SCAMP Anti-personnel Mine Roller Performance Testing

Humanistic Robotics Inc, a U.S.-based designer and manufacturer of mechanical demining machines and robotic-support equipment, hypothesized that a well-designed roller utilized in the appropriate environments would be an important part of the mechanical demining toolkit. To test this hypothesis, HRI designed, developed and tested a novel anti-personnel mine roller—the Specialized Compact Automated Mechanical Clearance Platform Roller. This article highlights the SCAMP Roller's unique design features, describes two testing events performed to evaluate effectiveness and discusses the test findings.

by Erik de Brun and Scott Poff [Consultants to Humanistic Robotics Inc.]

The use of mechanical demining equipment has greatly benefited humanitarian-demining operations worldwide. One machine type, the mine roller, has several key advantages when compared to other mechanical demining equipment. Because rollers are simple to operate, easy to maintain and have few consumable parts, they have low initial costs and operating expenses.

Despite their advantages in humanitarian-demining operations, rollers are not as widely used as other mechanical equipment, such as flails and tillers. Because roller testing is, to date, either ad hoc or limited mostly to surface-buried mines, the capabilities and limitations of rollers are not widely known.[1] This has led to a generally held belief in the humanitarian community that roller performance is suboptimal; consequently, roller development, testing and use has remained stagnant and limited.

Because of the advantages mine rollers offer and the variety of conditions in which demining operations occur (many of which are appropriate for rollers), HRI developed a novel AP mine roller—the Specialized Compact Automated Mechanical Clearance Platform Roller. As part of the development process, HRI studied existing mine rollers and researched the key characteristics governing mine-roller effectiveness. To properly evaluate the SCAMP Roller's clearance performance, a series of formal tests were conducted at the Keweenaw Research Center in Houghton, Michigan (U.S.) and the Swedish EOD and Demining Centre (SWEDEC) near Eksjö, Sweden. The key parameters evaluated were mine type, soil conditions, compaction level above and around the mine, and roller speed.

SCAMP Roller Description

Roller systems detonate landmines by applying enough force to the ground to trigger the mine. To be an effective tool, a roller must ensure that this force is applied evenly across its full width and is always above a predetermined threshold that is dependent on mine type, depth and ground conditions. To maintain an evenly distributed threshold ground force, the SCAMP Roller has a variable ballast system fixed above a set of independently suspended roller wheels. Each suspension element uses a purpose-built coil spring with a starting force and spring constant specifically tailored to provide relatively constant ground force throughout each roller wheel's vertical travel range. This ensures a minimum ground-force threshold is maintained for each roller wheel during all operations. The roller wheels themselves are aggressively textured "paddle-wheel" type rollers that effectively transmit force to the ground while maximizing blast ventilation. The roller wheel width, paddle spacing and contact surface area ensure that force is translated to even the smallest AP-mine trigger mechanisms. The roller wheels are arranged in two rows with a specifically set overlap between the front and rear roller wheels to ensure that the ground-force profile is constant across the roller's width. The modular, bolted construction of the SCAMP Roller frame also provides a level of flexibility in applying the tool to different mined environments. The roller width and/or target ground force can be set to best suit the mission based on user observations of mine type, soil conditions, mine depth, etc.


Image 1. HRI's SCAMP Roller.
All photos courtesy of the authors.

Materials and Methods

During the clearance performance testing at KRC and SWEDEC, the SCAMP Roller was driven at 1.7, 4.0, 7.7 and 15.0 km/hr over a number of test mines (Type 72A, PMN-1, PMN-2 and M/49) buried at multiple depths (surface, 2.5, 5.0, 7.5 and 10.0 cm). Multiple soil conditions (topsoil, gravel and silt/gravel mix), as defined by the European Committee for Standardization (CEN) Workshop Agreement 15044:2004 were tested.[2] For the topsoil and silt/gravel mix conditions, the compaction level of the soil surrounding each mine was varied.

