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Advanced Highway Maintenance and Construction Technology Research Center

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Evaluation of New Technology in Culvert Cleaning

Allyson E. Clark, Ben C. Creed, Wilderich A. White, &
Professor Steven A. Velinsky: Principal Investigator

Report Number: CA12-1954
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ABSTRACT

Caltrans is responsible for maintenance of California’s state road network. The maintenance and repair of culverts is a critical aspect of road maintenance. Cleaning culverts is necessary to eliminate blockages that prevent inspections and thus can lead to failures either due to the blockage itself or a failure that was not identified and addressed due to the lack of inspections. The present options of clearing larger culverts are very costly and subject workers to work hazards that require confined spaces procedures. This document reports on the field evaluation of specialized remote control equipment, a tunnel mucker, used to clean box culverts measuring at least 4 ft by 4 ft or circular culverts measuring at least 5 ft in diameter. It details the operations with Caltrans maintenance over 20 months and includes tests of antenna configurations and radio signal attenuation. The use of this machine was very effective and demonstrated a 79% reduction in costs when compared to the use of typical vacuum truck systems. The use of a remote control tunnel mucker has the potential to significantly improve safety and efficiency of many culvert cleaning operations.

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LIST OF ACRONYMS AND ABBREVIATIONS

Acronym	Definition
AHMCT	Advanced Highway Maintenance and Construction Technology Research Center
Caltrans	California Department of Transportation
dB/dBm	Decibel / Decibel-milliwatts
DOT	Department of Transportation
DRISI	Caltrans Division of Research, Innovation and System Information
GPS	Global Positioning System
GSM	Global System for Mobile (Communications)
IEEE	Institute of Electrical and Electronics Engineers
IMMS	(Caltrans) Integrated Maintenance Management System
LED	Light Emitting Diode
R&D	Research & Development
UHF	Ultra High Frequency

CHAPTER 1
INTRODUCTION

1.1 Problem

Caltrans is responsible for the maintenance of California's state road network. The maintenance and repair of culverts is a critical aspect of road maintenance. Cleaning culverts is necessary to eliminate blockages that prevent inspections and thus can lead to failures either due to the blockage itself or a failure that was not identified and addressed due to the lack of inspections. Caltrans is committed to inventorying, inspecting and repairing the state highway culvert system. The present options of clearing larger culverts are very costly and subject workers to work hazards that require confined spaces procedures. The research question is whether recently available, specialized remote control equipment can be used to clean these larger culverts.

1.2 Background

Culvert cleaning is a critical maintenance issue that Caltrans performs to avoid flooding and damage to roadway infrastructure. Debris of all kinds can build up in the culvert causing water flow to be blocked. If water begins to flow outside of the path defined by the culvert, it will damage the culvert or road under which it is passing. Additionally, culverts have to be cleaned for regular inspections of their integrity.

Caltrans presently uses high pressure water spray systems (jetters) on large vacuum trucks to clear out debris from culverts. This is very effective in smaller round culverts but clearing the large culverts is very difficult and time consuming. It requires the use of large amounts of water that typically must be collected during the cleaning operation and can only be disposed of in approved areas.

Even the larger culverts that are tall enough for people to enter cannot be cleared easily with manually operated machines because this work environment qualifies as a Confined Operating Space. This requires special training and procedures to avoid hazards associated with poor air quality. Finding alternate solutions to Caltrans current practices is important to Caltrans Maintenance.

In 2008 the Caltrans Division of Research and Innovation (DRI) asked researchers at the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at UC Davis to evaluate the Rohmac Microtraxx SL436. This machine is known as a tunnel mucker, an excavating machine designed to remove particulate material from within a confined area, as in a tunnel or mine. This Rohmac tunnel mucker is a unique remote controlled machine that is designed and marketed for use in rectangular culverts measuring at least 48 inches by 48 inches or circular culverts at least 60 inches in diameter.

AHMCT researchers deployed the tunnel mucker in a cooperative effort with the Caltrans Division of Maintenance. Caltrans Maintenance incorporated the machine into its statewide fleet and deployed it with 8 of its 12 districts.

1.3 Research Approach

AHMCT researchers obtained, deployed and maintained the remote control tunnel mucker with Caltrans Maintenance. Researchers outfitted the machine with a remote data logging system. They made direct observations via field visits, interviewed operators and other personnel, obtained Caltrans feedback via photographs and work logs and combined this with the details from the data logger.

1.4 Overview of Research Results and Benefits

Crews using the Microtraxx instead of the vacuum truck based system removed debris four times as fast with lower equipment costs, yielding a 79% reduction in debris removal costs. In addition, the crews can stand back from the operation where they are less exposed to potential injuries associated with handling the high pressure hoses and vacuum nozzles. As a result of the successful evaluation, maintenance wants to incorporate the machine into the fleet. The use of the tunnel mucker has the potential to significantly improve safety and efficiency of many culvert cleaning operations.

CHAPTER 2
CULVERTS AND THE CLEANING OPERATION

This chapter introduces the culvert and its associated maintenance operations. It describes the cleaning options available and describes the tunnel mucker and its operation.

2.1 Brief Introduction to Caltrans and Culverts

Caltrans is responsible for maintaining the safety of California's road network. This includes the maintenance and repair of storm drainage systems meant to keep standing water off of traveled surfaces. There are a range of drainage system types. Some dispel their contents into receiving waters while others discharge into municipal storm drain systems [1].

A local drainage system can serve anywhere from 1 to 10 acres. During a storm, these systems can carry unwanted debris such as litter, roadway sediment, chemicals, and plant matter. Because this can often lead to storm drain blockage, Caltrans, as part of the Maintenance Storm Water Management Program, observes and inspects drain inlets annually in the fall and winter as needed to determine if cleaning or repairs are needed. The culverts are a component of these drainage systems.

