 0.18 per square meter
Current Techniques Elaborated (Metallic Mine Detector and Probing)

Sequence:
1. A metallic detector indicates a mine or marker finds visual indicator
2. Marker marks indication and sweep continues
3. Probers advance and verify (uncovers object)

On completion of sweep of specified area, or when sweepers have advanced at least 50 m from mine ...
4. Neutralizers advance to mines and other personnel withdraw 50 m
5. Neutralizers place grapnel or explosives
6. Neutralizers withdraw 50 m and detonate explosive if grapnel is not employed
7. Neutralizers pull grapnels and wait (up to 5 mines can be neutralized at a time with an A-frame, per BRDEC PAM 350-4. Theoretically, there is no limit on the number of mines that can be linked and neutralized using explosive and det cord.)
8. Mines are removed for later disposal

Legend
- Supervisor
- Mine detector
- Marker
- Neutralizer
- Medic
- Prober

Figure 8. Metal Detector Mineclearing Process
Process #3  Dogs and Metal Detectors
          Sniff - Detect - Probe - Excavate

Assumptions:

All sniffs are immediately marked for follow-up verification by metal detector, probing and excavating. Valid targets must be neutralized en masse at the end of the day, since residual odor will prevent dogs from further work if a mine is detonated. Therefore, the total area swept each day is limited to the number of mines which can be completely neutralized by the end of the day. Using the grapnel pull method to dislodge the mine, 5 targets can be dealt with simultaneously at the end of the day. If a mine does not detonate, wait 5 minutes and then carry it to a mass destruction pit.

two dog teams, detectors, and markers sweep a 3 meter lane
   -- 6400 m2 in 4 hours
256 mines expected.
during this time
   -- 12 minutes to excavate/verify each target
   = 51.2 manhours required
   = 10 excavators for 5.12 hours

neutralize 5 mines at a time in 2 safe distance zones
(each zone is 50x50 meters), each zone has a neutralizer and supervisor
   = 2.2 hours to neutralize

total daily working time = 7.32 hours
Staffing:

2 dogs
2 dog handlers
4 detector operators
2 target markers
10 probers who also excavate
2 zone neutralizers
2 zone supervisors
1 medic
1 top supervisor

total 26 personnel at $ 16 per day = $ 416

Equipment:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tools</td>
<td>$ 43.20</td>
</tr>
<tr>
<td>Backup Explosives</td>
<td>$ 391.00</td>
</tr>
<tr>
<td>4 metal detectors at $ 2.30 per day each</td>
<td>$ 9.20</td>
</tr>
<tr>
<td>2 dogs depreciate at $ 10 per day</td>
<td>$ 20.00</td>
</tr>
</tbody>
</table>

Total Daily Cost -- $ 879.40
Total Cost to Clear -- $ 0.14 per square meter

Other Processes

Figures 10 and 11 show additional mineclearing processes, equipment employed, and personnel employed.
Current Techniques Elaborated (Dog, Metallic Mine Detector and Probing Where Metallic Detectors are Effective)

- Wind direction
- Scent cone
- 10 m
- 2 m
- 25 m

Legend:
- Supervisor
- Handler
- Dog
- Mine detector
- Marker
- Neutralizer
- Medic
- Prober
- Mine

Sequence:
1. A dog indicates a mine
2. Handler, mine detector and marker advance - 1 min
3. Mine detector sweeps area in which mine is indicated (10 m² scent cone) - 2.9 min
4. If mine detector indicates a mine, marker marks mine - negligible
5. Prober verifies (uncovers mine) - 12 min
6. Neutralizers advance to mines and other personnel withdraw 50 m - 1 min
7. Neutralizers place grapnel or explosives - 2 min
8. Neutralizers withdraw 50 m and detonate explosive if grapnel is not employed - 1 min
9. Neutralizes pull grapnels and wait (up to 5 mines will be neutralized at a time) - 5 min
10. Mines are removed for later disposal - 1 min

Is designated area swept?
- Yes
- No

Is it a mine?
- Yes
- No

Is it safe to neutralize mines?
- Yes
- No

Wait till area is safe
- Yes
- No

Are there additional objects?
- Yes
- No

Detector advances to next area
- Yes
- No

Mark Object

Is object detected?
- Yes
- No

Advance & sweep with detector

Is explosive used?
- Yes
- No

Detonate Explosive

Do/does mine(s) explode?
- Yes
- No

Wait 5 Minutes

Are there additional mines in specified area?
- Yes
- No

Prober advances to next area

Figure 9. Dog and Metal Detector Mineclearing Process
Current Techniques Elaborated (Dog, Metallic Mine Detector and Probing Where Metallic Detectors Are Not Effective)

Sequence:
1. A dog indicates a mine - 1 min
2. Handler and probers advance - 1.67 hrs
3. Probers sweep area - negligible
4. Marker marks object - 12 min
5. Prober verifies (uncovers mines) - 12 min

On completion of sweep of specified area, or when dogs have advanced sufficiently not to be affected by detonation effects...

6. Neutralizer advances to mine and other personnel withdraw 50 m - 1 min
7. Neutralizer places grapnel or explosives - 2 min
8. Neutralizer withdraws 50 m and detonates explosive if grapnel is not employed - 1 min
9. Neutralizer pulls grapnel and waits (up to 5 mines will be neutralized at a time) - 5 min
10. Mine is removed for later disposal - 1 min

Legend:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Supervisor</td>
</tr>
<tr>
<td>O</td>
<td>Handler</td>
</tr>
<tr>
<td>O</td>
<td>Dog</td>
</tr>
<tr>
<td>O</td>
<td>Marker</td>
</tr>
<tr>
<td>O</td>
<td>Neutralizer</td>
</tr>
<tr>
<td>O</td>
<td>Medic</td>
</tr>
<tr>
<td>O</td>
<td>Prober</td>
</tr>
<tr>
<td>+</td>
<td>Mine</td>
</tr>
</tbody>
</table>

Figure 10. Dog, Metal Detector, and Probing (for plastic mines) Mineclearing Process
Current Techniques Elaborated (MDDS)

Vapor Detection
- Two man crew

Sequence:
1. Vapor collection indicates a mine
   - .5 hrs
2. Dog and Clearance Teams move to area (assume 25 km at 50 km/hr)
   - 5.1 hrs
3. Dogs exit vehicle and localize mines (5,000 m² / 1,571 m²)
   - negligible
4. Clearance vehicle advances (assume .5 km at 50 km/hr)
   - .6 min
5. Clearance vehicle detects and marks mine (assume metallic mine detector with the same sweep rate as manual detector and a scent cone of 10m²)
   - 2.9 min
6. Clearance vehicle withdraws
   - negligible
7. Sensor head is removed, excavation head is affixed to robotic arm (educated guess)
   - 15 min
8. Clearance vehicle returns to site
   - negligible
9. Clearance vehicle excavates mine (educated guess)
   - 5 minute
10. Clearance vehicle moves mine to edge of road for disposal
    - negligible
11. After 5 minutes mine is picked-up and moved to designated site for later disposal
    - 5 minutes

Dogs are presented samples

Do dogs alert?
- Yes
  - Teams advance to next area
- No
  - Clearance team advance to next area

Dog and clearance teams move to area

Dogs sweep
- No
  - Is designated area swept?
    - Yes
      - Dog team advance to next area
    - No
      - Clearance team returns

Do dogs alert?
- Yes
  - Clearance team advances
- No
  - Clearance team sweeps

Clearance team locates and marks mine

Clearance team replaces head

Clearance team withdraws

Are there additional markers?

Figure 11. Mobile Dog and Robotic Mineclearing Process
4. Summary of Demining Costs

Administrative and logistics overhead for demining operations typically multiply clearance costs by 2.75 as a burdened rate to sustain the operations. These cost involve purchasing and maintaining a base camp and its equipment, training demining personnel, feeding and housing personnel, establishing radio and telephone communications, and supporting transportation within the country. Applying this burden rate to the base rate per square meter cleared shows the following cost effectiveness breakout for the three baseline demining processes:

<table>
<thead>
<tr>
<th></th>
<th>Probing</th>
<th>--</th>
<th>$ 3.85 per square meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Metal Detectors</td>
<td>--</td>
<td>$ 0.50</td>
</tr>
<tr>
<td>#2</td>
<td>Dogs</td>
<td>--</td>
<td>$ 0.39</td>
</tr>
</tbody>
</table>

Since most real world scenarios will involve conditions other than those assumed in this basic analysis, a sensitivity analysis of these result is presented. This sensitivity analysis varied the minefield density from the assumed average of 4 mines per 100 square meters. This simple variation shows dramatic cost effectiveness shifts when using these three baseline demining processes.

Sensitivity Analysis

<table>
<thead>
<tr>
<th>Minefield Density per 100 m²</th>
<th>Process #1 Probing</th>
<th>Process #2 Detectors</th>
<th>Process #3 Dogs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>daily area</td>
<td>cost factor</td>
<td>daily area</td>
</tr>
<tr>
<td>0</td>
<td>108</td>
<td>1</td>
<td>2040</td>
</tr>
<tr>
<td>4</td>
<td>108</td>
<td>1</td>
<td>1700</td>
</tr>
<tr>
<td>10</td>
<td>108</td>
<td>1</td>
<td>1700</td>
</tr>
<tr>
<td>20</td>
<td>108</td>
<td>1</td>
<td>1200</td>
</tr>
<tr>
<td>30</td>
<td>90</td>
<td>1.2</td>
<td>900</td>
</tr>
<tr>
<td>40</td>
<td>80</td>
<td>1.4</td>
<td>750</td>
</tr>
</tbody>
</table>
The effect of increasing minefield density is that clearing the land costs more. However, this increase is different for each technology. The cost driver is again the issue that closure must be reached at the end of each day. Therefore, one must stop detecting mines at the limit which can be destroyed by that evening.

Although the most expensive demining approach, probing is the most predictable from a cost effectiveness and planning point of view. Regardless of the number of mines in the ground, probing will cost roughly the same per square meter cleared, with the cost factor increasing over the baseline only with ridiculously dense minefields. Nevertheless, probing remains the single most expensive approach to clearing landmines, regardless of minefield density.

An interesting reversal in cost effectiveness, however, occurs between using detectors alone and detectors with dogs. At minefield densities between 4 and 10 mines per 100 square meters, at about 5.3, the use of dogs may begin to increase clearance costs. The reason for this is that dogs can very quickly indicate that mines are present, but if there are too many mines it becomes dangerous for the dogs to operate. Plus it becomes difficult for them to pinpoint the mine location. In very dense minefield, the dog can only indicate that there are mines there. Pinpointing then is turned over to the detector operators.

When there are no mines present, which often happens, either dogs or detectors provide the most cost effective approach to certifying the location as mine free. In this analysis the dogs are considered to be operating on foot so there is no cost reduction when no mines are found. The excavators and neutralizers end up having nothing to do, but must be paid any way.

When detectors are used and no mines are found, the costs are shown to decrease. However, this may only be a anomaly in the analysis. This analysis assumed that false alarms were consistent between technologies, or there were no false alarms considered. This is highly unlikely when using metal detectors. A false alarm could be considered a mine detection in this case. More than likely, detectors will be operating in an environment where several false alarms per 100 square meters exist.
Only the dogs are nearly immune to false alarms, unless intentionally spoofed. However, as discussed earlier, only a well trained dog handler can determine that the dog is indeed working as expected that day in that location. If a dog does not indicate a mine, it's not always because there is no mine. It's because the dog did not smell a mine.

