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Throwing Out Mines: The Effects of a Flail

by Ian McLean, Rebecca Sargisson, Johannes Dirscherl and Havard Bach [Geneva International Centre for Humanitarian Demining]

The authors discuss a study conducted on flail machines to prove the effectiveness of this technology in destroying anti-personnel mines.

Recent tests and trials on the clearance capability of flail machines have shown that if machines are adequately operated and the operating environment is favorable, flails are able to achieve clearance rates approaching 100 percent.[1] However, some field operators have experienced clearance rates as low as 50–60 percent. The main reason for the discrepancy is that a proportion of aged mines have faulty detonation mechanisms.[2] Having failed to detonate, some also remain apparently intact after flailing. When found by quality-assurance teams, these mines are reported as missed because examining their firing mechanism is time-consuming and dangerous. The resulting under-representation of clearance capability suggests that flail machines should only be used as ground preparation for subsequent demining, a conclusion that we believe to be inappropriate.

To satisfy the requirements of statistical analyses, tests on clearance capability of flail machines require a large number of mines. Real mines are scarce and dangerous, mine mimics are expensive, and testing may be constrained to using too few mines to support statistical analysis. Despite such resource constraints, a continued effort to test machines is desirable and should be prioritised. Clearly, any study designed to explore the proportion of mines that are initiated or broken up by a machine will need to use real mines. However, some research questions allow testing without using real mines (or real mine-mimics).

Here, we investigate the pattern of throw-out for mines that are not broken up or destroyed by a flail. The study used unbreakable "mine-mimics," so it explored issues of throw-out only. The results address issues about the direction and distance mines are likely to be thrown and their visibility after flailing, in relation to standard treatment factors in mine clearance (soil type and mine depth).

Methods

The study was conducted at the Swedish Explosive Ordnance Disposal and Demining Centre test site in Eskjö, Sweden, in December 2003. All test fields were laid out in the same way: a strip 5 metres long and 80 centimetres wide within a soil platform 3 metres wide[3] (see Figure 1 on next page). The "mines" used were made of a hard plastic material and similar in dimensions to hockey pucks or a small round can of tuna. The 60-mm puck had a height of 35 mm, the 90-mm a height of 50 mm and the 110-mm a height of 80 mm.[3] A metal washer had been screwed into the puck to make it searchable. Twenty were laid in a standard array in each strip, giving a sample size for each treatment combination of 20 (or slightly fewer in a few cases of missing data).

The treatment variables were:

- Three soils (sand, gravel, topsoil)
- Four depths (0, 5, 10 and 15 centimetres)
- Three sizes of mines (60-, 90-, 110-mm diameter)

Sand and gravel were tested with all mine sizes and depths. Topsoil was tested with 60-mm mines only, although at all treatment depths.

An MV-4 in action.
PHOTO COURTESY OF ERIC TOLLEFSON/GICHD

The machine, a DOK-ING MV-4, is described in detail in the *Mechanical Demining Equipment Catalogue*[4] and is shown in the picture above. It was run once only along the strip in one direction, which is treated as "north" for analyses of the throw angle. The machine has a clearance width of 1.725 metres, thus the test clearance strip of 80 centimetres gave a margin of error of about 45 centimetres on each side. Flail depth was set at 10 centimetres.[3]

Parameters measured were:

- Distance the mine was thrown
- Direction the mine was thrown
- Visibility of the mine after flailing

Soil	Depth (cm)	Size (mm)	Mean Angle	S.E.	N
Sand	0	60	97.0	1.65	20
Sand	0	90	116.3	1.47	19
Sand	0	110	120.5	1.59	20
Sand	5	60	127.0	1.49	20
Sand	5	90	118.5	1.79	20
Sand	5	110	125.5	1.60	20
Sand	10	60	92.8	1.77	20
Sand	10	90	127.3	1.56	20
Sand	10	110	117.1	1.90	17
Sand	15	60	112.0	1.59	20
Sand	15	90	122.0	1.68	20
Sand	15	110	107.0	1.83	20
Gravel	0	60	97.8	1.89	20
Gravel	0	90	92.0	1.79	20
Gravel	0	110	113.0	1.81	20
Gravel	5	60	100.3	1.76	20
Gravel	5	90	114.5	1.66	20
Gravel	5	110	102.5	1.84	20
Gravel	10	60	100.3	1.81	20
Gravel	10	90	97.8	1.87	20
Gravel	10	110	79.5	1.85	20
Gravel	15	60	123.5	1.41	20
Gravel	15	90	120.8	1.72	20
Gravel	15	110	107.3	1.78	20
Topsoil	0	60	103.8	1.86	20
Topsoil	5	60	107.5	1.70	20
Topsoil	10	60	95.3	1.77	19
Topsoil	15	60	75.3	1.62	20

Table 1: Summary of data for throw direction (adjusted data for one side of the compass only). The flail moved north; thus 0° = N, 180° = S.

