Operational Evaluation Test Report on Beaver Micro-Vegetation Cutter

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FOREWORD

The Micro-Vegetation Cutter (MVC) system was tested in the late summer and early fall of 2004 at a U.S. Army Countermine development site in central Virginia. The MVC project was funded by the U.S. Army's Night Vision and Electronic Sensors Directorate (NVESD), Countermine Division, Humanitarian Demining (HD) Research and Development Office located at Ft. Belvoir, Virginia. The MVC system, consisting of a remote-controlled vegetation cutter vehicle and a command vehicle, is the product of the project engineer, Mr. J. Michael Collins. Mr. Collins was responsible for the concept, its design, and directed the MVC's fabrication. All work was performed in the Modeling and Mechanical Fabrication Shop located at Ft. Belvoir, Virginia.

The test director and test engineer for the test were Mr. Gregory Bullock and Mr. Peter Reed, respectively. Mr. Reed was also the operator for the entire test program. Mr. Collins and Mr. Reed provided vehicle mechanical support during the test. Mr. David Eisenhower, Mr. Richard Kendorza, and Mr. Steve Shorter provided electronic systems support. Mr. Arthur Limerick, a development test-site staff member, provided test range support by opening roads to some of the test areas and keeping the vehicles supplied with diesel fuel. Mr. Harold Bertrand, Mr. Isaac Chappell, and Mr. Robert Kaercher, of the Institute for Defense Analyses (IDA), collected field data during the test. Messrs. Bertrand and Kaercher wrote this report.

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1 INTRODUCTION

1.1 Background

During the annual Department of Defense Humanitarian Demining Requirements Workshop, sponsored by the U.S. Army's Humanitarian Demining Program Office, located at Ft. Belvoir, and attended by representatives of demining organizations throughout the world, one of the more frequently requested equipment needs was for systems that can be used to prepare areas for demining operations. While there are many commercial off-the-shelf (COTS) pieces of equipment available, most are large and expensive. Thus, there was still a need for a small, affordable, robust system having cross-country mobility and the capability to clear light to moderately heavy vegetation and remove surface ferrous metal scrap in preparation for demining activities. With this objective, the Humanitarian Demining Program Office funded the design and fabrication of a concept developed by Mr. J. Michael Collins, a mechanical systems engineer in the Program Office. The concept, consisting of a multi-attachment, remotely controlled, boom and stick work vehicle, named the Beaver, and an armored control vehicle, named the Duck*,* comprise the Micro-Vegetation Cutter (MVC) System. Fabrication was completed in the summer of 2004. A pre-evaluation test was conducted in March 2004 at Ft. Belvoir to insure that all systems functioned as intended. The results of the MVC system pretest are included as this report's Appendix. After completing the system assembly and addressing some of the issues raised during the pretest, an operational evaluation test was scheduled for late summer 2004.

1.2 Purpose

The purpose of this operational evaluation test was to evaluate the performance capabilities of the MVC when operated by a remote operator in the Duck. This included off-road, cross-country mobility; the ability to cut vegetation down to a level that would not interfere with a deminer's ability to search for mines using a hand held mine detector; the effectiveness of an electromagnet to remove surface-strewn ferrous scrap from underneath the vegetation debris left behind by the vegetation cutter; and the effectiveness of the system with a bucket attachment to dig a 5 meter long, ½ meter deep ditch. Secondary issues, which were investigated during the test, included documenting the consumables (fuel, oil, hydraulic fluid, and spare parts) for deployment planning purposes; assessing the time required for an operator to gain proficiency in remotely operating the MVC; and determining the best location for the remote operator (in the Duck) relative to the Beaver to optimize the system's operation.

2 SYSTEM DESCRIPTION

Lessons learned from past efforts, deployments, and operations were incorporated into the design and fabrication of the MVC. This resulted in a remote controlled system with improved performance levels that is smaller than currently fielded systems, easily transported, and economical to operate and maintain. The Beaver (the working vehicle) is a small, diesel-powered, tracked vehicle with provisions for attaching and operating a vegetation cutter, an electromagnet, or an excavating bucket. Power is provided by a Deutz BF3l1011FL three-cylinder diesel engine producing 40 kW of power (53.6 hp). The Beaver's track chassis is designed to traverse most terrain in which mines have been laid. In addition to the vehicle's hydraulic system, a second hydraulic pump is dedicated to providing power for the hydraulic operation of the attached tools (vegetation cutter, bucket, and electromagnet). This results in maximum performance of the attached tool without degrading the hydraulic power needed for vehicle mobility. The Beaver's body is armored with ½ inch (12.7 mm) 6061 aluminum armor plate and is optimized in layout to provide essential mounting locations and access to all components. Table 1 gives the measurements. In addition, an improved remote-control system, named the Standardized Remote Control System (SRCS), has been incorporated. The flexibility of the SRCS allows control across a wide range of machine functions. The SRCS incorporates carrier-grade radios that transmit/receive all control, video, and feedback functions. The SRCS is expandable to accommodate additional control and sensor functions.

A video camera is mounted on the top of the Beaver and its signal is transmitted to the operator in the Duck. Camera movement and zoom, controllable by the operator, assist in the remote driving of the vehicle and afford the operator a close look at the orientation and functioning of the attached tool.