Test Procedure

A test lane was set aside in each soil condition by marking the outside edges and centerline. Each lane was conditioned by tilling the soil, adding moisture if necessary, and compacting until the desired level was achieved. The lane was divided into equal sections along its length—one section for each test mine. The mines were buried in the lane at the desired depth, and if they were placed below surface level, they were covered with overburden. The mine's depth was measured from the top of the pressure plate to ground level. If required, the soil above and around the mine was then compacted to the desired level. During each test run, a prime mover pushed the roller down the test lane at a predetermined constant speed. After the roller was clear of the lane, the mine detonation results were recorded. If one-time test mines were used, they were carefully dug up and inspected to check detonation status. The test lane was then reconditioned prior to reburying any of the test mines.


Image 2. SCAMP Roller with Bobcat T-250 prime mover.

KRC Testing Effort

Test equipment. A 2-meters wide version of the SCAMP Roller pushed by a Bobcat T-250 skid steer loader was utilized for the majority of testing. For the high-speed testing, a high-mobility multipurpose wheeled vehicle prime mover was utilized.

Image 3 (top). Inert Type 72A test mine.
Image 4 (middle). Inert PMN-1 test mine.
Image 5 (bottom). KRC PMN-2 SIM test mine.

Test mines. Inert reproductions of the Chinese Type 72A, Russian PMN-1 and PMN-2 were utilized for testing. The Type 72A and PMN-1 contain internal trigger mechanisms that change state when a "detonation" occurs; they needed resetting after each test run. KRC provided the PMN-2 simulant (SIM) test mines. The SIMs measure pressure plate deflection in real time, which allows for multiple test runs without needing to reset targets or recondition the test lane.

Conditions. One of the main goals of performance testing is determining how a machine will perform in real-world environments. Since mines are found in a variety of conditions (different soil types and surrounding compaction level), testing needs to account for this. To accomplish this, SCAMP Roller testing was conducted in various representative soils, and the compaction level above and around the mine was varied to simulate both recently emplaced and legacy mine conditions.

Soil types. Three different test lanes, with dimensions 4.88-meters wide by 35-meters long, were utilized, each containing a different type of soil. The soil types were based on the standard test soils described in the CEN Workshop Agreement 15044:2004.[2] The soil types used were: screened topsoil (similar consistency to planting soil), silt/gravel mixture (a low-moisture, silt-gravel soil) and 22A road gravel (common gravel used for road construction).


Image 6. KRC test lanes.

Mine-emplacement technique. During the development of the SCAMP Roller, it became clear that the compaction level of the soil surrounding a mine had a significant effect on the performance of mechanical demining machines. The soil above and around the mine can be either loosely packed (simulating a recent emplacement), hard compacted (simulating a legacy condition where a mine was left in the ground for a long period of time) or something in between (see Figure 7 on page 76). The compaction level is particularly important when evaluating roller performance because roller mine neutralization is based on transferring force/deflection to a mine pressure plate through the soil. To simulate recent emplacement, mines were buried in accordance with the mine-emplacement guidelines in the U.S. Army's *FM20-32 Field Manual*.[3] To simulate legacy conditions, the test mines were buried in large holes (2–3 times the mine body diameter), and the soil above and around the mine was aggressively compacted until the compaction level matched the rest of the test lane.

Test Points

- Gravel lane: 4 different speeds (1.7, 4.0, 7.7 and 15.0 km/hr) and 2 depths (2.5 and 5.0 cm)
- Topsoil lane: 3 different speeds (1.1, 7.7 and 15.0 km/hr), 3 depths (5.0, 7.5 and 10.0 cm) and 2 mine compaction levels (recent and legacy)

Report Documentation Page

Form Approved
OMB No. 0704-0188

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1. REPORT DATE **2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **SCAMP Anti-personnel Mine Roller Performance Testing**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Ripple Design,444 N. 4th Street,Philadelphia,PA,19123**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