The dog can also smell something that is not a real mine danger. There are ways to spoof dogs intentionally. For example, a dog will cue on finely ground explosives mixed in with the soil. The handler and detector will discover nothing, but the dog will smell explosives. However, such practice and its effect is out of the scope of this basic analysis.
V.
COMPUTER MODELING

The computer model developed to evaluate the cost effectiveness of different processes and parameters comprises four modules: 1) Scenario Development, 2) Survey, 3) Clearance, and 4) Cost Analysis. This organization to the model is consistent with the community oriented demining philosophy and incorporates the distinct elements involved in a demining program. Within the scenario development, a distribution of landmine concentrations can be postulated, which may represented the likely situation with a particular country or region. Using a flexible scenario approach in the modeling permits the survey process to be fully challenged and evaluated from a cost and effectiveness perspective. Survey outputs include the distribution mines which were identified by the survey technique, and the amount of un-mined area which will also end up being cleared, due to errors in the survey process. The results of the survey, which are now scenario dependent, are then passed on to the clearance module. Each candidate clearance process is evaluated against the survey results to determine the level of clearance achieved. Finally, the cost module calculates the total cost and duration of all survey and clearance processes considered for that scenario, based on cost and level-of-effort (LOE) input parameters.

This model is sufficiently flexible and robust to permit a multitude of survey and clearance processes -- either existing, emerging, or postulated -- to be evaluated against real world demining scenarios. For this reason, this model is useful not only for achieving the stated objectives of this study, but also as a planning and evaluation tool for ongoing and upcoming demining efforts.
1. Scenario Generation Module

The inputs for the scenario generation are shown in Table 6 for the Mozambique scenario evaluated in this study.

<table>
<thead>
<tr>
<th>Table 6</th>
<th>Mozambique Scenario Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total area to be considered (square kilometers)</td>
<td>39,350</td>
</tr>
<tr>
<td>Total estimated number of mines</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Estimated mine cluster distribution:</td>
<td></td>
</tr>
<tr>
<td>% occurrence</td>
<td>cluster area (square meters)</td>
</tr>
<tr>
<td>5</td>
<td>1000</td>
</tr>
<tr>
<td>20</td>
<td>1000</td>
</tr>
<tr>
<td>50</td>
<td>1000</td>
</tr>
<tr>
<td>20</td>
<td>1000</td>
</tr>
<tr>
<td>5</td>
<td>1000</td>
</tr>
</tbody>
</table>

The rationale for entering an estimated mine cluster distribution within the country is that residual landmines are not evenly distributed throughout a war zone. Mines are typically placed in clusters, and if the clusters are large enough one may call it a minefield. In Mozambique, as in other guerrilla war zones, large minefields are rare, but may still occur. More often, however, several mines are placed in relatively close proximity around a bridge, road intersection, etc., which is heavily traveled. The estimated distribution of mine clusters can have a significant effect on surveying and clearing operations, and should be considered in the cost and effectiveness modeling. Table 6 shows our best estimate of what could be expected in Mozambique, based on reported mine clearing operations to date.

The percent occurrence in Table 6 means that this percentage of mines will occur in clusters of this many mines. For example, 5% of mines will be found in clusters containing only two mines, and these two mines will be located within an area of 1000 square meters. Depending on the estimated distribution of mines within the country, some survey techniques may have more or less effectiveness, as will be discussed in the survey module of this model.

Table 7 shows cluster distribution output for the Mozambique scenario.

<table>
<thead>
<tr>
<th>Table 7</th>
<th>Mozambique Scenario Output</th>
</tr>
</thead>
<tbody>
<tr>
<td># clusters</td>
<td># mines in cluster</td>
</tr>
<tr>
<td>25,000</td>
<td>2</td>
</tr>
<tr>
<td>40,000</td>
<td>5</td>
</tr>
<tr>
<td>50,000</td>
<td>10</td>
</tr>
<tr>
<td>10,000</td>
<td>20</td>
</tr>
<tr>
<td>1,667</td>
<td>30</td>
</tr>
</tbody>
</table>
2. Country Survey Module

Table 8a,b,c shows typical survey system inputs for the three survey technologies assessed in this study.

<table>
<thead>
<tr>
<th>Table 8a</th>
<th>Human Intelligence (HUMINT) Survey Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>probability of mine detection</td>
</tr>
<tr>
<td>0.95</td>
<td>probability of cluster detection</td>
</tr>
<tr>
<td>0.00</td>
<td>number of false mine detections per square kilometer</td>
</tr>
<tr>
<td>0.33</td>
<td>false cluster detection area as a percentage of a square kilometer</td>
</tr>
<tr>
<td>0.00</td>
<td>maximum detection location error in meters</td>
</tr>
<tr>
<td>30.00</td>
<td>local man-hours per square kilometer surveyed</td>
</tr>
<tr>
<td>0.00</td>
<td>expatriate man-hours per square kilometer surveyed</td>
</tr>
<tr>
<td>8.00</td>
<td>work day number of hours</td>
</tr>
<tr>
<td>0.00</td>
<td>survey system square kilometers per hour</td>
</tr>
<tr>
<td>0.00</td>
<td>survey system duty cycle hours per day</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 8b</th>
<th>MEDDS Survey Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.95</td>
<td>probability of mine detection</td>
</tr>
<tr>
<td>0.00</td>
<td>probability of cluster detection</td>
</tr>
<tr>
<td>0.00</td>
<td>number of false mine detections per square kilometer</td>
</tr>
<tr>
<td>0.00</td>
<td>false cluster detection area as a percentage of a square kilometer</td>
</tr>
<tr>
<td>125.00</td>
<td>maximum detection location error in meters</td>
</tr>
<tr>
<td>0.00</td>
<td>local man-hours per square kilometer surveyed</td>
</tr>
<tr>
<td>40.00</td>
<td>expatriate man-hours per square kilometer surveyed</td>
</tr>
<tr>
<td>8.00</td>
<td>work day number of hours</td>
</tr>
<tr>
<td>0.05</td>
<td>survey system square kilometers per hour</td>
</tr>
<tr>
<td>8.00</td>
<td>survey system duty cycle hours per day</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 8c</th>
<th>Airborne Survey Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.70</td>
<td>probability of mine detection</td>
</tr>
<tr>
<td>0.00</td>
<td>probability of cluster detection</td>
</tr>
<tr>
<td>0.50</td>
<td>number of false mine detections per square kilometer</td>
</tr>
<tr>
<td>0.00</td>
<td>false cluster detection area as a percentage of a square kilometer</td>
</tr>
<tr>
<td>150.00</td>
<td>maximum detection location error in meters</td>
</tr>
<tr>
<td>0.00</td>
<td>local man-hours per square kilometer surveyed</td>
</tr>
<tr>
<td>0.47</td>
<td>expatriate man-hours per square kilometer surveyed</td>
</tr>
<tr>
<td>8.00</td>
<td>work day number of hours</td>
</tr>
<tr>
<td>4.30</td>
<td>survey system square kilometers per hour</td>
</tr>
<tr>
<td>8.00</td>
<td>survey system duty cycle hours per day</td>
</tr>
</tbody>
</table>

As shown in Tables 8a through 8c, survey technologies either detect the presence of landmines by directly detecting clusters or by detecting individual mines and then surmising the presence of a minefield cluster. For example, HUMINT is a process of interviewing local people, checking records, and looking at maps to make an educated guess as to
whether a particular location should be checked for landmines. Therefore, HUMINT is not a landmine detection process, it is a cluster detection process. Detection of the cluster occurs when a correct decision is made based on relevant information concerning that location. There may or may not be any landmines in that location, but the location will be cleared by a demining team anyway. Hence, there is a large percentage of area that will be cleared that contains no mines at all -- 33% of the total area in this scenario.

Our best estimate of the percentage of landmine clusters which will be correctly identified in this scenario is 95% by HUMINT. However, this is at a cost of having to clear 33% of the total area. If we had wanted to correctly identify 100% of the clusters by HUMINT, the only option is to clear 100% of the area in question. Therefore, there is a tradeoff when using HUMINT, as to how many mines will eventually be cleared.

The MEDDS and Airborne detection systems identify landmine clusters through direct detection of an individual landmine. As a result, clusters with many mines have a higher inherent chance of being detected than low density clusters. For example, a 70% chance of identifying any one mine will result in a 70% chance of correctly finding a 1 mine cluster. The probability of finding clusters with more than one mine is correspondingly higher, since a few mines can be missed and the cluster will still be found. This illustrates the importance of estimating the mine cluster distribution within the country.

Tables 9a,b,c show the survey results for the three survey systems, based on the above inputs.

<table>
<thead>
<tr>
<th>cluster size</th>
<th>number of clusters</th>
<th>percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>23,749</td>
<td>95</td>
</tr>
<tr>
<td>5</td>
<td>37,999</td>
<td>95</td>
</tr>
<tr>
<td>10</td>
<td>47,499</td>
<td>95</td>
</tr>
<tr>
<td>20</td>
<td>9,499</td>
<td>94.99</td>
</tr>
<tr>
<td>30</td>
<td>1,583</td>
<td>94.96</td>
</tr>
</tbody>
</table>

unmined area to be cleared (square kilometers) 12,985.5
local man-hours expended for survey 1,180,500
expatriate man-hours 0
survey system hours 0
survey system days 0
Table 9b
Survey Results for MEDDS

<table>
<thead>
<tr>
<th>cluster size</th>
<th>number of clusters</th>
<th>percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>24,937</td>
<td>99.75</td>
</tr>
<tr>
<td>5</td>
<td>39,999</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>49,999</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>10,000</td>
<td>100</td>
</tr>
<tr>
<td>30</td>
<td>1,667</td>
<td>100</td>
</tr>
</tbody>
</table>

unmined area to be cleared (square kilometers) 6214.5
local man-hours expended for survey 0
expatriate man-hours 1,574,000
survey system hours 787,000
survey system days 98,375

Table 9c
Survey Results for Airborne

<table>
<thead>
<tr>
<th>cluster size</th>
<th>number of clusters</th>
<th>percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>22,749</td>
<td>91</td>
</tr>
<tr>
<td>5</td>
<td>39,902</td>
<td>99.75</td>
</tr>
<tr>
<td>10</td>
<td>49,999</td>
<td>100</td>
</tr>
<tr>
<td>20</td>
<td>9,999</td>
<td>99.99</td>
</tr>
<tr>
<td>30</td>
<td>1,666</td>
<td>99.94</td>
</tr>
</tbody>
</table>

unmined area to be cleared (square kilometers) 1,390
local man-hours expended for survey 0
expatriate man-hours 18,297
survey system hours 9,151
survey system days 1,144

For each supplemental survey, the above primary survey results are then resurveyed using the supplemental system. The results are less landmine clusters identified, but also a significant reduction in unmined area that has to be cleared. In this model, the supplemental survey throws out a previous positive detection if it is not reconfirmed by the supplemental survey. Hence, the supplemental survey should have at least as high a detection probability as the primary.

There may be other ways of handling supplemental survey information. For example, an area will be cleared if either survey indicates a positive detection. In this case, the number of clusters detected by the primary survey will not decrease as a result of a supplemental survey. However, more false alarms will be generated by the supplemental survey, so unmined area to be cleared will not decrease as much as before.

One could also do a complementary survey. This means, take the area declared unmined and not to be cleared by the primary survey, and resurvey it with the second survey process. This will also increase the number of cluster ultimately identified and cleared, but will also increase the unmined area that has to be cleared due to more false
 detections. So again there are tradeoffs in how one configures the survey process. These latter two survey options are not considered in this study.

3. Landmine Clearance Module

The clearance process to be used requires similar inputs in order to evaluated effectiveness and efficiency. Tables 10a, b, c, and d show the inputs used for the five clearance processes evaluated in this study.