Table 1: MVC Beaver Measurements

Measurements	Dimensions
Weight, with boom and stick	7380 lb / 3348 kg
Max Shipping Height, to top of exhaust	70 in. / 1.78 m
Length of Track	82 in. / 2.08 m
Max Width, track	65.5 in. / 1.66 m
Max Length, no boom and stick	107.0 in. / 2.72 m
Width, cab	50.5 in. / 1.28 m
Length, cab	91.0 in. / 2.31 m
Max Length, with boom, stick and cutter	231.0 in. / 5.87 m
Chassis Clearance	10.0 in. / 25.4 cm
Max Pivot Radius	72.0 in. / 1.83 m
Fuel Capacity	9.9 gal / 37.5 L
Oil Capacity	3.0 gal / 11.5 L
Hydraulic Fluid Capacity	15.0 gal / 56.9 L

The control vehicle, the Duck, is also a tracked vehicle. It contains the SRCS used by the operator to maneuver the Beaver and to control the operation of the attached tool. The vehicle is air conditioned for the benefit of the operator. The Duck and Beaver are independently controlled allowing the operator to move both vehicles at the same time. The engine is a three-cylinder Briggs and Stratton diesel, generating 19.4 kW (26 hp). Table 2 gives the measurements of the Duck.

Pictures of the Beaver and the Duck are shown in Figures 1 and 2.

Figure 1: MVC Beaver

Figure 2: MVC Duck

Table 2: MVC Duck Measurements

Measurements	Dimensions
Max Shipping Weight	4010.0 lb / 1822.7 kg
Max Working Height, antenna up	79.75 in. / 2.025 m
Min Working Height, antenna down	77.0 in. / 1.96 m
Max Shipping Height	77.0 ft / 1.96 m
Track Length	54 in. /1.35 m
Max Width, track	53.5 in. / 1.36 m
Max Length	90.0 in. /2.29 m
Width, cab	40.0 in. / 1.02 m
Length, cab	90.0 in. / 2.29 m
Chassis Clearance	6.5 in. / 16.5 cm
Max Pivot Radius	52.0 in. / 1.32 m
Fuel Capacity	4.3 gal / 16.3 L
Oil Capacity	3.5 qt / 3.3 L
Hydraulic Fluid Capacity	10.0 gal / 37.8 L

2.1 Attachments (Tools)

The current set of attachments tested during the MVC operational evaluation was comprised of the vegetation cutter, an electromagnet, and an excavation bucket. A brief description of each follows.

- Vegetation Cutter: The vegetation cutter was designed and fabricated in the Humanitarian Demining Program's fabrication shop at Ft. Belvoir. A second hydraulic pump is mounted in the Beaver to power the cutter. As a result of the high failure rate of the commercially procured cutting blades used during the pre-evaluation test, new cutters were designed and manufactured in the fabrication shop and used throughout the operational evaluation test. Figures 3 and 4 show the damage sustained by the two-piece cutters used during the pre-evaluation test (wt. = 434 grams); Figure 5 shows the pre-test cutters (left) and the T-1 steel machined cutter (right) used during the operational evaluation test (wt. = 634 grams); and Figure 6 shows the machined cutter (left) and the 4130 heat-treated cast alloy cutter (right) that will be used on future fabricated vegetation cutters (wt. = 756 grams). The weights and materials are shown for each of the cutters as an indicator of each cutter's strength and durability.

Figure 3: Pre-Test Cutters

Figure 4: Broken Pre-Test Cutters

Figure 5: Pre-Test & Operational Evaluation Cutters

Figure 6: Machined and Cast Operational Evaluation Cutters

- Electromagnet: The electromagnet, manufactured by Ohio Magnetics, Inc., is a Model 12 × 20, rated for 24 volts at 36 amps.
- Excavation Bucket: The excavation tool is a 300 mm COTS bucket from JCB Inc.

Table 3 gives the dimensions and weights of the attachments.

Table 3: Measurements of MVC Attachments

Measurements	Dimensions
Cutter Weight	346.0 lb / 157.3 kg
Cutter Width	40.0 in. / 1.02 m
Cutting Width	29.5 in. / 0.75 m
Magnet Weight	238.0 lb / 108.2 kg
Magnet Dimensions	30.5 x 50.8 cm
Bucket Weight	70.0 lb / 31.8 kg

Removal and replacement of the tools was accomplished in the field with little difficulty using the common tools described in section 5.2.2. Time to remove and replace was approximately 10 to 15 minutes for two people, the Duck operator and a mechanic at the tool attachment point.

3 TEST SITE DESCRIPTION

3.1 Test Site Location and Terrain

The operational evaluation test was conducted at a U.S. Army Countermine development test facility located on a military reservation in central Virginia. The development test facility is fully equipped with a heavy equipment maintenance shop, vehicular and light electronic service bays, and office space for the field engineers. Full-time staff consists of mechanics, technicians, explosive ordnance disposal (EOD) and range safety personnel. The terrain is characterized as densely forested rolling hills and plains interspersed with open meadows of heavy, thick field grass and shrubs. Soil is clay and loam. Areas containing the four categories of vegetation described in Table 4 were identified and used to conduct the tests in this report. Pictures representative of each category of vegetation are presented in Figure 7 through Figure 10.

Table 4: Vegetation Categories

Category 1 (Easy)	**Category 2** (Moderate)	**Category 3** (Difficult)	**Category 4** (Very Difficult)
Light vegetation with minimal saplings up to 3 cm diameter	Moderate vegetation with sparse brush and saplings up to 6 cm diameter	Moderate vegetation with brush, saplings and trees up to 10 cm diameter	Heavy vegetation with dense brush, saplings and trees greater than 10 cm diameter
Fairly level terrain with minimal ruts	Level to light rolling terrain with some ruts	Rolling terrain with lots of ruts	Steep hills with lots of ruts, very rugged terrain
Minimal debris and obstacles	Some debris and obstacles	Moderate debris and obstacles	Heavy debris and obstacles

Figure 7: Category 1, Easy

Figure 8: Category 2, Moderate

Figure 9: Category 3, Difficult

Figure 10: Category 4, Very Difficult

3.2 Test Site Weather

The weather was seasonal for August. Daytime temperatures ran from high 80^{o} F to mid 90^{o} F with high humidity. Nighttime temperatures were in the mid 60^{o} F to low 70^{o} F range. Light rains occurred on two nights but left the ground dry enough that no test delays were encountered. Heavy morning dew usually burned off by 10 AM.