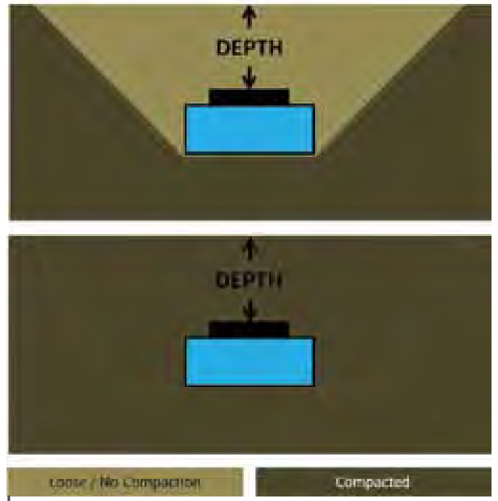

Image 7. Simulated recent (top) and legacy (bottom) conditions.

Image 8. SCAMP Roller with a Bobcat T-200 prime mover.

- Silt/gravel mix lane: 2 different speeds (1.7 and 7.7 km/hr), 3 depths (5.0, 7.5 and 10.0 cm) and 2 mine compaction levels (recent and legacy)

SWEDEC Testing Effort

Test equipment. A 2-meters-wide version of the SCAMP Roller was pushed by a Bobcat T-200 skid steer loader during the SWEDEC testing event.

Test mines. The test targets used in this trial were standard SWEDEC performance test mines. The test mines had live fuzes from the M/49 AP mine installed in inert, plaster-filled plastic bodies. These targets closely replicate many typical, small AP mines. Because the trigger mechanism is extremely small (representative of the smallest common AP-mine triggers) a roller must have complete coverage across its width to contact every mine in the lane.

Conditions

Soil types. Two test lanes, one containing topsoil and the other gravel, based on the standard test soils described in the CEN Workshop Agreement 15044:2004, were used for testing.[2]

Mine emplacement technique. All test mines were surface-buried as shown in Image 9 above.

Test Points. Gravel and topsoil lanes: speed of approximately 7.7 km/hr with all mines surface-buried (0.0 cm).

Results

The results from KRC and SWEDEC testing are presented in the tables on page 77. Clearance performance is measured as a percentage of successful "detonations" versus available targets. For the PMN-2 SIMs, a successful "detonation" is denoted by any measureable pressure-plate deflection. Results are analyzed for each mine type in the following categories:

- Performance versus soil type and mine depth
- Performance versus speed
- Performance versus mine-emplacement technique

Image 9. SWEDEC m/49 test mine.

Image 10. SWEDEC test lanes.

Clearance Performance—Variable Soil Conditions [KRC]. Table 1 shows clearance-performance results for gravel-lane testing. All data from the PMN-2 SIMs indicated successful triggering at the 5.0 cm and 7.5 cm depths (a total of 356 test mines). The same was true for the PMN-1 test mines (a total of 45). For the Type 72As, 34 of 37 targets were triggered at the 5.0 cm depth, while 12 of 12 were triggered at the 7.5 cm depth.

For the topsoil lane the results were similar (Table 2). Again, all data from the PMN-2 SIMs indicated successful triggering at each depth (5.0 cm, 7.5 cm and 10.0 cm). A total of 252 PMN-2 SIMs were tested in this lane. All 23 PMN-1 test mines were triggered at the 5.0 and 7.5 cm depths, but only 3 of 4 were triggered at the 10.0 cm depth. With the Type 72As, all test mines were triggered at each depth (5.0, 7.5 and 10.0 cm). A total of 32 Type 72A test mines were used in the topsoil lane.

In the silt/gravel mix lane (see Table 3), all PMN-2 SIM data indicated successful triggering at each depth (5.0, 7.5 and 10.0 cm). A total of 269 test mines were used. For the PMN-1s, all 27 mines were triggered. For the Type 72As, all test mines at the 5.0 and 7.5 cm depths were triggered, but only 4 of 5 test mines were triggered at the 10.0 cm depth.

When comparing average PMN-2 SIM pressure-plate deflection at different depths for topsoil and silt/gravel mix conditions (see Table 4), the data shows that deflection decreases as the depth increases.