Soil	Depth (cm)	Size (mm)	Mean Dist	S.E.	N	Range
Sand	0	60	2.0	0.44	20	0.3–15
Sand	0	90	2.2	0.54	19	0.3–25
Sand	0	110	1.0	0.15	20	0.2–2
Sand	5	60	1.2	0.19	20	0.5–3
Sand	5	90	1.6	0.24	20	0.6–5
Sand	5	110	2.0	0.28	20	0.4–4
Sand	10	60	1.6	0.40	20	0.3–15
Sand	10	90	0.9	0.15	20	0.2–1.8
Sand	10	110	1.4	0.17	17	0.5–1.8
Sand	15	60	1.3	0.29	20	0.2–8
Sand	15	90	1.1	0.24	20	0.3–1.4
Sand	15	110	1.9	0.38	20	0.2–14
Gravel	0	60	3.8	0.74	20	0.4–50
Gravel	0	90	1.5	0.13	20	1–2.3
Gravel	0	110	2.0	0.18	20	1.1–3.4
Gravel	5	60	1.6	0.26	20	0.4–7
Gravel	5	90	1.4	0.18	20	0.2–3
Gravel	5	110	1.5	0.19	20	0.3–3
Gravel	10	60	1.9	0.33	20	0.5–11
Gravel	10	90	1.3	0.14	20	0.5–2
Gravel	10	110	1.3	0.17	20	0.1–2.4
Gravel	15	60	1.2	0.14	20	0.5–2
Gravel	15	90	2.7	0.40	20	0.3–8
Gravel	15	110	1.6	0.28	20	0.4–8
Topsoil	0	60	4.0	0.40	20	0.3–9
Topsoil	5	60	5.8	0.84	20	0.5–65
Topsoil	10	60	3.0	0.42	19	0.1–10
Topsoil	15	60	3.3	0.55	20	0.1–25

Table 2: Summary of data for throw distance (Dist), in metres. S.E. = standard error.

The angle (direction) of throw required some adjustment for statistical analysis and visual representation for the following reasons:

- The mean of several angles might not portray a sensible conceptual pattern. For example, if one mine is thrown forward (20 degrees) and another is thrown backwards (160 degrees), the average throw direction for these two mines (90 degrees) does not portray a meaningful direction in absolute terms. The data given in Table 1 are means and are useful for statistical comparison between treatments, but they should not be used to represent typical throw angles.
- A similar problem applies to mines thrown to the left or right. Mines thrown at 20 degrees and 340 degrees are thrown at equivalent angles in terms of forward direction, but the mean (180 degrees) is clearly inappropriate. To address this problem, the data were adjusted for analysis so that all mines were thrown on one side only.

The throw angle is therefore presented as frequencies rather than as means, calculated from equal-sized (45 degrees) sectors of one side of a compass.

Results Summary

A typical throw-out result, seen in Figure 2 (see page 102), is for 60-mm mines buried at 15 centimetres in the three soil types. In this figure, the (0,0) point is the original site at which the mine was laid, and the datum points indicate where the mine was thrown after flailing. Most mines remained close to and slightly behind where they were laid. If these were real mines, they would likely be compressed into the soil (although they might be exposed due to soil disruption),