4 SYSTEM TESTING

An operational evaluation test is designed to test each of the functions that the vehicles and tool attachments are designed to accomplish. Unlike a field operational test, equipment is not tested to destruction, nor are tests that might cause equipment damage (such as blast tests) conducted. However, the equipment under test is used in a normal manner to highlight early normal wear and tear issues, system infant mortalities, design weaknesses, and the like. To the extent possible and appropriate, tests and measurements identified in the draft International Test and Evaluation Program (ITEP) test protocol for Mechanical Demining Equipment were incorporated into this test.

5 TEST RESULTS

The test results presented do not define the operating limits of the MVC System, the individual vehicles, or the tool attachments. However, they do represent the result of tests that were conducted under what is anticipated to be continual use conditions in the field.

5.1 Performance and Operational Mobility

5.1.1 Operational Performance of the Vegetation Cutter

Timed vegetation cutting tests were conducted in each of vegetation Categories 1, 2 and 3. In addition, a test was conducted to see if the cutter could handle a 15.4 cm diameter tree (Category 4 vegetation), and if so, how long it would take.

5.1.1.1 Category 1, Light Vegetation Cut

Two Category 1 vegetation cutting operation assessments were undertaken. The first cutting operation was made to give the system operator an opportunity to gain experience in controlling the Beaver and the attached cutter, to determine the best location from which to observe and control the operation, and to obtain a performance time-measurement data point. The first vegetation-cutting site was on the side of a hill, which allowed for the assessment of system operation on a slope. The area cut measured 25 meters long by 6.3 meters wide. The slope of the cut area was 24.5 degrees on the left side of the cut area, gradually easing to 16.5 degrees at the right end side of the cut area. Cutting was performed across the slope, from left to right, with the Beaver backing up (returning) to the starting point before making each subsequent cut. The control vehicle, the Duck, was located on the road above the hillside so that the operator could observe the position of the cutter head.

The area of the first vegetation cut was 157.5 m^2 and took 41 minutes 47 seconds. This equated to 226 m^2 per hour.

The second Category 1 vegetation cut was conducted in a level field bordered by a gravel road. For this cut, the procedure was to cut for 1 hour and then calculate the area that was cut. The cutting front, running parallel to the road, was 25.2 meters long. Cutting started with the Beaver on the road with the boom at 90 degrees to the road. The initial cutting pass was adjacent and parallel to the road, from right to left. At the end of the pass, the Beaver backed up to the starting point on the right hand side and made the second pass. The maximum boom extension allowed for three passes before the Beaver had to be moved into the area just cut. See Figure 11. (In an operational situation, the area cut would be searched for mines before the Beaver would be allowed to continue cutting from the previously cut area.) At the end of the hour, a measurement was taken of the area cut. The length of the area was 25.2 meters. The depth was 7.7 meters on the right side, 8.4 meters on the left side, for an average depth of 8.05 meters. See Figure 12.

The area of the second Category 1 vegetation cut was 202.9 m^2 in 1 hour.

Throughout the cut, the control vehicle, the Duck, was behind and off to one side of the Beaver, which allowed the operator a clear line of sight of the position of the cutter head.

The Duck never entered the area being cut. The operator said that the Beaver-mounted camera was very useful in lining up the cuts.

Figure 11: Category 1 Cutting

Figure 12: Completed Cutting

5.1.1.2 Categories 2 and 3, Moderate to Difficult Vegetation Cut

A timed cut of Category 2 vegetation was made in a 16-meter-long area adjacent to a graded fire road. The first 1.5 to 2 meters in from the road were judged to be Category 1 vegetation (heavy field grass with no brush or saplings). The next 2.5 meters consisted of Category 2 saplings and trees measuring 3 to 10 meters tall, most being up to 6 cm in diameter. The final two trees cut, classified as Category 3, each measured 7.5 cm in diameter.

The timed Category 2 cutting test procedure was as follows. The first two passes through the Category 1 vegetation were from right to left, parallel to the road, with the Beaver backing up between passes. A slight drainage ditch along the side of the road required the operator to continually adjust the attitude of the cutter to follow the changing pitch of the ground. Before starting to cut the Category 2 vegetation, the cutter head was rotated 90 degrees so that cutting was accomplished by pushing the cutter on a path that was out away from the vehicle, much in the same way that a push lawnmower might be used to cut grass on a short side slope. After each cut, the operator had to move the Beaver the distance of one cutter width to start the next cut, a process which is much slower than that followed for the Category 1 vegetation cut. When cutting the trees, the technique was to extend the boom and stick, raise the cutter high, and top the trees at some point above the ground. The cutter was then used to chew the standing stumps down to ground level.

Two larger Category 3 size trees, each measuring 7.5 cm in diameter, were removed in the following manner. The cutter was used to put a cut into the front side (side facing road) of the tree trunks at a height of about 3 meters. The cutter was placed behind the trees, above the cut, and used to pull the trees back toward the road, snapping the trees off at the point of the front cut. The cutter was then used to chew the standing stumps down to ground level and to mulch the tops.

The area cut measured 16 meters by 4.5 meters, an area of 72 m^2 cleared in 1 hour.