Table 10a
Clearance Process Inputs
Probing

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>basic team size number of people</td>
</tr>
<tr>
<td>12.00</td>
<td>minutes to excavate and verify a suspected target detection</td>
</tr>
<tr>
<td>2</td>
<td>1=batch process, 2=continuous flow of excavating/verifying</td>
</tr>
<tr>
<td>0.00</td>
<td>area of neutralization safe zone in square meters</td>
</tr>
<tr>
<td>1</td>
<td>number of mines per simultaneous neutralization</td>
</tr>
<tr>
<td>1</td>
<td>number of mines per simultaneous excavation/verify</td>
</tr>
<tr>
<td>5.25</td>
<td>minutes to neutralize a mine</td>
</tr>
<tr>
<td>8.00</td>
<td>work day hours</td>
</tr>
<tr>
<td>3.00</td>
<td>false alarms per 100 square meters</td>
</tr>
<tr>
<td>1.00</td>
<td>probability of true mine detection</td>
</tr>
<tr>
<td>6.00</td>
<td>basic team sweep rate (no false alarms and no true detections) square meters per hour</td>
</tr>
</tbody>
</table>

Table 10b
Clearance Process Inputs
Detectors

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>basic team size number of people</td>
</tr>
<tr>
<td>12.00</td>
<td>minutes to excavate and verify a suspected target detection</td>
</tr>
<tr>
<td>1</td>
<td>1=batch process, 2=continuous flow of excavating/verifying</td>
</tr>
<tr>
<td>2500</td>
<td>area of neutralization safe zone in square meters</td>
</tr>
<tr>
<td>5</td>
<td>number of mines per simultaneous neutralization</td>
</tr>
<tr>
<td>2</td>
<td>number of mines per simultaneous excavation/verify</td>
</tr>
<tr>
<td>5.25</td>
<td>minutes to neutralize a mine</td>
</tr>
<tr>
<td>8.00</td>
<td>work day hours</td>
</tr>
<tr>
<td>3.00</td>
<td>false alarms per 100 square meters</td>
</tr>
<tr>
<td>0.92</td>
<td>probability of true mine detection</td>
</tr>
<tr>
<td>340</td>
<td>basic team sweep rate (no false alarms and no true detections) square meters per hour</td>
</tr>
</tbody>
</table>
Table 10c
Clearance Process Inputs
Dogs and Detectors

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>basic team size number of people</td>
</tr>
<tr>
<td>12.00</td>
<td>minutes to excavate and verify a suspected target detection</td>
</tr>
<tr>
<td>1</td>
<td>1=batch process, 2=continuous flow of excavating/verifying</td>
</tr>
<tr>
<td>2500</td>
<td>area of neutralization safe zone in square meters</td>
</tr>
<tr>
<td>5</td>
<td>number of mines per simultaneous neutralization</td>
</tr>
<tr>
<td>10</td>
<td>number of mines per simultaneous excavation/verify</td>
</tr>
<tr>
<td>5.25</td>
<td>minutes to neutralize a mine</td>
</tr>
<tr>
<td>8.00</td>
<td>work day hours</td>
</tr>
<tr>
<td>3.00</td>
<td>false alarms per 100 square meters</td>
</tr>
<tr>
<td>0.95</td>
<td>probability of true mine detection</td>
</tr>
<tr>
<td>1600</td>
<td>basic team sweep rate (no false alarms and no true detections) square meters per hour</td>
</tr>
</tbody>
</table>

Table 10d
Clearance Process Inputs
Dogs and Probing

<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>basic team size number of people</td>
</tr>
<tr>
<td>12.00</td>
<td>minutes to excavate and verify a suspected target detection</td>
</tr>
<tr>
<td>1</td>
<td>1=batch process, 2=continuous flow of excavating/verifying</td>
</tr>
<tr>
<td>2500</td>
<td>area of neutralization safe zone in square meters</td>
</tr>
<tr>
<td>5</td>
<td>number of mines per simultaneous neutralization</td>
</tr>
<tr>
<td>3</td>
<td>number of mines per simultaneous excavation/verify</td>
</tr>
<tr>
<td>5.25</td>
<td>minutes to neutralize a mine</td>
</tr>
<tr>
<td>8.00</td>
<td>work day hours</td>
</tr>
<tr>
<td>3.00</td>
<td>false alarms per 100 square meters</td>
</tr>
<tr>
<td>0.95</td>
<td>probability of true mine detection</td>
</tr>
<tr>
<td>1600</td>
<td>basic team sweep rate (no false alarms and no true detections) square meters per hour</td>
</tr>
</tbody>
</table>

The development of these inputs requires considerable preparatory work and analysis on how best to employ different demining technologies. The costs involved in clearance operations are more complicated than just counting the number of people working and measuring the area covered each day. To evaluate efficiency, individual jobs, duty cycles, and task efficiencies have to be considered in relation to the minefield cluster parameters.

As shown in the inputs tables, clearance operations are structured around a basic clearance team. Team size varies based on the clearance technique and the safe zone area within which each team may operate independently from another team. Teams which are bigger will normally be covering more area. For example, 26 men support only two dogs in the Dogs and Detectors process. This is because the dogs can very rapidly locate suspected mine sights to within ten meters. However, detector operators work much slower when pinpointing the exact location to be excavated. Therefore, this technology employs a basic team which is much larger than a probing alone team, but it can cover more area in a day’s work. Even more personnel support in the form of probers is needed when the detectors are unsafe to use, as in a minefield situation which includes plastic or low-
metallic landmines. Each team also employs a proportional number of support personnel, such as medics and supervisors.

An important aspect of demining operations is that all mines detected in a work day must be neutralized by the end of the day, in order to avoid pilferage. Therefore, the actual amount of area cleared will be affected by the false alarm and true detection rates of the clearance technique. The basic sweep rate of a team is based on no detections or false alarms. However, as each false alarm is marked and excavated, time is lost. Similarly, each true detection, excavation, and neutralization costs more time than a false alarm. Therefore, for each cluster density and the system false alarms rate, the model calculates the maximum area which can be swept and neutralized each work day.

Some clearance processes can be characterized as batch processes or continuous flow processes. Making this distinction also affects process and team efficiency. Probing alone is a continuous flow process, since each time a detection (false or true) is made the target has to be excavated and neutralized (if true) before that prober can continue on. It is simply too dangerous for a prober to continue to probe on after making a suspected contact.

Conversely, some processes can be characterized as batch clearance processes. Dog teams and metal detector teams can more rapidly sweep and area with less risk of accidentally detonating a suspected target. The dog will immediately sit at the edge of the target sent cone, and will perhaps never actually step on a mine that it does not smell. Similarly, a metal detector operator does not step on every square inch of terrain as he sweeps his detector. Therefore, using a dog or detector system permits the operator to continue sweeping as another individual marks the suspected target, to be followed by another individual who may begin excavation of that target once the dog or detector team has moved safely ahead. After all suspected targets are excavated and verified, bulk or batch neutralization can then occur. When structuring a batch process clearance team, the number of excavators and neutralizers has to be carefully balanced with the number of dog teams or detector teams, based on suspects false alarm and true detection rates.

Structuring the clearance process inputs to this level of detail permits tradeoffs and optimization of demining teams to be performed, as well as evaluating the efficiency of current team structure.

For each survey process, the resulting landmine cluster distribution which has been identified by the survey is then cleared according to these input parameters. The clearance process outputs are the total number of mines cleared and the number of team days to perform the clearance of all unmined and mined areas identified in the survey.

4. Survey and Clearance Cost Module

Each survey and clearance process requires specific cost inputs in order to assess the total cost of operations. Since operations costs can vary depending on the length of the demining program, the level of effort must also be entered. For this Mozambique scenario, all survey and demining team levels of effort were adjusted so that each technology combination required ten years to complete. Surveying is assumed to be able to run concurrently with clearing, with a negligible time delay before the first clearance assignments. Therefore, both survey and clearance operations are staffed for ten years of work. Where survey systems are very efficient, such as with the airborne technology, only one survey team may be required, and they may complete work in less than ten years. However, one cannot field less than one whole team under these circumstances. Survey system and logistics daily costs are based on the purchase price of equipment amortized
over a life cycle of 10 years. The following tables present the primary survey and clearance cost and level of effort inputs. Level of efforts for supplemental surveys vary, as will the clearance team levels of effort. Cost inputs are constant, however. There are a total of 24 clearance process levels of effort for a total of 6 survey processes. A representative sample is provided here.

Table 11a
Survey System Cost Inputs
HUMINT

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>survey local personnel daily rate in dollars</td>
</tr>
<tr>
<td>300</td>
<td>survey expatriate personnel daily rate</td>
</tr>
<tr>
<td>0</td>
<td>survey system daily rate</td>
</tr>
<tr>
<td>3000</td>
<td>total training cost each person</td>
</tr>
<tr>
<td>12</td>
<td>daily logistics cost per man</td>
</tr>
<tr>
<td>50</td>
<td>local personnel level of effort in survey (# men)</td>
</tr>
<tr>
<td>0</td>
<td>expatriate level of effort</td>
</tr>
<tr>
<td>0</td>
<td>survey system level of effort (# systems)</td>
</tr>
</tbody>
</table>

Table 11b
Survey System Cost Inputs
MEDDS

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>survey local personnel daily rate in dollars</td>
</tr>
<tr>
<td>300</td>
<td>survey expatriate personnel daily rate</td>
</tr>
<tr>
<td>160</td>
<td>survey system daily rate</td>
</tr>
<tr>
<td>3000</td>
<td>total training cost each person</td>
</tr>
<tr>
<td>12</td>
<td>daily logistics cost per man</td>
</tr>
<tr>
<td>0</td>
<td>local personnel level of effort in survey (# men)</td>
</tr>
<tr>
<td>160</td>
<td>expatriate level of effort</td>
</tr>
<tr>
<td>40</td>
<td>survey system level of effort (# systems)</td>
</tr>
</tbody>
</table>

Table 11c
Survey System Cost Inputs
Airborne

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>survey local personnel daily rate in dollars</td>
</tr>
<tr>
<td>300</td>
<td>survey expatriate personnel daily rate</td>
</tr>
<tr>
<td>2500</td>
<td>survey system daily rate</td>
</tr>
<tr>
<td>3000</td>
<td>total training cost each person</td>
</tr>
<tr>
<td>12</td>
<td>daily logistics cost per man</td>
</tr>
<tr>
<td>0</td>
<td>local personnel level of effort in survey (# men)</td>
</tr>
<tr>
<td>4</td>
<td>expatriate level of effort</td>
</tr>
<tr>
<td>1</td>
<td>survey system level of effort (# systems)</td>
</tr>
</tbody>
</table>
### Table 11a
Clearance System Cost Inputs
Probing

<table>
<thead>
<tr>
<th>25.4</th>
<th>backup explosives cost per mine neutralization $</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.50</td>
<td>explosives cost per batch or individual neutralization $</td>
</tr>
<tr>
<td>16</td>
<td>daily rate for local personnel $/day</td>
</tr>
<tr>
<td>300</td>
<td>daily rate for expatriate personnel $/day</td>
</tr>
<tr>
<td>1.75</td>
<td>equipment daily cost $/day</td>
</tr>
<tr>
<td>3000</td>
<td>training cost per man $</td>
</tr>
<tr>
<td>12</td>
<td>logistics daily cost per man $/day</td>
</tr>
<tr>
<td>12,128</td>
<td># of basic teams Level of Effort</td>
</tr>
<tr>
<td>0</td>
<td>number of expatriate in a team</td>
</tr>
</tbody>
</table>

