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Quality and Equipment Considerations in Humanitarian Demining

HAUGSTAD, Bjarne

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Director of Research

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Simple arguments show that the commonly adopted UN requirement (99,6%) of mine clearance is too low for realistic situations if mines in a cleared region shall not be the leading cause of death also after demining.
It is argued that no single demining tool can provide the required quality of clearance. Rather, several different tools that are independent in a statistical sense should be used in a consecutive fushion on the same area. For such tools, the total clearance rate increases exponentially with number of tools employed, while operating costs increase in an additive fashion only. R & D efforts in humanitarian demining should therefore focus on finding techniques that are (essentially) independent of others in a statistical sense and of moderate quality (80-90% clearance), consistent with reasonable capital and operating costs.

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Preface

CONTENTS

Quality and Equipment Considerations in Humanitarian Demining

1 INTRODUCTION

Practitioners and other experts of humanitarian demining consider themselves haunted by a dismal perspective: considering the number of anti-personnel mines and the current rate at which they are being removed, it may take hundreds of years to clear the currently deployed mines alone. Although the estimated number of layed mines has been reduced over the past few years, the current clearance rate is far too low to meet the goal proclaimed by former president Bill Clinton that all antipersonnel mines should be removed by the year 2015.

Why is humanitarian demining so slow? The most frequently presented answer is that alone manual prodding, which is slow and hence costly, can provide the necessary guarantee that mine cleared areas are (essentially) free of mines. Considering the 50-100 million mines in the world and the current rate of removal (10 – 20 000 per year), it may take several hundred years to clear all mines. The formidable task at hand and the slow rate at which mines are being removed, stresses the need for improved and more cost-effective techniques for mine clearance. In fact, considerable international efforts have been expended to device innovative and hopefully more cost-effective techniques, including ground penetrating radars, mechanic mine clearance devices, improved metal detectors, and techniques based upon detection of explosive molecules emanating from buried land mines.

Deminers and developers of new demining equipment are both confronted with the fundamental question of *quality of mine clearance.* In technical terms this translates into a question of probability of detection or destruction of mines. For some types of demining equipment, there is also the attendant question of maximum allowable false alarm rate. The traditional UN requirement for mine clearance is 99,6%, meaning that in any given area contaminated by anti personnel mines, 99,6% of the mines actually present should be detected and/or destroyed. While there is general agreement that a clearance rate corresponding to the UN figure is both arbitrary and very difficult to verify in actual circumstances, there is still need for a realistic *demining requirement* to be established. This could either be in the form of a specific figure or figures stipulating the clearance probability, as by the UN figure above, or by a set of requirements related to the demining process and the equipment used to detect/destroy the mines, like in a quality assurance program. Provided that the equipment and process requirements were met, the demining operation would be considered producing an acceptable outcome.

Development of new demining equipment must also be based on a performance requirement. Without such a measure any new developments are essentially meaningless.

What should be the performance goal for demining equipment or, rather, for the demining process? The ideal requirement would be to remove *all* mines in mine infected areas. This is unrealistic, however, and statistically no guarantee can ever be issued that a previously mined area is free of mines with absolute certainty. I will here propose the following criterion for mine clearance effectiveness: For any mine effected area, mines should be cleared to such an extent the *lethality to the remaining mines are less than or at most equal to that due to ordinary, accidental causes of death in the society.*

The justification for this criterion proposed is rather obvious: if lethality to the remaining mines after mine clearance were a dominant cause of death or injury in a region, then obiously efforts should be made to reduce the risk to the "ambient" level. On the other hand, if deaths to remaining mines were substantially less than those due to other causes, a reasonable national strategy would be to reduce the dominant ambient causes of death before reducing mine deaths still further.

The mine clearance criterion proposed above effectively relates demining probability to the actual mine density in the region. In fact, the demining probability is directly proportional to the mine density, implying that the criterion is not consistent with a universal figure, such as the UN requirement of 99,6%. It is a relative measure also in the sense that the "ambient lethality" may vary from one country to another, and possibly also from one region to another within the country. This latter "problem" may be circumvented by stipulating a fixed, common and reasonably low, probability of death to ordinary causes, e. g.,

$$p_d = 10^{-5}/year.$$

While a mine clearance criterion as proposed above may seem rational and realistic, its consequences does not appear to have been explored and taken into account so far. I show below that, contrary to common belief, the criterion leads to the conclusion that the seemingly very restrictive UN requirement of 99,6%, normally is *too low* and hence inconsistent with the proposed criterion.