Figure 13: Category 2-3 Vegetation

Figure 14: Cutting Procedure

Figure 15: Grinding Stump

Figure 16: Completed Cutting

5.1.1.3 Category 4, Difficult Vegetation Cut

A Category 4 deciduous, maple variety tree, 12 to 14 meters high and 15.4 cm in diameter, was selected for the Category 4 cutter operational evaluation test. The procedure followed with this tree was slightly different than followed with the two smaller trees in the Category 2 and 3 test. The tree was topped by cutting through the tree with the cutter at a height of 3–4 meters. The top fell behind the tree and the portion of the trunk left standing was then chewed down to ground level. Total time for this operation was 10 minutes. See Figure 17.

In instances where the vegetation growth was quite heavy, regardless of the category of the vegetation, the debris left on the ground from cutting was found to be much heavier than desirable when sending deminers in to look for mines. Some means of removing the debris is needed. (In the months following this test, a blower that attaches to the boom and stick was developed and will be tested later in 2005.)

Figure 17: Tree to be Cut (left), Cutting (top right), Stump (bottom right)

5.1.1.4 Summary of Vegetation Cutting Test

In summary, the MVC system performed extremely well in each of the vegetation cutting tests. Although the MVC is capable of cutting, in 1 hour, an area greater than a deminer can work in one day, the MVC system will most likely be limited to cutting an area up to the limit of the reach of the boom and stick on the Beaver. The cut area will then be cleared of mines by deminers before the Beaver can traverse the cut and cleared area to make the next vegetation cut.

Table 5 shows the results of the vegetation cutting tests.

Table 5: Results of Vegetation Cutting Tests

Vegetation Cut	Area Cut (m^2)	Time (hrs:mins:sec)
Category 1 Vegetation	157.5 m^2	00:41:47
Category 1 Vegetation	202.9 m^2	1:00:00
Category 2 & 3 Vegetation	72 m^2	1:00:00
Category 4 Tree	1 tree	00:10:00

5.1.2 Operational Performance of the Electromagnet

A Category 1 area, 25 meters by 9 meters, was mowed with the cutter. Thirty-nine pieces of ferrous scrap of various sizes, painted bright orange, were placed randomly throughout the mowed area under the debris from the cutting (see Figure 18). The electromagnet was passed over the area, sweeping the total area in a series of 13 passes. On each pass, the operator kept the magnet as close to the ground as possible without dragging the magnet over the cut vegetation. The magnet was turned off to collect retrieved scrap after every two passes (down and back). A total of 36 pieces of scrap were recovered. A visual search of the area found one more piece. The remaining two pieces were never recovered. However, a metal link from an ammunition belt, not part of the test scrap, was also recovered by the electromagnet. The operator could not guarantee that 100% of the area had been covered since the magnet left no visual tracks of previous passes.

To test the effectiveness of the magnet, seven various pieces of the scrap were selected and placed on a flat area of ground. The magnet was raised above the scrap, turned on, and slowly lowered until the first piece of scrap was picked up. The distance was measured. The lowering of the magnet was continued until all pieces were picked up, with measurements being made as each piece was pulled to the magnet. The test was run twice. The results are presented in Table 6. The difference in pickup height for the same object in the two trials is attributed to the attitude of the electromagnet presenting a changed magnetic field. Figure 19.

Figure 18: Ferrous Scrap

Figure 19: Magnet Sweep

Table 6: Height at Which Magnet Attracted Ferrous Objects

Description of Ferrous Items	Height of magnet above ground at which Item was picked up (inches/cm)	
	Trial 1	Trial 2
Small piece metal, 1.5" per side	3.5/8.9	9.0/22.9
Bent wire, 4" long	9.0/22.9	9.0/22.9
2 inch metal sliver	8.0/20.3	9.0/22.9
Triangle bent metal rod	8.0/20.3	7.0/17.8
8"square, ¼" inch thick	3.5/8.9	5.5/14.0
Nut	3.5/8.9	4.0/10.2
Bolt, 3/8 x 4 inches	3.5/8.9	3.0/7.6

5.1.3 Operational Performance of the Bucket

The operational performance test of the 300 mm JCB bucket consisted of recording the time it took to dig a 5 meter long, ½ meter deep ditch in a mixed clay-loam, undisturbed, sod-covered soil. The operator, who had never operated an excavating bucket before, was allowed ½ hour to "get the feel" of the attachment and how it responded to the controls. Digging of the 5 meter long, ½ meter deep trench took 23 minutes, 39 seconds. Time required to fill the trench was 7 minutes, 52 seconds. Filling of the ditch was accomplished using the blade attached to the rear of the Duck (control vehicle).

5.1.4 Operational Mobility of the MVC System

The operational mobility test of the MVC System vehicles did not push either the Beaver or the Duck to their operational limits. However, each was tested to what were considered practical operating extremes without risking damage to the vehicles or injury to the operator.

5.1.4.1 Speed Test

A short speed test course was established on a level, graded, dirt road for the on-road test and in the adjacent field running parallel to the road for the off-road test. Being slow moving vehicles, both equaled their on road speed when performing off road. The Beaver, the slower moving work vehicle, had a top speed of 1.08 mph (1.74 kph) on and off road. The Duck was almost 5 times faster at 5.1 mph (8.2 kph) both on and off road. The speed advantage afforded the Duck is necessary to allow the operator to position himself at a point where he can view the working area and the tool being used to work the area. This frequently requires the operator to change control locations during an operational mission.