### Table 11b
Clearance System Cost Inputs
Detectors

<table>
<thead>
<tr>
<th>25.4</th>
<th>backup explosives cost per mine neutralization $</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.50</td>
<td>explosives cost per batch or individual neutralization $</td>
</tr>
<tr>
<td>16</td>
<td>daily rate for local personnel $/day</td>
</tr>
<tr>
<td>300</td>
<td>daily rate for expatriate personnel $/day</td>
</tr>
<tr>
<td>20</td>
<td>equipment daily cost $/day</td>
</tr>
<tr>
<td>3000</td>
<td>training cost per man $</td>
</tr>
<tr>
<td>12</td>
<td>logistics daily cost per man $/day</td>
</tr>
<tr>
<td>292</td>
<td># of basic teams Level of Effort</td>
</tr>
<tr>
<td>0</td>
<td>number of expatriate in a team</td>
</tr>
</tbody>
</table>

### Table 11c
Clearance System Cost Inputs
Dogs and Detectors

<table>
<thead>
<tr>
<th>25.4</th>
<th>backup explosives cost per mine neutralization $</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.50</td>
<td>explosives cost per batch or individual neutralization $</td>
</tr>
<tr>
<td>16</td>
<td>daily rate for local personnel $/day</td>
</tr>
<tr>
<td>300</td>
<td>daily rate for expatriate personnel $/day</td>
</tr>
<tr>
<td>75</td>
<td>equipment daily cost $/day</td>
</tr>
<tr>
<td>3000</td>
<td>training cost per man $</td>
</tr>
<tr>
<td>12</td>
<td>logistics daily cost per man $/day</td>
</tr>
<tr>
<td>62</td>
<td># of basic teams Level of Effort</td>
</tr>
<tr>
<td>0</td>
<td>number of expatriate in a team</td>
</tr>
</tbody>
</table>
Table 11d
Clearance System Cost Inputs
Dogs and Probing

<table>
<thead>
<tr>
<th>Amount</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.4</td>
<td>backup explosives cost per mine neutralization $</td>
</tr>
<tr>
<td>3.50</td>
<td>explosives cost per batch or individual neutralization $</td>
</tr>
<tr>
<td>16</td>
<td>daily rate for local personnel $/day</td>
</tr>
<tr>
<td>300</td>
<td>daily rate for expatriate personnel $/day</td>
</tr>
<tr>
<td>65</td>
<td>equipment daily cost $/day</td>
</tr>
<tr>
<td>3000</td>
<td>training cost per man $</td>
</tr>
<tr>
<td>12</td>
<td>logistics daily cost per man $/day</td>
</tr>
<tr>
<td>195</td>
<td># of basic teams Level of Effort</td>
</tr>
<tr>
<td>0</td>
<td>number of expatriate in a team</td>
</tr>
</tbody>
</table>

5. Casualty Modeling

Casualty assessment is performed as a straight probability depending on the clearance process and the number of mines to be cleared. Casualty information to any level of statistical confidence is not available. The most comprehensive casualty information that we have found was made available by Navy Explosive Ordnance Disposal personnel located at Indian Head, Maryland. They performed a casualty rate retrospective for handling unexploded ordnance in an attempt to quantify expected risks for future range cleanup operations. Their conclusions were that there exist too many types of explosive ordnance and too many possible dud failure conditions to provide any statistical confidence in likely handling risks. At most they could say that the risk of handling a dud munition ran from one detonation in one thousand to one in one hundred thousand.

For our purposes, we selected the higher risk end of their zone of probability. Therefore, for each mine neutralized, we assessed a probability of a casualty at one in one thousand. This casualty rate affects those deminers who neutralize a true mine target. The exception to this casualty rate for neutralizers is when using the clearance process of probing alone. Since in our Mozambique scenario, there are only one million mines to be cleared, but nearly one million deminers are required on a continuous basis, experience among the neutralizers in dealing with a live mine will be very low. Most neutralizers may not even encounter one live mine during the ten year demining project. That makes for a lot of false alarms and perhaps a lessening of care when probing and excavating a suspected target. We feel this will result in much greater risk to the deminer. For this reason, casualty rates for neutralizers when probing alone is used are assessed at one in one hundred mines encountered.
The casualty rate for a prober, if he is not the individual who then excavates and verifies the target, is assessed at one in one thousand mines detected. Probers used in this manner have the opportunity to turn a suspected target over to an excavator for verification, and the prober may perhaps retain a higher level of caution. The tradeoff here is whether to shift the burden of verification to someone other than the prober, and who will become more careless as a result. Our feeling is than someone will become careless as a result of excavating or probing numerous false alarms over the years. Either the prober or the excavator should be assessed a higher casualty rate. Our choice is the latter individual.

Assessing the casualty rate for a detector operator is more difficult than a prober, since the detector operator does not normally step upon every square inch of terrain. Therefore, there is the chance that he will not detect a target, and still not step upon it. We estimated that on an average, a detector operator will step upon 5% of the area of the minefield he is sweeping. In our Mozambique scenario, 8% of the mines are undetectable. This gives a combined probability of the detector operator stepping on an undetected mine as four in one thousand mines.

When using dogs as the detection method, the dogs are also estimated to step upon 5% of the terrain they are sweeping. However, unless the dog handler is using the dog during conditions where the dog cannot smell any explosives at all, the likelihood of the dog not smelling a mine which passes right under its nose and paws as it advances is practically zero. We estimate that the probability of the dog being employed during inappropriate conditions at one in one thousand mines encountered. This coupled with a 5% chance of stepping on it gives a casualty rate of fifty dogs in one million mines encountered. However, lacking statistical information, almost any number could be justified in these casualty rates. We have selected casualty rates which seem plausible.

Recently published research performed on behalf of the United Nations seems to support our casualty estimates, based on large scale demining operations. According to their report, a 50-fold increase in mineclearing capacity by the year 2000 to respond to the number of mines being laid annually would probably result in about 2,000 de-miners injured or killed each year.13 Such a large increase in demining operations above current

---

levels would approach our hypothetical Mozambique scenario. Our modeling results estimate between approximately 2,000 to 10,000 casualties over a ten year demining program depending on the technology employed. Our casualty estimates are within the same range as those of the United Nations.

6. Cost and Operational Effectiveness Analysis Results

The following two spread sheets summarize the cost and effectiveness results for each technology approach for the Mozambique scenario.
## TABLE 12A.
Demining Technology Analysis Results
for a Mozambique Scenario:
Process Costs

<table>
<thead>
<tr>
<th>Survey Type</th>
<th>Clearance Type</th>
<th>Detection Probability</th>
<th>% Mines</th>
<th>% Cleared</th>
<th>Unmined Area</th>
<th>Survey Cost</th>
<th>Clearance Costs</th>
<th>Total Costs</th>
<th>Survey</th>
<th>Clearance</th>
<th>Total Cost/Area</th>
<th>Total Cost/Mine</th>
<th>Cost/Mine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humint</td>
<td>probing</td>
<td>0.999</td>
<td>94.9</td>
<td></td>
<td>13,000 km²</td>
<td>104</td>
<td>71.3 billion</td>
<td>1.81 million</td>
<td>1.81 million</td>
<td>75,132</td>
<td>4.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>87.4</td>
<td></td>
<td></td>
<td></td>
<td>1.7 billion</td>
<td>0.43 million</td>
<td>0.43 million</td>
<td>1,945</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>90.2</td>
<td></td>
<td></td>
<td></td>
<td>872 million</td>
<td>22,000</td>
<td>22,109</td>
<td>1,001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.95</td>
<td>90.5</td>
<td></td>
<td></td>
<td></td>
<td>4.03 billion</td>
<td>0.102 million</td>
<td>0.102 million</td>
<td>4,610</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEDDS</td>
<td>99.99</td>
<td>6,215</td>
<td>75 million</td>
<td></td>
<td>1,906</td>
<td>34 billion</td>
<td>0.86 million</td>
<td>0.86 million</td>
<td>34,034</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>probing</td>
<td>0.999</td>
<td>99.9</td>
<td></td>
<td></td>
<td></td>
<td>34 billion</td>
<td>0.86 million</td>
<td>0.86 million</td>
<td>34,034</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>92.2</td>
<td></td>
<td></td>
<td></td>
<td>859 million</td>
<td>22,000</td>
<td>22,000</td>
<td>934</td>
<td>103</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
<td>453 million</td>
<td>14,000</td>
<td>14,000</td>
<td>477</td>
<td>556</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>95</td>
<td></td>
<td></td>
<td></td>
<td>2.04 billion</td>
<td>54,040</td>
<td>54,212</td>
<td>2,148</td>
<td>2,323</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>99.5</td>
<td>1,391</td>
<td>3.6 million</td>
<td></td>
<td></td>
<td>7.76 billion</td>
<td>0.92 million</td>
<td>0.92 million</td>
<td>7,807</td>
<td>3.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>probing</td>
<td>0.999</td>
<td>99.4</td>
<td></td>
<td>1,391 km²</td>
<td>757</td>
<td>32.5 billion</td>
<td>0.83 million</td>
<td>0.83 million</td>
<td>34,247</td>
<td></td>
<td>646</td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>91.5</td>
<td></td>
<td></td>
<td></td>
<td>264 million</td>
<td>7,000</td>
<td>7,100</td>
<td>289</td>
<td>293</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>94.5</td>
<td></td>
<td></td>
<td></td>
<td>150 million</td>
<td>4,000</td>
<td>4,100</td>
<td>159</td>
<td>163</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>94.5</td>
<td></td>
<td></td>
<td></td>
<td>606 million</td>
<td>15,160</td>
<td>15,240</td>
<td>1,642</td>
<td>1,664</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humint-MEDDS</td>
<td>94.99</td>
<td>5,064</td>
<td>29 million</td>
<td></td>
<td></td>
<td>32.5 billion</td>
<td>0.83 million</td>
<td>0.83 million</td>
<td>34,247</td>
<td></td>
<td>646</td>
<td></td>
</tr>
<tr>
<td></td>
<td>probing</td>
<td>0.999</td>
<td>94.9</td>
<td></td>
<td></td>
<td></td>
<td>32.5 billion</td>
<td>0.83 million</td>
<td>0.83 million</td>
<td>34,247</td>
<td></td>
<td>646</td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>97.4</td>
<td></td>
<td></td>
<td></td>
<td>816 million</td>
<td>21,000</td>
<td>22,000</td>
<td>934</td>
<td>967</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>95.2</td>
<td></td>
<td></td>
<td></td>
<td>431 million</td>
<td>11,000</td>
<td>12,000</td>
<td>478</td>
<td>510</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>95.2</td>
<td></td>
<td></td>
<td></td>
<td>1.94 billion</td>
<td>49,500</td>
<td>51,400</td>
<td>2,152</td>
<td>2,184</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Humint-airborne</td>
<td>94.92</td>
<td>459</td>
<td>5.3 million</td>
<td></td>
<td>135</td>
<td>2.65 billion</td>
<td>70,000</td>
<td>70,132</td>
<td>2,807</td>
<td>2,813</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>probing</td>
<td>0.999</td>
<td>94.4</td>
<td></td>
<td></td>
<td></td>
<td>2.65 billion</td>
<td>70,000</td>
<td>70,132</td>
<td>2,807</td>
<td>2,813</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>97</td>
<td></td>
<td></td>
<td></td>
<td>145 million</td>
<td>4,000</td>
<td>4,100</td>
<td>167</td>
<td>172</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>89.8</td>
<td></td>
<td></td>
<td></td>
<td>88.6 million</td>
<td>2,300</td>
<td>2,400</td>
<td>99</td>
<td>105</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>89.8</td>
<td></td>
<td></td>
<td></td>
<td>320 million</td>
<td>6,132</td>
<td>6,229</td>
<td>358</td>
<td>363</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MEDDS-airborne</td>
<td>99.49</td>
<td>220</td>
<td>75.8 million</td>
<td></td>
<td>1926</td>
<td>1.35 billion</td>
<td>34,000</td>
<td>34,260</td>
<td>1,358</td>
<td>1,428</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>probing</td>
<td>0.999</td>
<td>99.4</td>
<td></td>
<td></td>
<td></td>
<td>1.35 billion</td>
<td>34,000</td>
<td>34,260</td>
<td>1,358</td>
<td></td>
<td>1,428</td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>91.5</td>
<td></td>
<td></td>
<td></td>
<td>120 million</td>
<td>3,000</td>
<td>3,000</td>
<td>131</td>
<td>124</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>94.5</td>
<td></td>
<td></td>
<td></td>
<td>76.7 million</td>
<td>2,000</td>
<td>2,000</td>
<td>81</td>
<td>162</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>94.5</td>
<td></td>
<td></td>
<td></td>
<td>259 million</td>
<td>6,600</td>
<td>6,500</td>
<td>274</td>
<td>355</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 12B.
Demining Technology Analysis Results for a Mozambique Scenario: Process Effectiveness