To summarize, the roller triggered 100% of the PMN-2 SIMs over all conditions (gravel, topsoil and silt/gravel mix) and depths (5.0, 7.5 and 10.0 cm) for a total of 877 test mines. The roller triggered 100 of 101 PMN-1 test mines (99%) over all conditions and depths with one mine at a depth of 10.0 cm in the topsoil lane not triggered. For the Type-72As, the roller triggered 110 of 114 test mines (96%) over all conditions and depths. The roller failed to trigger three test mines at 5.0 cm depth in the gravel lane, and one test mine buried at 10.0 cm in the silt/gravel mix lane.

Gravel Lane, Nominal Speed (<7.7 Km/hr)

	PMN-2-SIM		PMN-1		Type 72A	
Depth(cm)	Hits/Targets	Hit%	Hits/Targets	Hit%	Hits/Targets	Hit%
5.0	196/196	100	27/27	100	34/37	92
7.5	160/160	100	18/18	100	12/12	100

Topsoil Lane, Nominal Speed (<7.7 Km/hr)

	PMN-2-SIM		PMN-1		Type 72A	
Depth(cm)	Hits/Targets	Hit%	Hits/Targets	Hit%	Hits/Targets	Hit%
5.0	180/180	100	18/18	100	21/21	100
7.5	40/40	100	5/5	100	6/6	100
10.0	32/32	100	3/4	75	5/5	100

Silt/Gravel Mix Lane, Nominal Speed (<7.7 Km/hr)

	PMN-2-SIM		PMN-1		Type 72A	
Depth(cm)	Hits/Targets	Hit%	Hits/Targets	Hit%	Hits/Targets	Hit%
5.0	170/170	100	18/18	100	22/22	100
7.5	49/49	100	5/5	100	6/6	100
10.0	50/50	100	4/4	100	4/5	80

Table 1 (top). Clearance performance (depth versus mine type).
Table 2 (middle). Clearance performance (depth versus mine type).
Table 3. bottom) Clearance performance (depth versus mine type).

Topsoil & Silt/Gravel Mix Lanes, Nominal Speed (<7.7 Km/hr), Ave PMN-2 Pressure Plate Deflection

	5.0 cm depth	7.5 cm depth	10.0 cm depth
Soil Type	Deflection (cm)	Deflection (cm)	Deflection (cm)
Topsoil	0.14	0.09	0.08
Silt/Gravel Mix	0.11	0.07	0.06

Table 4. Clearance performance versus depth.

Topsoil and Gravel, Nominal Speed (<7.7 Km/hr)

		M/49 AP mine sim (live fuse)	
Soil Type	Depth (cm)	Hits/Targets	Hit%
Gravel	0.0	48/50	96
Topsoil	0.0	50/50	100

Table 5. Clearance performance: surface-buried mines.

Clearance Performance—Surface-Buried Mines [SWEDEC]. During the testing at SWEDEC, the roller's clearance performance was evaluated against surface-buried M/49 mine simulants with live fuzes.

As shown in Table 5, in the gravel lane, the roller detonated 48 of 50 test mines. In the topsoil lane, it detonated 50 of 50 test mines.

Roller Speed Effects [KRC]. Clearance performance of the roller was measured at multiple speeds (1.7, 7.7 and 15.0 km/hr) in the gravel and topsoil lanes with the test mine depth held constant at 5.0 cm.

In the gravel lane (Table 6 on page 78), test-mine trigger percentage was lower at the higher speed for the PMN-2 SIMs (100 triggered out of 110 versus 160 out of 160 at the slower speed) and the Type 72As (6 of 8 triggered versus 12 of 12 at the slower speed).

In the topsoil lane (Table 7 on page 78), the results were similar with fewer PMN-2 SIMs and Type 72As triggered at the faster speed. For the PMN-2 SIMs, 88 of 90 test mines were triggered at the faster speed, where as 160 of 160 were triggered at the slow speed. For the Type 72As, 9 of 11 test mines were triggered at the faster speed, and 21 of 21 targets were triggered at the slow speed.