5.1.4.2 Off-Road Mobility Test

The off-road mobility test for the Beaver was conducted in three different areas in order to provide a satisfactory range of terrain environments. See Figure 20. One was a watershed track through a hilly, wooded expanse of the military reservation housing the test site. The most critical parts of the test were the ingress and egress. Once into the track, which was rough and gullied from rainwater runoff, neither the Beaver nor the Duck vehicles encountered any operating problems. The maximum slope encountered by the Beaver in entering and departing the run-off gully, which consisted of a mix of raw clay and sand, did not exceed 27 degrees. On a vegetation and mulch-covered slope, the Beaver climbed and descended slopes up to 32.5 degrees. During the vegetation cutting on a hillside, the maximum side slope traversed by the Beaver was 24.5 degrees.

The Duck chose a more gradual slope to follow when entering and departing the run-off track and at no time exceeded a slope of 23 degrees. The maximum tested side slope for the Duck was 17 degrees. The 32.5-degree slope was not used to test the Duck. It is believed that if later models of the Duck were to incorporate a longer track like that of the Beaver, the Duck would have no trouble following any off-road terrain negotiable by the Beaver.

Figure 20: Off-Road Mobility

5.1.4.3 Angle of Approach and Departure Test

This test was only conducted with the Beaver. The surface cover for the slope climbed was loose soil and gravel intermittently covered with leaf mulch, sparse grass, and low shrubs. The approach and departure angle negotiated, without loosing traction, was 32.5 degrees. The Beaver continued to climb the hill, with subsequent grades up to 28 degrees, to a height of about 60 feet without any problems. See Figure 21.

Figure 21: Angle of Approach/Departure

5.1.4.4 Minimum Turning Radius

Since both vehicles are tracked vehicles, the minimum turning radius will be that achieved by pivoting in a "zero-radius turn," that is, turning by having one track move forward while the other track moves backwards. By so doing, a tracked vehicle will turn on a point midway between the vehicle's track system. The minimum turning radius measured for the Beaver was 16.25 feet (4.96 meters) and for the Duck was 8.8 feet (2.69 meters). See Figures 22 and 23.

Figure 22: Beaver Turning Radius

Figure 23: Duck Turning Radius

5.1.4.5 Ground Clearance

The final measurement taken was the ground clearance. The limiting clearance on the Beaver was the underside of the track housing at 10.6 inches (26.9 cm). On the Duck, clearance was limited by the maximum up position of the rear-mounted blade, or 5.5 inches (14 cm). Table 7 lists the operational mobility measurements.

Table 7: Operational Mobility Measurements

Operational Mobility	Measurement
Beaver On-Road Speed	1.08 mph / 1.74 kph
Beaver Off-Road Speed (Average)	1.08 mph / 1.74 kph
Duck (Control Vehicle) On-Road Speed	5.1 mph / 8.2 kph
Duck Off-Road Speed (Average)	5.1 mph / 8.2 kph
Max Cutting Distance (to side), Parallel to Beaver Path	10.2 ft / 3.1 m
Max Cutting Distance (to front), Perpendicular to Beaver Path	10.2 ft / 3.1 m
Left-Right Movement of Boom to Front	± 30 degrees
Max Approach Angle - Slope, Beaver (max tested)	32.5 degrees
Max Approach Angle – Slope, Duck (not tested)	N/A
Max Departure Angle – Slope, MVC (max tested)	32.5 degrees
Max Departure Angle – Slope, Duck (not tested)	N/A
Max Climb Angle Tested – Slope, no veg. or mulch, Beaver	28 degrees
Max Climb Angle Tested – Slope, veg. or mulch, Beaver	32.5 degrees
Max Climb Angle Tested – Slope, no veg. or mulch, Duck	23 degrees
Max Climb Angle Tested – Slope, veg./mulch, Duck (no test)	N/A
Max Tested Side Slope Working Angle, Beaver	24.5 degrees
Max Tested Side Slope Working Angle, Duck	17 degrees
Turning Radius, Beaver, boom and stick in	16.25 ft / 4.96 m
Turning Radius, Duck	8.8 ft / 2.69 m
Ground Clearance, Beaver	10.6 in. / 26.9 cm
Ground Clearance, Duck (max blade clearance is limiter)	5.5 in. / 14 cm

5.1.5 Operational Consumables

5.1.5.1 Fuel, Oil and Lubricants

Fuel, engine oil, and hydraulic fluid logs were kept for each vehicle. Engine hours and the amount of fuel or oil added were recorded each time a vehicle was serviced.

Both vehicles are fuel-efficient. The Beaver consumed 1 gallon (3.785 liters) of diesel fuel per operating hour. For the Beaver, an operating hour usually meant that the vehicle (engine) was under load, that is, the vehicle was either moving or performing an operational function. Between moves and operational tests, the Beaver was turned off, not left sitting with the engine idling. Therefore, the fuel consumption rate was not diluted by logging engine idling hours. The petroleum, oil and lubricants (POL) log for the Beaver is shown in Table 8.

Table 8: Beaver POL Log

Date	Engine Clock	Quantity Added (liters/qt/gal)		
mm/dd/yy	Hours	Fuel (gal/L)	Oil (qt/L)	Hydraulic (gal/L)
08/09/04	55.6	Full	Full	Full
08/10/04	59.3	3.4 / 12.9	Full	Full
08/11/04	62.1	3.4 / 12.9	1 / 0.95	Full
08/12/04	64.4	2.1 / 7.95	Bit low	Full
08/16/04	67.8	3.2 / 12.11	Bit low	Full
08/16/04	71.2 end of test	3.5 / 13.25	Bit low	Full
Totals	**15.6**	**15.6 / 59.05**	**1 / 0.95**	**Full**