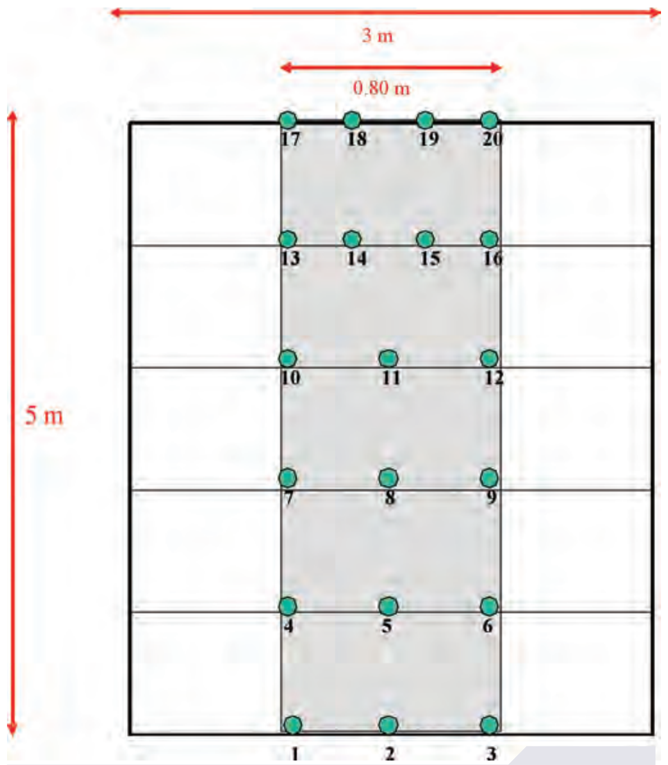

Figure 1: The standard layout of test strips for the throw-out tests.

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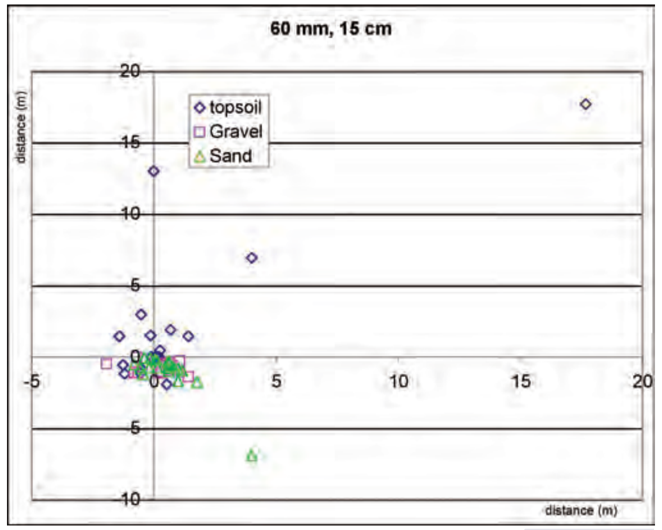

Figure 2: Throw-out effect after flailing for 60-mm mines laid at 15 cm in three soil types.
FIGURE COURTESY OF IAN MCLEAN

initiated or broken up. A small number of mines were thrown several metres, and a very small number were thrown a considerable distance, which in this case included a mine thrown 25 metres. Mines thrown several or more metres were generally thrown forward.

Summaries of all data are in Tables 1 and 2 (previous page). In order to eliminate bias in the means due to extreme values, all throw distances greater than 10 metres were removed for calculation of means and variances in these tables. The extreme values are noted in the ranges, but the reported sample sizes (N) are those used to calculate the means.

Extreme throw distances include the following values (in metres): 65, 50, 2 x 25, 2 x 15. Of a total of 555 mines for which data were available, 2.2 percent (12) were thrown more than nine metres, and 5.6 percent (31) were thrown less than four metres.

Results for All Soil Types, 60-mm Mines Only

Distance thrown. Significant variation was found for distance thrown in different soils, with mines thrown greater distances in topsoil relative to sand and gravel (Figure 3, $F_{2,227} = 10.7$, $P = 0.00$). There was no significant difference between sand and gravel.

Angle of throw. Side (laterality) of throw was investigated across all soils and depths for the 60-mm mines. Mines thrown directly forward (0±9 degrees) or backward (180±9 degrees) were removed from this analysis. Ignoring soil type and depth, significantly more mines were thrown to the right (136) than to the left (79) (X^2=7.6, P<0.01), indicating that the flail had an asymmetric action. No significant effects were found for angle of throw in relation to soil type or depth for the 60-mm mines. The data for each angle were therefore lumped across all soil and mine types, and are reported below.