2 RELATION BETWEEN CLEARANCE GOAL AND AMBIENT LETHALITY

In order to explore the quantitative consequences of a proposed mine clearance goal, let n be the (assumed uniform) mine density in a region. Let p be the (assumed uniform) probability of mine clearance of the equipment or process adopted. After demining, the density n_1 of remaining mines is

$$n_1 = (1- p)\, n \qquad (1)$$

The actual lethalities caused by the remaining mines depend on the individual patterns of movement in the "mine-cleared" area. From knowledge of, or by making assumptions about, how people actually move the lethality can in principle be estimated. Instead of pursuing this line of reasoning, we shall adopt a more simplistic, yet revealing, approach.

Let a be the new effective area covered by one person in one year in a mine-cleared region ("cumulative foot-print area"). Below is indicated how a person, having an effective foot-print area da, moves to map out a total cumulative area

$$a = \ ?da \qquad (2)$$

It is noted that the *effective* foot-print area *da* is slightly larger than the physical foot-print area, and that only truly *new area* (neither the persosn in question nor anyone else has stepped on it before) should be counted in the summation above. With these qualifications, and assuming also that a person dies if being hit by a mine, then to a first approximation the lethality to the remaining mines is given by

$$a\ n_1 = a \cdot n \cdot (1 - p) \qquad (3)$$

according to equation (1). If this lethality is equated to the lethality to ambient causes (= q), then equation (3) can be cast into the following form

$$p = 1 - \frac{q}{n \cdot a} \qquad (4)$$

for the relationship between p, q, n and a. For given values of q, n and a, this relationship stipulates what p has to be for remaining mines after clearance not to be the leading cause of death in a region (strictly speaking, to be *equal* to that of other causes).

In our part of the world, $q \sim 10^{-5}$. Realistic mine densities may be in the range of 0.1 – 1000/km^2, and locally even higher. Assuming $q = 10^{-5}$, table 1 shows the relationship between p, n and a.

p \ n	0,1	1	10	100	1000
0,996	$2{,}5 \cdot 10^{4}$	$9{,}5 \cdot 10^{3}$	$2{,}5 \cdot 10^{2}$	$2{,}5 \cdot 10^{1}$	2,5
0,90	10^{3}	10^{2}	10^{1}	1	0,1
0,0	10^{2}	10	1	10^{-1}	10^{-2}

Table 1. *Calculated values for cumulative foot-print area a for different values of n, assuming* $q = 10^{-5}$

Assuming $n = 10$/km^2 and using p = 0,996 corresponding to the UN requirement, it follows from Table 1 that a = 250 m^2. If the elemental footprint area is assumed, conservatively, to be 0,05 m^2, it follows that one person can traverse only 250 m^2 / 0,05 m = 5000 m. Even when multiple crossings of the ground is accounted for, this is obviously a very small figure. From examination of the table one is led to conclude that the UN requirement of $p = 99{,}6\%$ is *not* unreasonably strong. In fact, a much stronger requirement would seem appropriate in most cases.

The limiting case $p = 0$ corresponds to the maximum allowable (new) foot-print area for mines not to be a leading cause of death in a region not cleared for mines. We see that even for the lowest mine density considered above *(n = 0,1 km $^{-2}$),* mines will be the leading cause of death ($a = 10^2\ m^2$, corresponding an annual path length of ~ 2000 m).

3 STATISTICAL SIGNIFICANCE OF THE TOOL-BOX CONCEPT – MINE CLEARANCE STRATEGY

The need for a "tool-box" of different demining techniques is commonly motivated by the fact that different ground conditions (rock, vegetation, topography etc) may require different demining tools to be used. Mechanical demining equipment, metal detectors, dogs and manual demining ("prodders") constitute the inventory of most tool-boxes. As will be clarified below, there is good reason, however, to employ different tools also (in) *the same* area to be cleared. The immediate background for this claim is the realization that as of today, and with the possible exception of manual demining, no single demining tool alone appears to satisfy realistic clearance requirements.