Unlike the Beaver, the Duck, while frequently moved to place the operator in an optimum position to observe the working tool installed on the Beaver, did spend a lot of time at engine idle. This was necessary to provide power for the communication link with the Beaver and to operate the Duck's air conditioning system for the operator. Even so, the fuel consumption averaged only 0.44 gallons (1.65 liters) per operating hour. Table 9 shows the Duck's POL log

Table 9: Duck POL Log

Date	Engine Clock	Quantity Added (Liters/qt/gal)		
/ /	hours	Fuel (gal/L)	Oil (qt/L)	Hydraulic (gal/L)
08/09/04	28.7	Full	Full	Full
08/10/04	32.6	1.4 / 5.3	Full	Full
08/11/04	35.5	1.6 / 6.06	Full	4 / 15.2
08/12/04	38.5	1.6 / 6.06	Full	Full
08/16/04	42.1	1.3 / 4.9	Full	Full
08/16/04	46.1 end of test	1.7 / 6.4	Full	Full
Totals	**17.4**	**7.6 / 28.77**	**0**	**4 / 15.2**

5.1.6 Operator Comments

Throughout the entire test program, comments were solicited from the operator regarding the operation and functioning of the system. Many of the comments will be used later as the basis for recommendations for modification to the existing MVC system or for design changes to be incorporated into subsequently built vehicles. The operator's comments follow.

- The air conditioning system in the Duck (control vehicle) becomes weak (does not put out cold air) as the day heats up. By 11 AM, the air conditioner was only putting out cool air.
- The operator commented that his feet and toes went to sleep because of the awkward angle at which he had to hold his feet on the pedals. This was corrected by adjusting the pedals.
- Camera feed to the cathode ray tube (CRT) went out intermittently on the long-distance operational test. At about 400 meters, the CRT was blank about 35% of the time while the Beaver (MVC) was moving away from the Duck (control vehicle). The signal returned to normal when the Beaver turned around and was facing the Duck. All other controls and displays were operational.
- Visibility is excellent in all directions. There are minor blind spots in the corners that are corrected by head movement.
- The Beaver joystick (in the Duck) has a large dead zone when hard over in either direction. There is no response from the Beaver when in the dead zone.
- The video camera is very useful, particularly in letting the operator know the position of the attached tool. The zoom is good. The camera is quite adequate for tasks addressed in the operational performance test.
- The Beaver was controllable when the Duck was sitting in other than a level position. Operator discomfort: Duck nose up—none; nose down—minor; side down—minor.
- The Duck is low on power in a turn. The vehicle bogs down and needs excessive power to complete the turn.
- Noise level in Duck is high, would like to see it dampened down.
- The control for operating the blade is backward. When you pull back on the control, the blade goes up. Intuitively, it should be the other way around.
- The Duck needs labels on the controls.
- The control for swinging and sluing is too sensitive. A very light touch on the control causes the Beaver to over-respond and generally results in the Beaver moving in excess of what the operator intended.
- The operator needs a minefield edge marker to help retain positioning control of the Beaver's attachment.
- The front windscreen has a gap at the top that allows dust generated by the Beaver's cutter to enter into the cab when the Duck is downwind of the Beaver.
- The smaller length track on the Duck does not allow it to go everywhere that the Beaver can go.
- Operator suggested shifts of 2 hours on, 2 hours off. In this way, two operators would have no trouble covering an 8–12 hour shift. For 12/7 to 24/7 operations, 4 to 6 operators would be needed.
- Stress level for an experienced operator is low. Because of a tight operator's cabin, operator must be able to exit the Duck every hour or so to move around and stretch legs.

- Operator has no trouble moving the Beaver vehicle and attached tool at the same time. Because the same vehicle controls are used for both the Beaver and Duck, only one vehicle at a time can be moved over the ground.

5.2 Maintenance and Maintainability

5.2.1 Maintenance Actions

Three unscheduled maintenance actions were required throughout the course of the test program. All were on the Beaver vehicle, none on the Duck or the MVC attachments. Table 10 lists the problem, maintenance actions, the dates performed, and the time required to perform them.

Table 10: Unscheduled Maintenance

Date	Problem	Maintenance Action	Time Required
8/10/04	Dry grease fittings	Greased boom and stick fittings	½ hour
8/11/04	Lost track control	Shut down, rebooted computer	5 minutes
8/16/04	Computer hot	Opened access covers to cool	15 minutes

The required greasing of the boom was the result of greasing not being performed in the shop before shipping the Beaver to the test site. Had this not happened, the total time spent on unscheduled maintenance for the whole test would have been 20 minutes. Post-test checks will be made to determine if the need to reboot the computer and the overheating of the Beaver computer are the result of the system design or are random occurrences. If necessary, design solutions will be instituted.

5.2.2 Tools Needed in the Field during Test

An issue that the test addressed was to develop a list of tools needed during normal operations. Only two standard toolbox items were needed during the test:

- A ½ inch wrench. This was needed to rotate the cutter head. A ½ inch wrench is included in the standard tool set planned for shipment with the MVC system.
- A universal pocket tool. A full-size *Leatherman* type tool will satisfy this requirement.

In addition, large, open-end wrenches were needed for the hydraulic fittings for the attachments. These wrenches were made in the Humanitarian Demining machine shop and are provided with the Beaver.

5.3 SRCS Functionality

All in all, there were no operational maneuvers desired of the Beaver or any of the attached tools that could not be performed by the operator using the radio link between the Duck and the Beaver. There were some things that came up that may or may not be a problem. For example, it was found that at about 400 meters separation between the Beaver and the Duck, video feed became intermittent depending on the direction that the Beaver was facing. It turned out that when the Beaver's exhaust stack was between the Beaver's video antenna and the Duck, video reception in the Duck broke up. In actual operations, the two vehicle would not be that far apart.