Visibility of 60-mm mines after flailing. About 40 percent of the 60-mm mines were visible after the flail had been through. After flailing, most mines were visible in topsoil and fewest were visible in sand (see Figure 4), although the pattern was not quite statistically significant (X^2=5.3, P=0.07). One reason for the greater visibility in topsoil is that mines were thrown farther from topsoil and were therefore more likely to be thrown outside the test strip, where they were less likely to be covered by the machine. This effect is less likely in a minefield, where a large area is flailed. The greater visibility of mines in gravel is likely due to the coarse texture of gravel relative to sand.

The proportion of 60-mm mines visible after flailing did not vary significantly in relation to depth (X^2=2.6, d.f.=3, P=0.45; see Figure 5).

Results for All Mine Sizes

Distance thrown. In sand and gravel, there were no significant effects on throw distance of either mine size ($F_{2,464} = 0.37$, NS) or mine depth ($F_{2,464} = 1.19$, NS). The interaction between size and depth was not significant ($F_{6,464} = 1.07$, NS). Thus mines of all sizes and depths were thrown similar distances in sand and gravel.

Angle of throw. As already reported for 60-mm mines in all three soil types (lumped), mines of all sizes were thrown more to the right than to the left in sand (L:R, 65:148; X^2=16.8, P=0.00) and in gravel (L:R, 85:136; X^2=5.8, P=0.016).

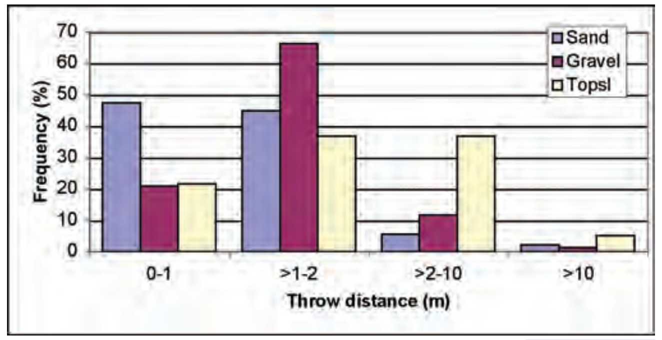

Figure 3: Distances mines were thrown in three soil types.
FIGURE COURTESY OF IAN MCLEAN

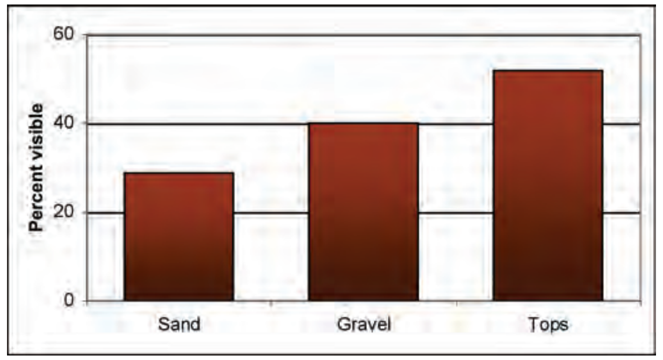

Figure 4: Proportion of 60-mm mines visible after flailing in relation to soil type.
FIGURE COURTESY OF IAN MCLEAN

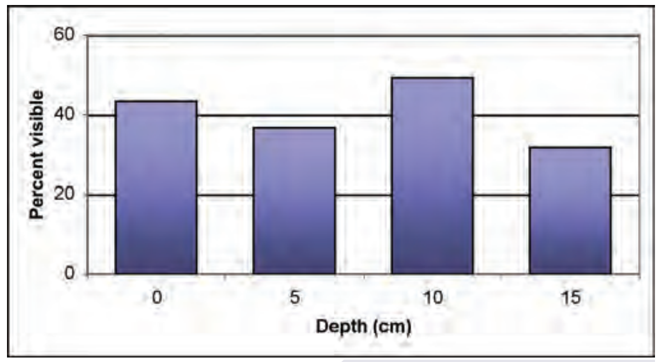

Figure 5: Proportion of mines visible after flailing in relation to original burial depth.
FIGURE COURTESY OF IAN MCLEAN

The angle of throw for all mines is summarised in Figure 6. Included in sand and gravel are mines of three sizes (60, 90 and 110 mm), whereas only 60-mm mines were included with topsoil. Adjusted data (all mines thrown to one side) were used for this analysis.

In general, most mines were thrown either directly forward (0–45 degrees) or directly backward (136–180 degrees), with a higher proportion of mines thrown backward overall. Very few mines were thrown laterally forward (46–90 degrees). The highest proportion of mines thrown forward was from topsoil.