As indicated in Table 8 on page 78, in the gravel and topsoil lanes, the average PMN-2 pressure-plate deflection decreases as roller speed increases.

Mine-Emplacement Effects [KRC]. In addition to clearance performance, the effect of mine-emplacement technique was also evaluated during the KRC testing effort. Because the PMN-2 SIMs provided continuous output of pressure-plate deflection, it allowed for multiple roller passes at each test condition.

Image 11 on page 78 shows the average PMN-2 SIM pressure-plate deflection for test mines in topsoil and silt/gravel mix at a depth of 5.0 cm versus roller pass. This shows that during the initial pass, when the condition is a true recent emplacement, the deflection is greatest. Over the first four roller passes the average deflection decreases by 30% and then levels off for the last four roller passes.

To compare a fresh "recent emplacement" and a heavily compacted "legacy emplacement," additional testing was performed at 7.5 and 10.0 cm mine depth in the topsoil and silt/gravel mix (Table on page 78). At

Gravel Lane, 5.0 cm Mine Depth

	PMN-2-SIM		PMN-1		Type 72A	
Speed(Km/hr)	Hits/Targets	Hit%	Hits/Targets	Hit%	Hits/Targets	Hit%
<7.7	196/196	100	18/18	100	12/12	100
15.0	100/110	91	7/7	100	6/8	75

Table 6. Clearance performance versus speed.

Topsoil Lane, 5.0 cm Mine Depth

	PMN-2-SIM		PMN-1		Type 72A	
Speed(Km/hr)	Hits/Targets	Hit%	Hits/Targets	Hit%	Hits/Targets	Hit%
<7.7	160/160	100	18/18	100	21/21	100
15.0	88/90	98	9/9	100	9/11	82

Table 7. Clearance performance versus speed.

Gravel & Topsoil Lanes, 5.0 cm Mine Depth, Ave PMN-2 Pressure Plate Deflection

	1.1Km/hr	7.7 Km/hr	15.0 Km/hr
Soil Type	Deflection(cm)	Deflection(cm)	Deflection(cm)
Gravel	0.20	0.14	0.07
Topsoil	0.15	0.15	0.10

Table 8. Clearance performance versus speed.

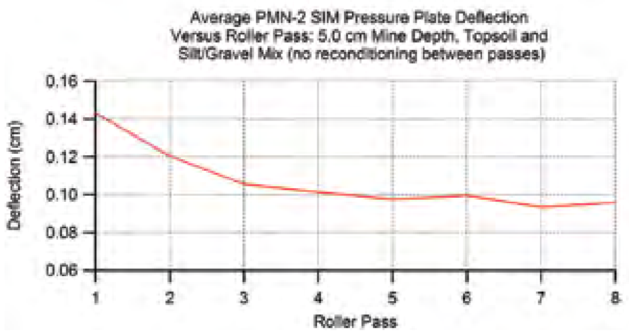

Image 11. Average pressure-plage deflection (cm) versus roller pass.

Topsoil & Silt/Gravel Mix Lanes, Nominal Speed (<7.7Km/hr), Ave PMN-2 Pressure Plate Deflection.

		7.5 cm depth	10.0 cm depth
Soil Type	Emplacement	Deflection (cm)	Deflection (cm)
Topsoil	Recent	0.088	0.080
	Legacy	0.039	0.022
Silt/Gravel Mix	Recent	0.063	0.071
	Legacy	0.047	0.051

Table 9. Clearance performance versus mine-emplacement technique.

7.5 cm in the topsoil, the average pressure-plate deflection decreased by approximately 55% from the recent to legacy-emplacement condition. At 10.0 cm in the topsoil lane, the decrease was approximately 73%. In the silt/gravel mix, the decrease at 7.5 cm was approximately 25%, and at 10.0 cm it was approximately 28%.