On the other hand, there is a joystick dead zone when it is hard over in either direction. When this happens, there is no joystick contact with the Beaver. Also, a very light touch on the control for swinging and sluing results in the Beaver boom and stick moving in excess to what is intended or desired. The project engineer will address both of these issues at the completion of the test.

No electromagnetic interference (EMI) test with the SRCS was conducted at the test site. The project engineer proposed that this test be conducted at Ft. Belvoir.

5.4 Personnel

5.4.1 Operator Training

If an operator has excavator, backhoe, or similar equipment experience, 2–3 days of practice with the vehicle and attachments should be sufficient before sending an operator into the field. Without such experience, it is estimated that upwards of 2 weeks' training will be needed before sending the operator to the field.

5.4.2 Maintenance Training

Any individual trained in automotive or heavy-equipment mechanics can quickly adapt to the automotive maintenance needs of the MVC system. Training or outside assistance may be needed for maintenance of the SRCS.

5.5 Transportation and Transportability

5.5.1 Local Transportation

Local transporting (to and from a staging area) of the Beaver and Duck vehicles, as well as the three attachments (cutter, electromagnet, and bucket shovel), is most easily accomplished with two four-wheel automobile trailers each pulled by a pickup truck. Since the Beaver weighs almost 8,000 pounds (3,629 kg), a heavy truck capable of towing 8,000 pounds will be needed. The Duck, with attachments and tools, weighs about 5,000 pounds (2,268 kg), and may permit the use of a truck with a lower towing capacity. However, if any off-road or unimproved secondary road travel is anticipated, a truck with a towing capacity similar to that used for the Beaver is recommended. Figure 24 is a picture of the Beaver being loaded for movement at the test site.

Figure 24: Beaver on Trailer

5.5.2 Overseas Transportation

Overseas shipping requirements for the MVC System were not addressed at this time.

6 Comments and Recommendations

The following comments and recommendations were the result of experience gained with the MVC system throughout both the pretest demonstration and the operational evaluation test.

- Air conditioner in the Duck does not have enough capacity to cool the cab when outside temperature approaches high 80^{o} F and above.
- Larger track on the Duck will enable it to go wherever the Beaver can go. However, the Duck is underpowered in turns with current track. Larger track may aggravate this situation.
- Overheating of the Beaver computer should be addressed, particularly if MVC system is to be deployed to the tropics.
- Since debris removal will be needed before deminers can work most cut areas, a tool or a procedure is needed to accomplish this without entering the cut area. A blower mounted on the boom and stick has been suggested.
- External front lights should be added to the Duck for predawn and post-dusk operations.
- Noise level in the Duck cab should be reduced.
- Corner markers are needed to assist the operator in cutting operations. Recommend sending set of four with each MVC system.
- Hydraulic reservoir filler cap leaked oil in angle of approach and departure test. It is recommended that a redesign be considered.
- The gap at the top of the Duck's front windscreen allows dust to blow in and into the operator's face.

7 SUMMARY OF PERFORMANCE DEMONSTRATION

The vehicles and attachments, particularly the cutter with the redesigned cutter heads, worked very well in the vegetation Category 1, 2, and 3 areas (and on a smaller Category 4 tree) available for the operational evaluation test. In each area, the cutter was able to remove the aboveground vegetation to a height that would enable a deminer with a handheld detector to search for mines without further cutting. The working speed of the Beaver and the area preparation tools, especially the cutter, is such that one system, in an hour, can prepare an area larger than a single deminer can clear in a day.

Training, even of an inexperienced operator, will not require an extensive period of time, expensive training aids, or off-site schooling. The vehicles' miserly use of fuel will not put a strain on the logistics support system.

In summary, the MVC System does the job it was design to do, and does it very well.

8 POST OPERATIONAL EVALUATION TEST ACTIVITIES

During the months following the operational evaluation test, a number of changes and initiatives have been instituted as a result of comments, observations, and performance noted during the test. The design and fabrication of a boom-and-stick-mounted blower and mine excavator is underway, and a COTS tree cutter has been added to the set of attachments. The computer problems experienced during the test resulted in an upgrade to the computer and a different computer mounting/installation arrangement in the Beaver. Quick disconnects for hydraulic and electrical power lines have been added to the front of the Beaver. The major activity, though, is a complete redesign of the Duck using the same track system, engine, transmission, chassis, and hydraulic pumps used on the Beaver. This will improve the operator's working environment and visibility, give the Duck the same on- and off-road mobility as the Beaver, and reduce the number of different systems that have to be maintained in the field. During this process, a redesign of the transmission has doubled the speed of the Beaver.

The improved MVC System will be available for test and demonstration in the summer of 2005.

GLOSSARY

amps	amperes
cm	centimeter
COTS	commercial off-the-shelf
CRT	cathode ray tube
EMI	electromagnetic interference
ft	feet
gal	gallon
HD	humanitarian demining
hp	horsepower
IDA	Institute for Defense Analyses
ITEP	International Test and Evaluation Program
in.	inch
kg	kilogram
kph	kilometers per hour
kW	kilowatt
L	liter
lb	pound
m	meter
mm	millimeter
mph	miles per hour
MVC	Micro-Vegetation Cutter
NVESD	Night Vision and Electronic Sensors Directorate
POL	Petroleum, oil, and lubricants
qt	quart
SRCS	Standardized Remote Control System

APPENDIX
RESULTS OF MICRO-VEGETATION CUTTER PRETEST,
29–30 March 2004

APPENDIX

Results of Micro-Vegetation Cutter Pretest, 29-30 March 2004

28 May 2004

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1. Purpose of Test

The purpose of the pretest was two-fold: (1) to make sure that the Micro-Vegetation Cutter (MVC) was ready for an operational demonstration test and to correct any deficiencies that might interfere with or prevent a more thorough test later on and (2) to allow the operators to gain experience in the remote-control operation of the MVC and its attachments. The test was conducted on 29–30 March 2004.