No relationship between angle of throw and soil type was found for 60-mm mines (as mentioned above). However, when data for all mine sizes were used (sand and gravel only), mines were thrown behind significantly more in sand than in gravel ($F_{1,452} = 4.21$, P=0.04; data in Table 1—see page 101).

Visibility of all mines after flailing. Figure 6 shows the proportion of mines visible in sand and gravel after the flail had completed its run for three mine sizes. Mines were increasingly likely to be visible with increasing size, with small mines being mostly buried and large mines being mostly visible. The pattern was highly significant using data lumped by original burial depth (X^2=31.3, 2 d.f., P=0.00).

Figure 7 suggests that original depth of burial affected visibility, with deeper buried mines being more visible after the flail. The effect was not significant using data lumped across mine size (X^2=3.9, 3 d.f., P=0.27).

Visibility of mines increased with distance thrown (see Figure 8). This effect was expected for mines thrown longer distances, as those mines were thrown outside the clearance strip. Many of the mines that moved less than one metre were likely compressed into the soil, whereas mines that moved several metres were more likely to have been lifted out of the ground before being deflected back downwards by components of the flail, and therefore ended up sitting on the surface.

Discussion

The flail is designed to prevent mines from being thrown large distances, and the effectiveness of that design can be seen in the high proportion of mines left close to their original laying site. A proportion of those mines would likely be compressed into the soil without being initiated or broken up. However, repeated passes with the flail should ensure that essentially all are rendered safe, in that the initiators are unlikely to be working.

Mines that were thrown up to several metres are likely to have been pulled out of the ground by the chains, and then deflected back downwards by the deflector plate or other components of the flail. Although many remained in the clearance strip, such mines are more likely to be visible than mines that were compressed, because they were lifted out of the ground rather than beaten into it. Mines that are pulled out of the ground are less likely to be broken up or initiated, might therefore be in better condition after flailing, and are potentially still live.

A small proportion of mines were thrown big distances, presumably because the chains hooked the mine past the deflector plate. Clearly, the flail design is not

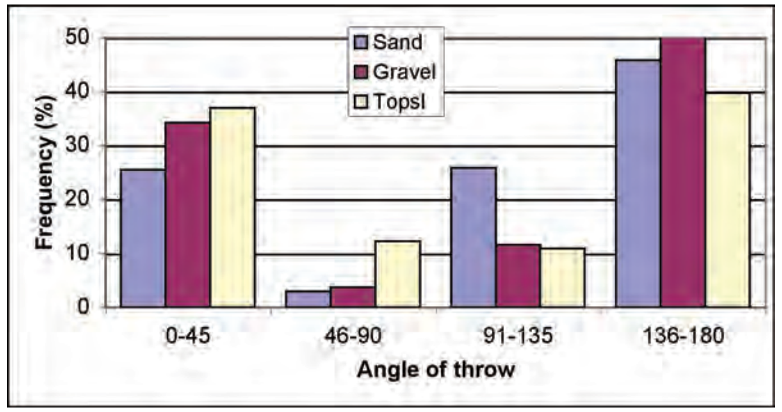

Figure 6: Summary of angle of throw using the data converted to one side of a compass only (e.g., ignoring laterality of throw), for mines in three soil types.
FIGURE COURTESY OF IAN MCLEAN