The idea that different tools can be applied successively on the same area, which to some extent happens also today, has some interesting statictical features. Assume that *n statistically independent* demining tools are used on the same piece of land in some consecutive fashion. The total clearance probability is then

$$p_{total} = 1 - (1 - p_1)(1 - p_2) \ldots (1 - p_n) \qquad (5\ a)$$

Where $p_1 \ldots p_n$ are the clearance probabilities of tool 1 … n, respectively. For purpose of illustration, assume that all $p_i = p$, so that

$$p_{total} = 1 - (1 - p)^n \qquad (5b)$$

Let the total cost of clearing a unit of land be K_i for tool i, so that the total cost of employing n tools becomes

$$K_{total} = \sum_{i=1}^{n} K_i \qquad (6a)$$

For simplicity, assume also that $K_i = K$, so that

$$K_{total} = n\,K \qquad (6b)$$

From eqs. 5b and 6b, one can draw the very important conclusion that *the total clearance probability increases exponentially with n, while the total clearance cost increases only linearly with n.* Even though this conclusion was conditioned on the assumption that all p_i and

K_i are equal (to p and K, respectively), the general conclusion for unequal p_i and K_i is that p_{total} increases in a multiplicative way with n, while the total cost increases only in an additive fashion. Again, by way of illustration, assume $n = 3$ and $p = 0{,}85$, so that

$$p_{total} = 1 - (1 - 0{,}85)^3 = 0{,}0997,$$

while (7)

$$K_{total} = 3\,K$$

That is, by successive application of three “modestly good” mine clearance tools, each having a clearance probability of 85 %, a total of 99,7 % (exceeding the old UN reguirement) is obtained. The cost is increased by only a factor of 3, however.

As another example, assume that $p_1 = p_2 = 0{,}90$. In this case the application of one more tool characterised by $p = 0{,}90$, increases the demining probability *by a factor of 10.*

It is emphasized that the conclusions drawn above are conditioned on the assumtion that the various techniques employed are truly independent in a statistical sense. This means that the probability that one tool both find or miss a mine must be independent of that of finding or missing the same mine with any of the other tools employed. If, in the extreme, the various techniques were fully dependent (correlated), than $p_{total} = p_1$ while $K_{total} = n\,K$ for n fully correlated techniques. That is, the mine clearance probability would stay constant independent of how many tools were used, while the cost would increase linearly with the number of tools.

The considerations and examples above suggests the following strategy for humaritarian mine clearance: Create a tool-box characterised by elements that have

- statistical independense
- a reasonable demining probability (80 – 90 %)
- acceptable cost
- acceptable clearance speed
- wide applicability in terms of ground conditions etc

The cost of demining a unit of land is expected to be strongly related to p for two reasons: a high probability clearance tool will in itself have a high cost, and since high p normally also leads to a high false alarm rate, the running cost will also increase dramatically with increasing p above, say, 90 %. Thus a modest requirement on p almost automatically guaranties both acceptable capital and running cost of the tools in question.

4 A STRATEGY FOR RESEARCH AND DEVELOPMENT

The considerations and conclusions above were based upon the assumption that tools in the tool-box were all statistically independent. Since the successive application of tools having this property on the same area has such profound consequences in terms of actually clearing the mines, it will be important to assess which of the commonly available demining tools that actually comply with this assumption. This, it turnes out, is not a straight forward question to answer. The question boils down to finding the reasons – systematic and/or stochastic – that a specific demining tool occasionally misses mines. Only when these reasons are fully stochastic can various techniques be independent in a statistical sense. At FFI work is in progress to examine these questions in a deeper sense, from a theoretical as well as an experimental point of view. Work so far indicate that tools based on different physical principles, to a large extent may be considered independent. Moreover, mechanical demining using the same tool (e g, a flail system) on the same area more than once, may even come close to statistical independence if also the running pattern is somewhat changed from one run to the next. In a general sense, checking demining equipment for degree of statistical dependence might be an important undertaking for the newly established International Test and Evaluation Program (ITEP), located on the premises of the Joint Research Center (JRC) in Ispra, Italy.

In a deeper, yet very important way, R&D for new demining equipment should not necessarily be focused on *"promising techniques"* characterised by a high probability of clearance, since such techniques are very different to find, costly, and will be characterized by high false alarm rates and therefore also high running costs. Rather, focus should be on techniques that are statistically independent of other available techniques, for which even a moderate clearance probability can be accepted, as shown above. This, as mentioned above, will be conducive to low capital and running costs and – most likely – also to (relative) ease of operation. R&D resources used in this way will provide a much higher chance of getting rid of antipersonnel mines at acceptable cost and in a reasonable time. It may even be that the box of currently available demining tools already offers a sufficient number of (essentially) independent techniques, allowing the demining strategy outlined above to be implemented in many areas without the fielding of new or improved techniques.

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