<table>
<thead>
<tr>
<th>survey type</th>
<th>clearance type</th>
<th>detection probability</th>
<th>% mines surveyed</th>
<th>% cleared by detection</th>
<th># people</th>
<th># people continuous LOE</th>
<th># systems</th>
<th># systems continuous LOE</th>
<th>casualty probability (detection)</th>
<th>casualty probability (neutralization)</th>
<th>casualties people</th>
<th>casualties systems</th>
<th>remaining mines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humint</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>probing</td>
<td>0.999</td>
<td>94.0</td>
<td>1.011 million</td>
<td>0</td>
<td>0.001</td>
<td>0.91</td>
<td>10,440</td>
<td>0</td>
<td>50,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>97.4</td>
<td>22,330</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,674</td>
<td>0</td>
<td>122,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>90.2</td>
<td>11,624</td>
<td>848 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>4,654</td>
<td>48 dogs</td>
<td>94,152</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>90.2</td>
<td>56,080</td>
<td>2704 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>1,604</td>
<td>48 dogs</td>
<td>97,050</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDDS</td>
<td>probing</td>
<td>0.999</td>
<td>99.9</td>
<td>484,632</td>
<td>0</td>
<td>0.001 detector</td>
<td>0.01</td>
<td>10,990</td>
<td>0</td>
<td>180</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>92</td>
<td>11,309</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,920</td>
<td>0</td>
<td>76,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>95</td>
<td>5,538</td>
<td>426 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>4,000</td>
<td>50 dogs</td>
<td>46,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>95</td>
<td>27,040</td>
<td>1,352 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>1,600</td>
<td>50 dogs</td>
<td>49,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>airborne</td>
<td>probing</td>
<td>0.999</td>
<td>99.5</td>
<td>109,152</td>
<td>0</td>
<td>0.001 detector</td>
<td>0.01</td>
<td>19,935</td>
<td>0</td>
<td>5,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>91.6</td>
<td>3,212</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,695</td>
<td>0</td>
<td>81,020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>94.6</td>
<td>1,812</td>
<td>124 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>4,675</td>
<td>50 dogs</td>
<td>51,020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>94.6</td>
<td>7,850</td>
<td>300 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>1,649</td>
<td>50 dogs</td>
<td>53,955</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humint-MEDDS</td>
<td>probing</td>
<td>0.999</td>
<td>94.9</td>
<td>458,739</td>
<td>0</td>
<td>0.001 detector</td>
<td>0.01</td>
<td>10,440</td>
<td>0</td>
<td>50,100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>87</td>
<td>10,659</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,674</td>
<td>0</td>
<td>122,200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>89.8</td>
<td>858</td>
<td>84 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>4,655</td>
<td>47 dogs</td>
<td>94,200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>89.8</td>
<td>4,000</td>
<td>200 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>1,600</td>
<td>47 dogs</td>
<td>97,050</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humint-airborne</td>
<td>probing</td>
<td>0.999</td>
<td>94.4</td>
<td>37,246</td>
<td>0</td>
<td>0.001 detector</td>
<td>0.01</td>
<td>10,390</td>
<td>0</td>
<td>50,000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>87</td>
<td>1,639</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,667</td>
<td>0</td>
<td>126,200</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>89.8</td>
<td>858</td>
<td>84 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>4,648</td>
<td>47 dogs</td>
<td>98,023</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>89.8</td>
<td>4,000</td>
<td>200 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>1,600</td>
<td>47 dogs</td>
<td>101,051</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEDDS-airborne</td>
<td>probing</td>
<td>0.999</td>
<td>99.4</td>
<td>18,648</td>
<td>0</td>
<td>0.001 detector</td>
<td>0.01</td>
<td>10,935</td>
<td>0</td>
<td>5,100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>detectors</td>
<td>0.92</td>
<td>91.5</td>
<td>1,298</td>
<td>0</td>
<td>0.004 detector</td>
<td>0.001</td>
<td>4,695</td>
<td>0</td>
<td>81,020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; detectors</td>
<td>0.95</td>
<td>94.5</td>
<td>678</td>
<td>52 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>4,875</td>
<td>50 dogs</td>
<td>51,020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>dogs &amp; probing</td>
<td>0.95</td>
<td>94.5</td>
<td>3,160</td>
<td>158 dogs</td>
<td>0.0005 dog</td>
<td>0.001</td>
<td>1,859</td>
<td>50 dogs</td>
<td>54,005</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7. Conclusions

1. Significant demining cost reductions are achievable by employing more advanced survey technologies. This results primarily from the great reduction in un-mined area which must be checked for mines, due to survey inaccuracies.

2. Survey inaccuracies, even with detection rates in the mid to high 90th percentile, result in large numbers of remaining undetected landmines. Short of sending bomb dogs (MEDDS) throughout the entire inhabited country, most survey technologies fail to ensure very high clearance rates.

3. Probing alone effectively clears every mine and minefield identified by the country survey (99.9% proof rate), and if dogs (MEDDS) is used as the survey process, 99.9% of all mines will be cleared. However, this is achieved at an enormous human and financial cost.

4. If all mines were detectable my metal detectors, the dog-detector clearance process is the most cost effective technology for achieving nearly a 95% proof rate.

5. In the presence of plastic and low-metallic mines, the reliance on metal detectors presents a serious casualty risk. Under these circumstances, probing must be employed, with the resulting decrease in efficiency and increase in clearance costs. The dogs-probing process more than doubles costs over dogs-detectors when using the most efficient survey process (MEDDS-airborne). For other survey processes, clearance costs increase dramatically.

6. Supplemental surveys will not increase the number of mines detected by the survey. However, large clearance cost reductions are obtainable by using a supplemental survey, if leaving slightly more undetected and uncleared mines is acceptable.

7. Although survey costs are relatively small compared to clearance costs, the accuracy of the survey process has the greatest impact on total clearance costs. This tradeoff highlights the need of the survey process to minimize the amount of un-mined area that must be cleared due to survey inaccuracies.
8. **Recommendations**

1. Develop rapid remote sensing survey processes with effectiveness well beyond the limited capabilities of human intelligence. Multi-spectrum airborne detection systems may offer promising emerging technology. An effective near term survey process should include the use of bomb dogs.

2. Develop an effective plastic and low-metallic mine detector system, which also detects conventional metallic mines. The availability of such a device will greatly reduce demining casualties, while boosting clearance efficiency at greatly reduced cost. A near term approach to this problem may involve performing more in-depth characterization of the effectiveness of bomb dogs, and developing knowledge on when dogs cannot detect mines, and how to improve the pinpoint accuracy of a dog detection.

9. **Summary**

Land which must be demined quickly becomes very expensive real estate. Even using dogs, in the most ideal of conditions, it will cost 39 cents a square meter to certify as clear of mines. To put that in perspective, there are 4047 square meters in an acre of land. That land, demined, just increased in cost by $1500. There are few places where agricultural land commands any where near that value, and certainly not in the Third World.

Imagine if it had to be prodded. Its cost increased by a staggering $15,000 an acre. Few industrialized countries have land values, which even when developed or used commercially, cost that much, and only in high density urban areas.

Nevertheless, this is the only land these people have. For the most part, if the land is safe, these people are largely self-sufficient. In this respect, their land has immeasurable value according to their standards. If their land is mined, these people become refugees. At which time the rest of us begin to pay the value of that land according to our standards, and it's not cheap.
This cost effectiveness analysis framework presented here is a rational approach to assessing the utility of demining technologies and processes during both demining operations and planning phases of a project. Not all tradeoff parameters have been addressed. However, the examples shown provide a guideline for developing tradeoff analyses tailored to specific requirements and conditions, of which regional experts will have the most detailed information. Nevertheless, employing an analytical approach such as this one helps to present the demining challenge in a structure which can be understood by people with diverse backgrounds, expertise, and interests. Hopefully, more efficient and effective demining programs will result which utilize their funding resources to maximum potential.
APPENDIX A
REFERENCES AND POINTS OF CONTACT

A Mine Clearance Plan for Mozambique. UN Document UNOMOZ 1, January 1993

Background Notes. US Department of State, 1986


Cost Estimates for FY94 DoD Humanitarian Demining Assistance


Hidden Killers: The Global Problem With Uncleared Landmines. Department of State Publication 10098


"MEDDS" detecting the "undetectable" mine." International Defense Review, 2/1993, p. 131

MIL-D-0023359G (ME) (Specifications for the AN/PSS-12)


U.S. Army Field Manual (FM) 5-34, Engineer Field Data, June 1987

U.S. Army Field Manual (FM) 7-41, Mine and Tunnel Dog Training and Employment, March 1973

U.S. Army Night Vision Laboratory briefing on the Close-In Man Portable Mine Detector ATD, 1994

U.S. Army Night Vision Laboratory briefing on the Vehicular Mounted Mine Detector ATD, 1994

U.S. Army Night Vision Laboratory/PM Mine, Countermine and Demolition briefing on ASTAMIDS, 1994


Discussions with:

American Eurocopter
Jean Paul Chausse, The World Bank
LCDR Dave Courtney, J-3 US SOCOM
Charles Gardner, PM Mine, Countermine and Demolition
Hap Hambric, Night Vision Laboratory Countermine Division
Roshni Mehta, Night Vision Laboratory Countermine Division
Ross Guckert, Night Vision Laboratory Countermine Division
Bill Schneck, Night Vision Laboratory Countermine Division
Rae McGrath, Mines Advisory Group
Major Don Corbert, Canadian MoD
Dave Lundberg, RONCO Consulting Corporation
Mike Farah, Airpower, Incorporated
Chip Hurlock, Washington, D.C. Bomb Squad
Ray Salamy, USAF, Andrews AFB, bomb dog team
Andy Pedersen, Naval Explosives Ordnance Disposal Center
Cheryl Parker, Explosives Technologies International
Laruie Fisher, American Red Cross
demining main routine with 4 modules
module 1  scenario development
module 2  survey
module 3  demining
module 4  costs

scenario development
common/inscene/atotal,mtotal,cluster(5,3)
atotal  total area km^2
mtotal  total number of mines
cluster  cluster distribution %,area,number

common/outscene/ncluster(5)
ncluster  number of each cluster

survey process
common/insurvey/surname(6,6),pdm(6,6),pdc(6,6),fmd(6,6),fcd(6,6)
& al(6,6),hrm(6,6),hrn(6,6),dayhr(6,6),aperhr(6,6),dcyc(6,6)
character=30 surname
surname  primary, secondary survey name
pdm  probability mine detection
pdc  probability cluster detection
fmd  false mine detection per km^2
fcd  false cluster detection % of a km^2
al  maximum location error meters
hrm  local manhours per km^2 of survey
hrn  expat manhours per km^2 of survey
dayhr  work day number of hours
aperhr  survey system km^2 per hour
dcyc  system duty cycle hours per day

common/outsurvey/aumn(6,6),hrms(6,6),hrnms(6,6),hrsyss(6,6),
& daysur(6,6),mcluster(6,6,5)
aumn  unmined area to be cleared
hrms  total local manhours in survey
hrnms  total expat manhours in survey
hrsyss  total system hours in survey
daysur  total number of days in survey
mcluster  distribution of clusters found by survey

demining process
common/indemine/dename(10),nteam(10),texp(10),ntype(10),safe(10),
& nsime(10,2),tnewt(10),workhr(10),fal(10),pd(10),srate(10)
character=30 dename
dename  demining process name
texp  minutes to excavate/verify a target
ntype  neutralization type - 1,batch 2,continuous
safe  neutralization safe zone area m^2
nsime  number of mines per simultaneous neutralization
\*1

tnewt  number of detections simultaneously excavated
\*2

workhr  work day hours
fal  false alarms per 100 m^2
pd  basic team sweep rate m^2/hr
srate  probability of mine detection

common/outdemine/mines(10,6,6),nbatches(10,6,6),teamdays(10,6,6)
mines  number of mines neutralized, per survey nbatches  number of batch neutralizations
teamdays  number of team days to clear surveyed area

common/outcosts/loes(6,6),loes(6,6),loessys(6,6),scl(6,6),scl(6,6),scl(6,6),sclog(6,6),
& loes(6,6),loes(6,6),loessys(6,6),scl(6,6),scl(6,6),scl(6,6),sclog(6,6),
scl  survey daily cost for local person
scx  survey daily cost for expat
scsys  survey daily cost for system
scx  survey cost to train each person
sclog  survey daily logistics cost per man
loes  survey level of effort (# men) local
loesx  survey LOE expat
loessys  survey LOE # of systems

common/outcosts/dcexp(10),dcx(10),dcxs(10),dct(10),dclog(10),
& loed(10),ndx(10),dct(10),dcx(10),dcsys(10),dct(10),dclog(10),
dcexp(10)  demine explosive neutralization cost per mine
dcx  demine additional cost per batch
dcl  demine daily cost for local person
dcx  demine daily cost for expat

dcsys  demine daily cost for system
dclog  demine daily logistics cost per man
loed  demine level of effort # of basic teams
ndx  demine number of expat in basic team

cost analysis
open(2,file='demine.out')
write(2,*')  ! for demining operations'
write(2,*')  !
write (*,*) 'cost and effectiveness model for demining operations'
call scenario
call survey
call clear
call costs
end

subroutine scenario
scenario development
common/incscene/ntotal,mtotal,cluster(5,3)
ntotal total area km^2
mtotal total number of mines
cluster cluster distribution %,area,number
c
common/incscene/ncluster(5)
c ncluster number of each cluster
c
open (1,file='scene.in')
read (1,*) ntotal
read (1,*) mtotal
do 10 i=1,5
read (1,*) k,cluster(i,1),cluster(i,2),cluster(i,3)
close (1)
do 50 k=1,2
if (k.eq.1) n=2
if (k.eq.2) n=0
write (n,*) 'scenario input'
write (n,*)
write (n,*) 'total area to be considered km^2',ntotal
write (n,*) 'total estimated number of mines ',mtotal
write (n,*) 'estimated mine cluster distribution:
write (n,*) ' % occur. area m^2 # mines'
format (3f15.0)
do 12 i=1,5
write (n,11) cluster(i,1),cluster(i,2),cluster(i,3)
write (n,*)
50 continue
calculate number of each cluster based on distribution
and total number of mines
do 100 i=1,5
ncluster(i)=int(mtotal*cluster(i,1)/100./cluster(i,3))
100 continue
do 200 k=1,2
if (k.eq.1) n=2
if (k.eq.2) n=0
write (n,*) 'scenario structure'
write (n,*)
write (n,*) 'number of clusters'
write (n,*) ' # mines # mines / 100m^2'
69 format (115,2f15.2)
do 70 i=1,5
density=cluster(i,3)/cluster(i,2)*100.
70 write (n,69) ncluster(i),cluster(i,3),density
write (n,*)
200 continue
return
end

subroutine survey
survey process
common/outsce/ncluster(5)
common/incscene/ncluster(5,3)
common/insce/surname(6,6),pdm(6,6),pdec(6,6),fmd(6,6),fdec(6,6)
& a(6,6),hrman(6,6),hrxman(6,6),dayhr(6,6),aperhr(6,6),dcyc(6,6)
character*50 surname
c surname primary, secondary survey name
c pdm probability mine detection
c pdc probability cluster detection
c fmd false mine detection per km^2
c fcd false cluster detection % of a km^2
c al maximum location error meters
c hrman local manhours per km^2 of survey
c hrxman expatriate manhours per km^2 of survey
c dayhr work day number of hours
c aperhr survey system km^2 per hour
c dcyc system duty cycle hours per day
return
end
common/outsurvey/aurum(6,6),hrilarms(6,6),hrxms(6,6),hrxys(6,6),
& daysur(6,6),mcluster(6,6,5)
c aurum: urinated area to be cleared
c hrilarms: total local manhours in survey
c hrxms: total expatriate manhours in survey
c hrxys: total system hours in survey
c daysur: total number of days in survey
c mcluster: distribution of clusters found by survey

c character*1 flag

do 10 j=0,5
  do 5 k=0,5
    surname(j,k)="blank"
    continue
  continue
open (1, file='survey.in')
do 100 i=1,10
  read (10,i, err=110) m,j,k
  read (10,i) msurname(j,k)
  read (10,i) m,pdm(j,k)
  read (10,i) m,pdc(j,k)
  read (10,i) m,fmd(j,k)
  read (10,i) m,fc(j,k)
  read (10,i) m,al(j,k)
  read (10,i) m,hrxman(j,k)
  read (10,i) m,hxman(j,k)
  read (10,i) m,dayhr(j,k)
  read (10,i) m,aperhr(j,k)
  read (10,i) m,dct(j,k)
  read (10,i)
  write (*,*) j
  continue
100 continue
110 continue

close (1)
do 200 k=1,2
  if (k.eq.1) n=2
  if (k.eq.2) n=0
  write (n,*), 'survey system inputs'
  write (n,*),
do 175 l=0,5
  do 170 m=0,5
    if (surname(m,l).eq."blank") go to 170
    write (n,*), 'primary or supplemental'
    write (n,*), 'surname(m,l)
    write (n,*), 'pdm(m,l)
    write (n,*), 'pdc(m,l)
    write (n,*), 'fmd(m,l)
    write (n,*), 'fc(m,l)
    write (n,*), 'al(m,l)
    write (n,*), 'hrxman(m,l)
    write (n,*), 'hxman(m,l)
    write (n,*), 'dayhr(m,l)
    write (n,*), 'aperhr(m,l)
    write (n,*), 'dct(m,l)
    write (n,*)
1 format (1x,a3,f10.2,a50)
170 continue
175 continue
200 continue

c survey total area with all primary systems

c l=0

do 300 m=1,5
  if (surname(m,l).eq."blank") go to 300
  for each cluster, find quantity surveyed
  inputs are based on either a mine detection or a cluster
detection probability. The one that is not zero is the
routine used.
  if (pdm(m,l).eq.0.0) then
    survey based on cluster detection probability
    do 210 mc=1,5
      mcluster(m,1,mc)=mcluster(mc)*pdc(m,l)
  else

77
cluster detection is based on individual mine detection

probability
do 220 mc=1,5
xmines=cluster(mc,3)
dpmine=pdm(1)

probability of detecting cluster is based on the probability of detecting any one mine, so you've got mines shots with

dpmine

200 mcluster(m,1,mc)=mcluster(mc)*(1.0-pdna)

endif

find area which must be surveyed due to false alarms.
again, this is based either on an individual mine or

individual cluster false detection rate

if (fmd(m,1),eq.0.0) then
false area is based on false cluster rate
of every square kilometer of interest, this percentage will be demined, but may contain no mines
farea=fcd(m,1)*atotal
else
false area is based on a false mine detection and the
location error radius
farea=fmd(m,1)*atotal*al(m,1)*al(m,1)*3.14159/1000./1000.
endif

if (fmd(m,1),eq.0.0.and.fcd(m,1).eq.0.0) then
this is a unique situation where the system does not give
significant false alarms, but may have a position error
on a valid target, which in effect gives false area that
must be searched. MEDDS is a good example of this. So
determine false area based on the total number of clusters
in the scenario and the location error area for this system.
find total number of clusters
ntotal=0

do 230 inc=1,5
230 ntotal=ntotal+mcluster(m,1,mc)

farea=ntotal*al(m,1)*al(m,1)*3.14159/1000./1000.

endif

aurm(m,1)=farea

hrms(m,1)=hrms(m,1)*atotal
hrxs(m,1)=hrxs(m,1)*atotal
if (aperrh(m,1),eq.0.0.and.dcy(m,1),ne.0.0) then
hrxys(m,1)=al(m,1)*aperrh(m,1)
daysur(m,1)=hrxys(m,1)/dcyc(m,1)
endif

300 continue

supplementary survey
for each primary system results, resurvey using each supplemental system.
the purpose of a supplemental survey is to throw more area away. However, you may throw mined area away as well. Obviously, the supplemental system should have a greater probability of detection than the primary system.
if this is not your intention, then do a complementary survey. This means survey the area not to be cleared and try to find those clusters missed. But you will also add more erroneous area. Create a new primary survey system that combines the detection probabilities and false detection probabilities of each into a complementary system.
do 500 i=1,5
if (surname(i,0),eq.`blank`) go to 500

do 400 m=1,5
if (surname(m,0),eq.`blank`) go to 400
surname(m,1)=`supplemental`

for each cluster, find quantity surveyed
c inputs are based on either a mine detection or a cluster detection probability. The one that is not zero is the routine used.
if (pdm(m,0),eq.0) then
survey based on cluster detection probability

do 310 mc=1,5
310 mcluster(m,1,mc)=mcluster(m,0,mc)*pdc(m,1)
else
cluster detection is based on individual mine detection
probability

do 320 mc=1,5
xmines=cluster(mc,3)
dpmine=pdm(0,1)

probability of detecting cluster is based on the probability of detecting any one mine, so you've got mines shots with

dpmine

pdno=1.0-dpmine)**xmines

320 mcluster(m,1,mc)=mcluster(m,0,mc)*(1.0-pdna)
find area which must be surveyed due to false alarms.
again this is based either on an individual mine or
individual cluster false detection rate

if (fmd(0,1).eq.0.0) then
false area is base on false cluster rate
of every square kilometer of interest, this percentage
will be demined, but may contain no mines
fare=fcd(0,1)*aunn(m,0)
elses
false area is based on a false mine detection and the
location error radius
fare=fmd(0,1)*aunn(m,0)*al(0,1)*3.14159/1000.*1000.
endif