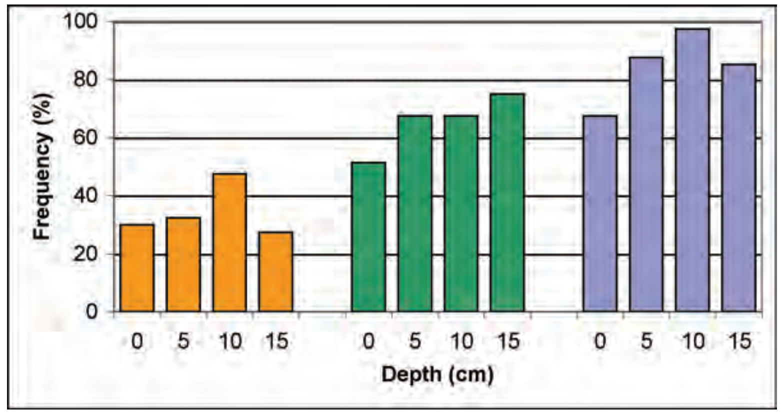

Figure 7: Visibility of mines of different sizes after flailing.[5]
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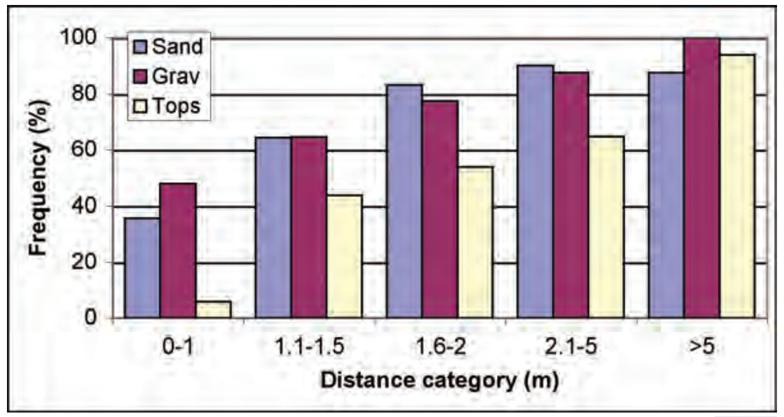

Figure 8: Visibility of mines after flailing in relation to distance thrown.
FIGURE COURTESY OF IAN MCLEAN

entirely effective at preventing long-distance throws. There are safety implications for the operators whether the machine is throwing mines or rocks, as this machine is routinely operated using a safety distance of 50 metres. Mines were more likely to be thrown forward, presumably due to the forward rotation of the chains and the protection behind the chains. Such mines could be thrown into previously cleared strips, or outside the minefield. Repeated passes are less likely to re-process such mines, particularly if the field is flailed in sectors. The MV-4 is a small machine. Whether larger machines could throw mines even greater distances than the maximum seen here of 65 metres remains to be tested, as throw distance is a function of length of chain, design of chain head, speed of rotation, and amount of protection around the flail head. Larger machines have longer chains but may use a slower rotation speed.

This flail tended to throw mines to the right. Given that it is impossible to prevent throw completely, it might be possible to adjust the action of the chains and design of the deflector plate to force an even higher proportion of throw to one side. Whether the laterality of throw is a characteristic of this individual flail or of the model generally does not matter. What matters is that with laterality of throw known, the machine can be deployed to ensure that the main direction of throw is into areas that are not yet processed. For example, this machine would be best deployed either in a clockwise direction from the perimeter of the minefield, or an anti-clockwise direction from the centre. With respect to mine throw, working back and forth along parallel lines would not be a good way to use this machine.

Soil type was the primary factor determining throw patterns. Mine size and depth were relatively unimportant. The depth setting of the flail is likely to affect some values in the data, but the overall trends found for mine size and depth should be similar.

Clearly, more tests of this sort on different makes and sizes of flails are desirable. The Geneva International Centre for Humanitarian Demining plans to continue these tests, but the manufacturers can also conduct tests so they can give advice to purchasers on laterality of throw, proportion of mines thrown beyond the flail, and likely maximum throw distance under different operating conditions. Consideration should be given to including information about throw patterns in the *Mechanical Demining Equipment Catalogue*, and eventually to developing a standard test to be incorporated into the International Mine Action Standards.

We thank the Swedish EOD and Demining Centre for supplying equipment, resources and the field site to support the study. Funding was provided by the governments of Germany, Norway and Sweden.

See Endnotes, page 112

Ian McLean worked for five years at the Geneva International Centre for Humanitarian Demining, conducting research on dog detection systems, environmental effects on landmine detection, and Remote Explosive Scent Tracing (REST) systems. Prior to that time, he was an academic biologist specialising on conservation issues with endangered species. He now works at the University of Otago in New Zealand, where he teaches wildlife management and is building a research programme on biosecurity issues.

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Havard Bach heads the Operational Support Unit for the GICHD. Projects under his responsibility currently include studies on mine-detection dogs, mechanical mine clearance, manual mine clearance and risk management. He also gives consultancy advice, often related to operational demining activities and demining technology. Prior to employment at the GICHD, Havard worked as a Norwegian military engineering officer before being employed by Norwegian People's Aid, managing several mine-action programmes worldwide.

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