2. Test Site

The vegetation-clearing test was conducted on a moderately difficult slope covered with shrubs 8–10 feet high with approximately a 35 degree slope over 12–15 feet. A level, three-foot-wide grass strip was at the top and bottom of the slope. The length of area cleared was about 125 feet. The slope separated a gravel road at the top from a paved road at the bottom. The MVC climbing tests were conducted on an adjacent hill, with a slope length of about 100 feet. The hill climbed contained trees, saplings, sparse grass, and shrub undergrowth, with little groundcover over the dirt and rocks.

3. MVC System Configuration

The MVC, as tested with the vegetation cutter, was lacking only a mounted camera to be complete. The control vehicle, whose assembly was not complete, was simulated by having an operator's station with a complete Standardized Remote Control System (SRCS) mounted in the bed of a pickup truck. The electromagnet and excavation bucket, which will complete the MVC toolkit, were not used during the pretest.

4. Test Description and Results

The pretest consisted of clearing the level grass strip and slope by cutting in a line parallel to the roads, with the cutter boom 90 degrees to the direction of movement of the vehicle. Since the slope extended farther than the reach of the MVC arm, the clearing was conducted from both the top and bottom of the slope. The MVC moved in a line parallel to the slope with the cutter boom facing up or down the slope, depending on the location of the MVC. The hill-climbing portion of the pretest was conducted on the adjacent hill described above. A list of events and issues that occurred during the 2-day test follows.

29 March 2004

- The engine clock for the MVC read 6.7 hours at the start of the day.
- A hydraulic leak developed at the check valve on the boom. The solution was to tighten the check valve in the field.
- The test was conducted with the cutter mounted parallel to the boom and the stick.
- Interference with the radio caused an automatic shutdown of the MVC. The solution was to restart the MVC engine.
- The hill-climb and descent tests were conducted. The slopes navigated in the order of encounter on the hill were 32.5 degrees, 16 degrees, 5 degrees, 21degrees, 23 degrees, and 30 degrees. The approach and departure angles were 32.5 degrees.
- The hydraulic fluid leaked out of the reservoir tank at the filler cap during the hill-climb test. The angle of the MVC caused the fluid level to reach the filler cap, resulting in leakage.

- The cutters were notched when they hit the inside bottom edge of the U-shaped cutter mounts. The notch propagated cracks and broke the cutters. The solution was to grind off the sharp shoulder on the U-shaped mount.
- Seven cutters were broken. The time to replace all seven of the cutters was 15 minutes.
- There was a delay between the operator command and the response of the MVC or the cutter. This led to over-control input from the operator. The solution was to adjust the SRCS to shorten the signal-response time.
- The operator had to keep the cutter in the line of sight to know the relation of the cutter to the ground.

30 March 2004

- The engine clock for the MVC read 9.8 hours at the start of the day.
- The clearing of the slope continued. During the clearing process, eight cutters broke and one cutter cracked. This issue was resolved by replacing the damaged cutters with new cutters.
- During the cutting operations, the cutter became tangled in barbed wire. On-the-spot correction was made by removing the barbed wire.
- The cutter encountered a loose telephone trunk line (a bundle of telephone wires sheathed in heavy plastic measuring almost 1 inch in diameter), which became wrapped in the vegetation cutter. The telephone trunk line was removed from the cutter.
- The bolts (which held the arm mounts) were secured with regular nuts. The nuts came loose, and both the washers and nuts fell off during operations. This issue was resolved by replacing missing washers and nuts with washers and nylon locking nuts.
- The locking mechanism on the quick-coupling holding the cutter to the stick broke. This issue was to be resolved in the shop because it occurred during the last part of the pretest.

Because the control vehicle was not available for the pretest, and a simulated control vehicle with the SRCS was used, some questions about simultaneous MVC and control-vehicle operation could not be answered. Also, because the perspective of the operator from the back of the truck is different than it will be from the actual control vehicle (the truck sits higher, is not enclosed, has a lower noise level, etc.), some questions about operator visibility, focus, and control will have to be answered in the operational demonstration test. Addressing these issues is important because the operator's visibility of the MVC will determine separation distance between the MVC and the control vehicle during operations, etc.

5. Assessment of Pretest Performance

The system worked very well cutting on the embankment, from the top of the slope on the gravel road with the cutter head reaching down and from the paved roadway with the cutter head reaching up. The MVC was able to climb and descend a hill of varying slopes containing some minor obstacles with no problem.

From an operator's point of view, the line of sight of the attached tool during operations will be necessary. Although there will be a camera on the operational test unit, the lack of depth perception from the single camera and the restricted range of view will make non-line-of-sight operations almost impractical.

6. Post-Pretest Things to Address

A few issues have to be addressed before the final test. First, the completion of the control vehicle is an absolute necessity. Second, the addition of gauges or indicator lights for oil pressure is being considered. Third, it appears that a blower attachment would be a good addition to the MVC tool kit. Given that the main function of the vehicle is site preparation for demining teams, a blower appears necessary to clear the remains of the vegetation after the cutting operations. Not only could cut vegetation interfere with the operation of the magnet in removing ferrous metal objects, but it would also make the cleared slope slippery for walking. Finally, the Project Engineer will look into the feasibility of replacing the vegetation cutters with hammers. The thought is that the hammers would be more durable, and their increased mass would enable faster clearing of heavier growth shrubs.