Discussion

Clearance performance. The data collected at KRC and SWEDEC shows that in a variety of soil conditions (topsoil, gravel and silt/gravel mix), the SCAMP Roller can consistently trigger different mine types down to a depth of 10.0 cm. When comparing performance between the different soil conditions, no individual condition appears more challenging than any other. Looking at the mine types tested, the Type 72As and the M/49s were the most difficult targets to trigger. This is not surprising due to the fact that they have very small pressure plates, and large force/deflection is required for activation. The Type 72A in particular was chosen as a test mine because of these characteristics. Even though the Type 72As and the M/49s are difficult mines to trigger, the data shows that across all depths and soil conditions the SCAMP Roller triggers these mines 97% of the time, thereby demonstrating its precise coverage and ability to transfer high forces deep into the ground. One clear trend is that as mine depth increases, force transfer and average pressure-plate deflection decreases. Table 4 on page 77 clearly shows where the PMN-2 pressure-plate deflection is noticeably lower at the deeper test-mine depths. Further testing in other conditions and at increased mine depths would round out the roller's performance specifications.

Speed effects. The majority of testing was performed with the roller speed at or below the nominal 7.7 km/hr. In practice, one would expect the roller to be operated well below this nominal speed. It was desirable to conduct testing at the highest speed where good performance was repeatable to allow for the calculation of a theoretical maximum efficiency of square meters of area cleared per hour. It was also important to test the hypothesis that as speed increases, the clearance performance will drop off. This is illustrated in Table 6 and Table 7 above. where the trigger percentage for the PMN-2 SIMs and the Type 72As drops off at high speed. Table 8 above also shows where the average PMN-2 pressure-plate deflection decreases as the roller speed increases.

Emplacement effects. As seen in Table 9 above, the PMN-2 pressure plate's average deflection is lower (in some cases significantly) when mine emplacement is set up to match a legacy condition. Image 11 on page 78 indicates that the average PMN-2 pressure-plate deflection decreases as the roller compacts the soil above and around a mine (emplacement condition moves from recent to legacy). This data confirms that for a given soil, neutralization of legacy-emplaced mines is more challenging than neutralization of recently emplaced mines, and comprehensive roller-performance testing needs to account for legacy simulation. Compaction of the soil surrounding a mine makes it harder for the soil directly above the mine pressure plate to move relative to the surrounding soil. Therefore, higher loads are required to achieve the same deflection.

HRI's SCAMP Roller design and subsequent testing efforts have shown that a well-designed roller used in the appropriate environments can consistently detonate recently and legacy-emplaced simulated mines up to a depth of 10.0 cm. If proper evaluation of roller-clearance effectiveness is performed (formal testing that includes legacy mine emplacement), then data can and should be compared with performance of other mechanical demining equipment.

See endnotes page 82

The SCAMP Roller development and testing was conducted as part of a contract with the U.S. Army Armaments Research, Development and Engineering Center. Special thanks to all involved in the testing efforts: Geoff Gwaltney and everyone at Michigan Tech KRC, Patrik Blomander, Joakim Engblom and Curt Larsson from SWEDEC, Rich Vanaman and his team from the ARDEC, and Pehr Lodhammar from the Geneva International Centre for Humanitarian Demining. Thanks also to Samuel Reeves, Josh Koplin and Justin Dodd from HRI.

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News Brief

Clearing Cluster Bombs on the Ho Chi Minh Trail Video Wins CNN Award

CNN announced the video *Clearing Cluster Bombs on the Ho Chi Minh Trail* as winner of the CNN iReport Community Choice Award on 15 March 2011 for best iReport submitted in 2010.

The four-minute news report compiled by reporter Samantha Bolton and the Cluster Munition Coalition, with help from an independent video-production team, was released in November 2010 at the First Meeting of States Parties to the *Convention on Cluster Munitions*.

Covering Lao PDR's history of contamination, the video provides personal glimpses into the lives of people injured, maimed and affected economically by cluster bombs. Additionally, it highlights the clearance initiatives of governments and international organizations, while addressing the slow demining progress caused by a lack of financial resources and aid needed to remove Laos' estimated 80 million remaining unexploded bomblets. To view the video report, visit http://bit.ly/f3wIio.

~Megan Sarian, CISR Staff