if (fmd(0,1).eq.0.0.and.fcd(0,1).eq.0.0) then
this is a unique situation where the system does not give
significant false alarms, but may have a position error
on a valid target, which in effect gives false area that
must be searched. MEDDS is a good example of this. So
c determine false area based on the total number of clusters
c in the scenario and the location error area for this system.
c find total number of clusters
nc总数=0
for i=1,5
next=nc总数+nccluster(m,1,inc)
fare=next*al(0,1)*al(0,1)*3.14159/1000.*1000.
endif

n=0
for i=1,5
n=n+nccluster(m,1,inc)
endif

write survey results

do 600 k=1,2
if (k.eq.1) n=2
if (k.eq.2) n=0
write (n,*), ' survey results'
write (n,*),
do 575 l=0,5

do 570 m=1,5
if (surnamem(m,1).eq.'blank') go to 570
write (n,*), ' surname(m,1)
if (surnamem(m,1).eq.'supplemental') then
write (n,*), ' primary surname(m,0)
write (n,*), ' secondary surname(m,0)
endif
write (n,*), ' distribution of clusters found by survey'
write (n,*), ' cluster size number percent of total'
format (110,5x,110,f15.2)
do 560 inc=1,5
culous=cluster(m,3)
um=acluster(m,1,mc)
pfound=n+100./nculous(m)
write (n,559), culus, num, pfound
write (n,*), ' unmined area to be cleared km^2'
write (n,*), ' km^2 of local manhours'
c write (n,*), ' km^2 of expatriate manhours'
write (n,*), ' km^2 of system hours'
write (n,*), ' system days'
write (n,*)
559 format (110,5x,110,f15.2)
do 560 inc=1,5
culous=cluster(m,3)
um=acluster(m,1,mc)
pfound=n+100./nculous(m)
write (n,559), culus, num, pfound
write (n,*), ' unmined area to be cleared km^2'
write (n,*), ' km^2 of local manhours'
c write (n,*), ' km^2 of expatriate manhours'
write (n,*), ' km^2 of system hours'
write (n,*), ' system days'
write (n,*)
570 continue
575 continue
600 continue
return
end

subroutine clear
demining process
common/Atscene/ncluster(5)
common/inscene/total,nc总数,cluster(5,3)
common/insurvey/surname(6,6),pdm(6,6),pdc(6,6),fmd(6,6),fcd(6,6)
&. al(6,6), hrlman(6,6), hrxman(6,6), dayhr(6,6), opehr(6,6), dcyc(6,6)
character*30 surname
common/outsurvey/surmm(6,6), hrlms(6,6), hrmms(6,6), hmsys(6,6),
& daysur(6,6), ncluster(6,6), 5
common/indemine/denname(10), nteam(10), tex(10), ntype(10), safe(10),
& nsize(10,2), tneut(10), workhr(10), fa(10), pd(10), srate(10)
character*50 demname
c
demname demining process name
nteam basic team size number of people
tex minutes to excavate/verify a target
ntype neutralization type - 1, batch 2, continuous
safe neutralization safe zone area m^2
nsize number of mines to be neutralized
nneut number of detections simultaneously excavated
tneut minutes for each neutralization
workhr work day hours
fal false alarms per 100 m^2
pd probability of mine detection
srate basic team sweep rate m^2/hr

common/outdmine/mines(10,6,6), nbatch(10,6,6), teamdays(10,6,6)
nmine number of mines neutralized, per survey
nbach number of batch neutralizations
teamdays number of team days to clear surveyed area
character*1 flag

do 5 k=1,10
dename(k)="blank"
5 continue
open (1, file = 'demine.in')
do 100 i=1,10
read (1,*, err = 110) m, j
read (1,*) m, demname
read (1,*) m, nteam
read (1,*) m, tex
read (1,*) m, ntype
read (1,*) m, safe
read (1,*) m, nsize(j, 1)
read (1,*) m, nsize(j, 2)
read (1,*) m, tneut
read (1,*) m, workhr
read (1,*) m, fa
read (1,*) m, pd
read (1,*) m, srate
write (*) i
100 continue

110 continue close (1)
do 200 k=1,2
if (k.eq.1) n=2
if (k.eq.2) n=0
write (n,*)
deming process inputs
write (n,*)
do 170 l=1,10
if (demname(l).eq. 'blank') go to 170
write (n, *)'1', l, demining process number
write (n, *)'2', demname(l), basic team size number of people
write (n, *)'3', nteam(l), basic team size number of people
write (n, *)'4', tex(l), minutes to excavate/verify
write (n, *)'5', ntype(l), type of batch or continuous
write (n, *)'6', safe(l), neutralization safe zone
write (n, *)'7', nsize(l, 1), number of mines to be neutralized
write (n, *)'8', nsize(l, 2), number of simultaneous excavations
write (n, *)'9', tneut(l), minutes for each neutralization
write (n, *)'10', workhr(l), work day hours
write (n, *)'11', fa(l), false alarm per 100 m^2
write (n, *)'12', pd(l), probability of mine detection
write (n, *)'13', srate(l), basic team sweep rate
write (n,*)
1 format (1x, a3, f13.2, p40)
2 format (1x, a3, f13.2, p40)
170 continue
200 continue
c demine each survey results using each clearance process
do 1000 k=1,10
if (demname(k).eq. 'blank') go to 1000
80
cycle through each survey results

do 950 l=0,5

do 900 m=1,5
    if (surname(m,l).eq.'blank') go to 950
    clear empty area while accounting for false alarms
    continuous flow processes must stop and verify each false alarm
    so slow down process by the time required for each false alarm
    fare=auvm(m,l)*1000.*1000.
    rate=1.0/srate(k)
    hrs/m²
    if (ntype(k).eq.2) then
        continuous flow
        frate=fal(k)/100.
        FA/m²
        rlos=rate*(tex(k)/60.0)
        hrs/m²
        effective clearing hours per meter squared
        rate=rate+rlos
        Inverse it:
        rate=1.0/rate
        else
        batch process
        batch process clears at the slower of either the sweep rate
        or the rate at which all false alarms can be excavated
    area of cluster
    aclus=cluster(mc,2)
    false alarm density in FA/m²
    false=fal(k)/100.
    tday=workhr(k)
    sum=false/nsine(k,2)*tex(k)/60.
    area1=tday/sum1
    sum2=1.0/srate(k)
    area2=tday/sum2
    if (area1.lt.area2) dayarea=area1
    if (area2.le.area1) dayarea=area2
    effective m² per day
    rate=dayarea
    convert to hourly rate
    rate=rate/tday
    endif
    convert to day rate
    drate=rate*workhr(k)
    team days to clear empty area
    teamdays(k,m,l)=farea/drate
    clear clusters
    nmbatch=0
    daysnum=0
    nummines=0
    do 210 mc=1,5
        cycle through each cluster type and find time to clear
    number of each cluster type
    kclus=cluster(m,l,mc)
    number of mines in this cluster type
    kmime=cluster(mc,3)
    area of cluster
    aclus=cluster(mc,2)
    false alarm density in FA/m²
    false=fal(k)/100.
    continuous clearing or batch clearing?
    if (ntype(k).eq.2) then
        continuous flow
        subtract neutralization rate from false alarm adjusted rate
        so slow down process by the time required for each mine
    rate=kmime/aclus
    mines/m²
    rlos=ratek*(tneut(k)/60.0)
    hrs/m²
    rate=1.0/rate
    hrs/m² (inverse false alarm clearing rate)
    rate=rate+rlos
    hours to clear this cluster
    hours=aclus*rate
    days to clear this cluster
    days=hours/workhr(k)
    days to clear all of these clusters
    days=day+kclus
    number of batches and mines cleared
    nmbatch=nmbatch+kmime*kclus
    nummines=nummines+kmime*kclus
    else
        batch process
        to reach closure, false alarms and live targets must be
        excavated and verified in time to destroy all live targets
        by the end of the day.
        therefore, find how many detections constitute ending the sweep
day.
two conditions: either sweep rate + neutralization rate
or excavation rate + neutralization rate
dominate.
calculate both sweep areas based on the working day
c and see which is smaller. That is the area cleared each day
c per team.
tday=workhr(k)
density=real(kmine/aclus)
nsafe=int(aclus/safe(k))
if (nsafe.eq.0) nsafe=1
sum1=(density*false)/nsime(k,2)*tax(k)/60.
sum2=sum1+density/nsime(k,1)/nsafe*tneut(k)/60.
area1=tday/sum1
sum2=1.0/srate(k)+density/nsime(k,1)/nsafe*tneut(k)/60.
area2=tday/sum2
if (area1.lt.area2) dayarea=area1
if (area2.le.area1) dayarea=area2
c days to clear this cluster
day=clus/dayarea
c days to clear all of these clusters
days=day*kclus
c number of batches
bpclus=kmine/nsime(k,1)
if (bpclus.le.1.0) nbpclus=1
if (bpclus.gt.1.0) nbpclus=int(bpclus)+1
nbatch=nbatch+nbpclus*kclus
nummines=nummines+kmine*kclus
endif
daysnum=days*num=days
c numclear based on probability of detection and total number
numclear=nummines*pd(k)
c if (ntype(k).eq.2) nmbatch=numclear
continuous flow
nummines(k,m,l)=numclear
nmbatch(k,m,l)=nmbatch
teamsdays(k,m,l)=teamsdays(k,m,l)+daysnum
210 continue
c continue
950 continue
1000 continue
do 2000 k=1,2
if (k.eq.1) h=2
if (k.eq.2) h=0
write (n,*),' demining process results'
write (n,*),
do 1700 l=1,10
if (dename(l).eq.'blank') go to 1700
do 1650 m=1,5

do 1600 j=0,5
if (surname(m,j).eq.'blank') go to 1600
write (n,*),' demining process ',dename(l)
write (n,*),' survey process ',surname(m,j)
if (surname(m,j).eq.'supplemental') then
write (n,*),' primary ',surname(m,0)
write (n,*),' secondary ',surname(0,j)
endif
write (n,*), 'numines(l,m,j),' number of mines neutralized'
write (n,*), 'nbatch(l,m,j),' number of batch neutralizations
write (n,1599) teamsdays(l,m,j),' number of team days to clear'
write (n,*),
1599 format (1x,f15.0,a30)
1600 continue
1650 continue
1700 continue
2000 continue
return
end

subroutine costs
cost analysis
common/outscene/ncluster(5)
common/inscene/stotal,mtotal,cluster(5,3)
common/insurvey/surname(6,6),pdm(6,6),pdc(6,6),fmd(6,6),fcd(6,6)
&.al(6.6),hrman(6.6),hrxman(6.6),dayhr(6.6),aperhr(6.6),dcyc(6.6)
caracter*30 surname
common/outsurvey/aurm(6.6),hrlms(6.6),hrxms(6.6),hrysys(6.6),
& daysur(6.6),mcluster(6.6),5
common/indemine/dename(10),nteam(10),texp(10),ntype(10),safe(10),
& rsmne(10.2),tneut(10),workhr(10),fal(10),pd(10),rate(10),
caracter*30 dename
common/outsurvey/nmates(10,6,6),nbatech(10,6,6),teamdays(10,6,6),
& loesl(6,6),loex(6,6),loesys(6,6)
scl survey daily cost for local person
scx survey daily cost for expatriate
scsys survey daily cost for system
scetr survey cost to train each person
sclog survey daily logistics cost per man
loesl survey level of effort (# men) local
loex survey LOE expatriate
loesys survey LOE # of systems
common/inc2/dcl(10),dct(10),dsys(10),dsys(10),dslog(10),
& dso(10),dcl(10),dcl(10),dcl(10),dcl(10),dcl(10),
cdmscl demine explosive neutralization cost per mine
dcadd demine additional cost per batch
dcl demine daily cost for local person
dcx demine daily cost for expatriate
dcys demine daily cost for system
dclt demine cost to train each person
dclog demine daily logistics cost per man
dloed demine level of effort # of basic teams
ndx demine number of expatriates in basic team

caracter*1 flag
open (1, file='cost1.in')
do 100 i=1,10
read (1,*,err=111) m,j,k
read (1,*) m,surname(j,k)
read (1,*) m,scl(j,k)
read (1,*) m,scx(j,k)
read (1,*) m,scys(j,k)
read (1,*) m,scetr(j,k)
read (1,*) m,sclog(j,k)
read (1,*) m,loesl(j,k)
read (1,*) m,loex(j,k)
read (1,*) m,loesys(j,k)
read (1,*)
write (*,*) i
100 continue
111 continue
close (1)
open (1, file='cost2.in')
do 120 j=1,10
read (1,*,err=121) m,j
read (1,*) m,dename(j)
read (1,*) m,cdmscl(j)
read (1,*) m,dcadd(j)
read (1,*) m,dcl(j)
read (1,*) m,dcx(j)
read (1,*) m,dcys(j)
read (1,*) m,dclt(j)
read (1,*) m,dclog(j)
read (1,*) m,loed(j)
read (1,*) m,ndx(j)
read (1,*)
write (*,*)
120 continue
121 continue
close (1)
do 200 k=1,2
if (k.eq.1) n=2
if (k.eq.2) n=0
write (n,*)
write (n,*) ' survey system cost inputs'
write (m,*)
do 175 i=0,5
200 continue
175 continue
close (1)
do 200 k=1,2
if (k.eq.1) n=2
if (k.eq.2) n=0
write (n,*) ' primary or supplemental'
write (m,*)
do 175 i=0,5
200 continue
175 continue
close (1)
do 200 k=1,2
if (k.eq.1) n=2
if (k.eq.2) n=0
write (n,*) ' survey local daily rate'
write (m,*)
do 175 i=0,5
200 continue
175 continue
close (1)
do 200 k=1,2
if (k.eq.1) n=2
if (k.eq.2) n=0
write (n,*) ' survey expat daily rate'
write (m,*)
do 175 i=0,5
200 continue
175 continue
close (1)
if (daysur(m,0).eq.0.0) then
  time based on manpower
  ptime=(dl+dx)/(nl+nx)
else
  time based on number of survey systems
  ptime=daysur(m,0)/nsys
endif

sum all costs:
  pcost=cdayl*dl+cdayx*dx+cdaysys*dsys+cdaylog*nl*ptime
  pcost=pcost+ctrain*(nl+nx)
  stime=0.0
  scost=0.0

if (1.ne.0) then
  add in supplemental survey time and costs
  costs:
    cdayl=scl(0,1)
    cdayx=scx(0,1)
    cdaysys=scsys(0,1)
    cdaylog=sclog(0,1)
    ctrain=cttr(0,1)
  hours:
    nl=hrms(m,1)
    hx=hrms(m,1)
    hsys=hsysys(m,1)
  convert hours to days:
    dh=dayhr(0,1)
    dl=nl/dh
    dx=hx/dh
    dsys=hsysys/dh
  levels of effort:
    nl=loesl(0,1)
    nx=loexs(0,1)
    nsys=loesys(0,1)
  find total supplemental survey time
  if (daysur(m,1).eq.0.0) then
    time based on manpower
    stime=(dl+dx)/(nl+nx)
  else
    time based on number of survey systems
    stime=daysur(m,1)/nsys
  endif
  sum all costs:
    scost=cdayl*dl+cdayx*dx+cdaysys*dsys+cdaylog*nl*stime
    scost=scost+ctrain*(nl+nx)
endif

c total time and cost of this survey process
  stime=ptime+scost
c total time is based on longest time, either primary or
supplemental, since they can be run nearly concurrently
if (ptime.ge.stime) then
  stime=ptime
else
  stime=stime
endif

find total cost of demining this survey, and total time

c costs:
  xpminex=dcmpex(k)
  xpbatch=dcmpadd(k)
  cdayl=dl(k)
  cdayx=dx(k)
  cdaysys=dsys(k)
  cdaylog=log(k)
  ctrain=cttr(k)

c clearing results:
  numines=mine(k,m,l)
  numbatch=batch(k,m,l)

c team days:
  dteam=dteamb(k,m,l)

c team makeup:
  nx=x(k)
  nt=xteam(k)-nx

c levels of effort:
  nteams=loed(k)

c sum a team-day cost:
  dcost=cdayl*nl+cdayx*nx+cdaysys*cdaylog*nteam(k)
  based on the number of team days for clearing, find cost of
  all teams:
  tcost=nteam*dcost

c sum cost for clearing mines and batches
  cclear=sumines*xpminex+numbatch*xpbatch

c combine for total clearing costs
  tcost=tcost+cclear

c find total clearing time based on number of teams
  tclear=dteam/nteam

output costs and time for area surveyed and cleared
do 800 kk=1,2
if (kk.eq.1) kn=2
if (kk.eq.2) kn=0
write (kn,*) ' survey and demining process costs'
write (kn,*) ' dename(k)
write (kn,*) ' survey process ', surname(m,l)
if (surname(m,l).eq.'supplemental') then
write (kn,*) ' primary ', surname(m,0)
write (kn,*) ' secondary ', surname(0,l)
endif
write (kn,799) stcost,' survey process cost (dollars)'
write (kn,799) sttime,' survey process time (days)'
if (surname(m,l).eq.'supplemental') then
write (kn,799) ptime,' primary survey time'
write (kn,799) stime,' supplemental survey time'
endif
write (kn,799) tcost,' clearance process cost'
write (kn,799) tclear,' clearance process time'
write (kn,*)
799 : format (1x,f15.0,040)
800  continue
900  continue
950  continue
1000 continue
return
derm end
primary and supplemental survey system parameters

1. primary survey number, supplemental survey number
2. name type
3. individual mine detection probability
4. cluster detection probability
5. false mine detection rate per km²
6. false cluster detection rate per km²
7. location accuracy (maximum error meters)
8. local manhours per km² of survey
9. expatriate manhours per km² of survey
10. work day (hours)
11. survey system km² per hour of survey
12. system duty cycle (hours per day)
cost data input each survey type
1. primary survey number, supplemental survey number
2. name type
3. local personnel daily cost
4. expatriate personnel daily cost
5. each survey system daily cost (assume purchase price=5 year life cycle)
6. training costs per man
7. supporting logistics costs per man-day (hardware/equipment=5 years)
8. survey local personnel level of effort (# men)
9. survey expatriate personnel level of effort (# men)
10. survey system level of effort (# systems)
cost data input each demining process

1. process number
2. process name
3. explosive neutralization cost per mine (bulk explosives+detcord)
4. additional neutralization cost per batch (electrical blasting cap)
5. local personnel daily cost
6. expatriate personnel daily cost
7. each demining system/team daily cost (purchase price=5 year life cycle)
8. training costs per man
9. supporting logistics costs per man (hardware/equipment=5 years)
10. each demining process level of effort (number of basic teams)
11. number of expatriates in a demining team
total area of interest km^2
# mines
cluster distribution (five max) i, %, area m^2, # mines
demining process inputs

1. process number
2. process name
3. basic team size (# people)
4. excavate/verify time each target (minutes)
5. neutralization process: 1 = batch, 2 = continuous flow
6. area of neutralization safe zone (m^2)
7. number of mines simultaneously neutralized
8. number of detections simultaneously excavated
9. time each neutralization (minutes)
10. work day (hours)
11. false alarms per 100 m^2
12. probability of detection
13. basic team sweep rate (zero targets) m^2/hr
cost and effectiveness model
for demining operations

scenario input

total area to be considered km² 39350.000000
total estimated number of mines 1000000
estimated mine cluster distribution:
% occur.  area m²  # mines
5% 1000. 2
10% 1000. 5
20% 1000. 10
30% 1000. 20
5% 1000. 30

scenario structure

number of clusters

#   # mines  # mines / 100m²
25000 2.00 .20
40000 5.00 .50
50000 10.00 1.00
10000 20.00 2.00
1667 30.00 3.00

survey system inputs

1 0 0

1  dogs (MEDOS)
2  .95
3  .00
4  .00
5  .00
6  .00
7  125.00
8  .00
9  .00
10  .00
11  .05
12  .00

primary or supplemental

1  0

2  airborne (helicopter)
3  .70
4  .00
5  .00
6  .00
7  150.00
8  .00
9  .47
10  .00
11  .00
12  .00

primary or supplemental

survey results

dogs (MEDOS)
distribution of clusters found by survey
cluster size  number  percent of total
2  24937  99.75
5  39999  100.00
10  49999  100.00
20  10000  100.00
30  1667  100.00
6214.5560000 unmined area to be cleared km²
0.0000000 local manhours
1574000.0000000 expatriate manhours
787000.0000000 system hours
98375.0000000 system days

supplemental
primary  dogs (MEDOS)
secondary  airborne (helicopter)
distribution of clusters found by survey
cluster size  number  percent of total
2  22202  90.72
5  39901  99.75
10  49999  100.00
20  99999  99.99
30  1666  99.94
219.6404000 unmined area to be cleared km²
0.0000000 local manhours
2889.7690000 expatriate manhours
1445.2460000 system hours
180.6557000 system days

1
demining process inputs
### Demining Process Results

Demining process: dogs and probing
Survey process: dogs (MEDDS)
949875 number of mines neutralized
1699281 number of team days to clear

Demining process: dogs and probing
Survey process: supplemental
Primary: dogs (MEDDS)
Secondary: airborne (helicopter)
945087 number of mines neutralized
197388 number of team days to clear

### Survey System Cost Inputs

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>0</th>
<th>Primary or Supplemental</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dogs (MEDDS)</td>
<td>.00</td>
<td>survey local daily rate</td>
</tr>
<tr>
<td>2</td>
<td>dogs (MEDDS)</td>
<td>.00</td>
<td>survey expat daily rate</td>
</tr>
<tr>
<td>3</td>
<td>300.00</td>
<td>survey system daily rate</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>160.00</td>
<td>total training cost each man</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>3000.00</td>
<td>survey daily logistics per man</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>12.00</td>
<td>local level of effort # men</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>expatriate LOE # men</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>160</td>
<td>system LOE # systems</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>40</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

### Demining Process Cost Inputs

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>0</th>
<th>Demining Process Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>dogs and probing</td>
<td>25.40</td>
<td>explosive cost per mine</td>
</tr>
<tr>
<td>2</td>
<td>dogs and probing</td>
<td>3.50</td>
<td>explosive cost per batch</td>
</tr>
<tr>
<td>3</td>
<td>30.00</td>
<td>local daily rate</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>16.00</td>
<td>expatriate daily rate</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>65.00</td>
<td>system daily rate</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>3000.00</td>
<td>total training cost per man</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>12.00</td>
<td>daily logistics cost per man</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0</td>
<td>79</td>
<td>level of effort # of basic teams</td>
</tr>
<tr>
<td>9</td>
<td>0</td>
<td>0</td>
<td>number of expatriates in a team</td>
</tr>
</tbody>
</table>

### Survey and Demining Process Costs

Demining process: dogs and probing
Survey process: dogs (MEDDS)
Survey process cost: 75245000.
Survey process time: 2459.
Clearance process cost: 2038742000.
Clearance process time: 21510.

### Survey and Demining Process Costs

Demining process: dogs and probing
Survey process: supplemental
Primary: dogs (MEDDS)
Secondary: airborne
Survey process cost: 75817010.
Survey process time: 2459.
Primary survey time: 2459.
Supplemental survey time: 2499.
Clearance process cost: 181.
Clearance process time: 25887010.