2.1.1 What is a culvert

According to U.S. Department of Transportation, culverts are defined as "water conduits that allow streams, brooks, and other flows to cross under highways." This definition is very broad and includes a range of structures.

2.1.2 Types of culverts and their components

There are two types of culverts: Stream Crossing and Runoff Management. The first type is required when the road passes over a moving body of water such as a stream or natural drainage pathway. The second is required to strategically drain the highway of excess water during storms [2].

Both functional types come in many sizes, shapes, and materials. Both consist of a mix of these particular components: span barrel, headwall, endwall, and wingwalls. The span barrel is the tunnel structure that traverses the width of the highway. These can range in shape from round to rectangular and anything in between. Culvert span barrels can be made from concrete or more flexible materials such as plastic, steel, or aluminum. Examples of different shapes and materials can be seen in Figures 2.1a to d.

Figure 2.1: (a) Corrugated steel pipe [3] (b) Concrete box culvert [3]
(c) Concrete culvert for stream crossing [2] (d) Corrugated steel pipe culvert [4]

The headwall and endwall are responsible for controlling the erosion around the culvert span barrel entrance and exit respectively. These walls also help to prevent debris from sloughing off the containing embankment into the culvert opening as well as prevent the movement of the culvert due to hydraulic pressures [5]. Examples of headwalls can be seen in Figures 2.2 a, b, and c.

2.2 Problems Surrounding Culverts

Culverts are constantly subject to harsh environments and thus multiple types of failures occur. Because water is often present, corrosion and rust are major problems for culvert maintenance. Abrasion can also occur as well as joint failures. Any failure that allows water to enter the surrounding soil of the culvert endangers the stability of the highway above it.

Figure 2.3 shows an example of a culvert with rust damage. Rust not only compromises the integrity of the barrel, but also pollutes the water travelling through it.

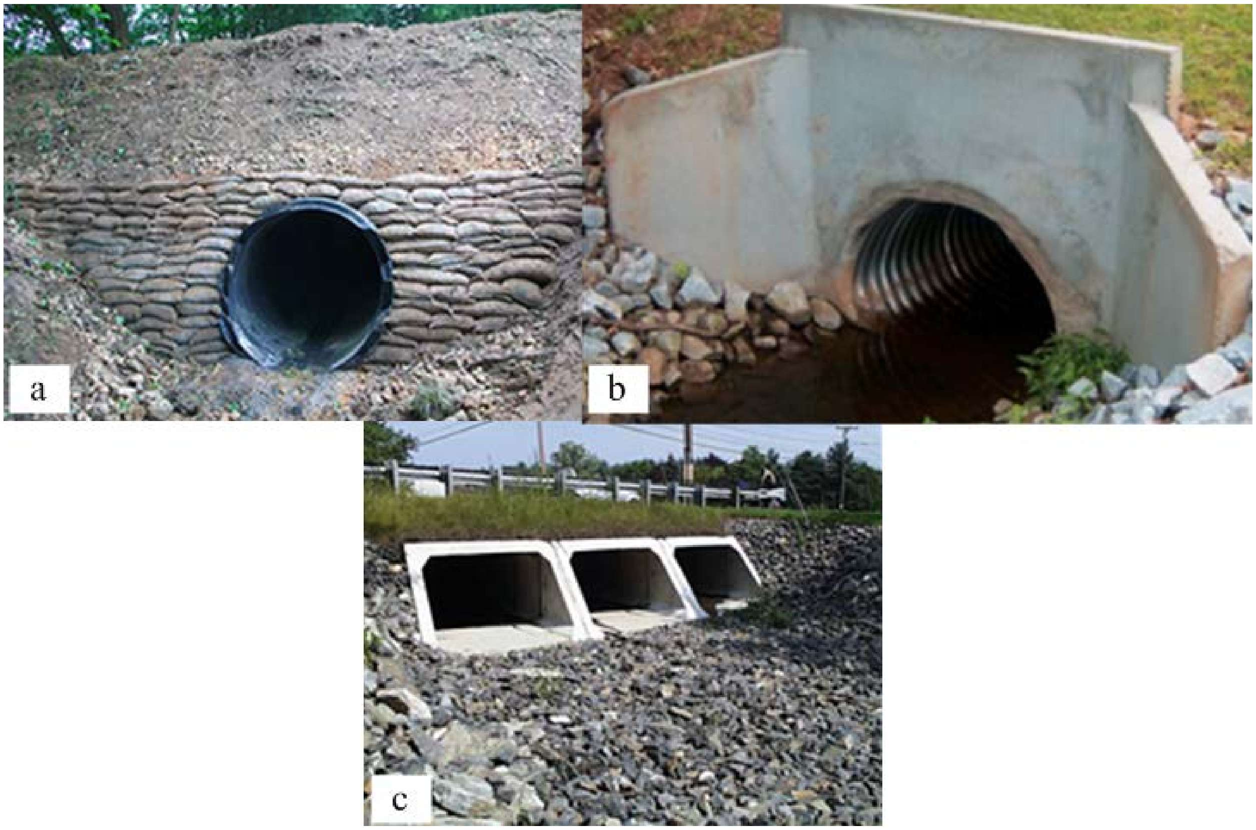

Figure 2.2: (a) Headwall constructed with hessian sacks filled with semi-dry C20 concrete mix [6] (b) Concrete headwall with two wingwalls [7] (c) Triple concrete box culvert [8]

Figure 2.3: Rusted corrugated culvert [9]

Culverts can also fill with debris thus limiting their ability to transport water. This can lead to flooding on the roadway or in the inlet areas. A blocked culvert can be seen in Figure 2.4.

Figure 2.4: Blocked culvert [3]

If not maintained or repaired on a regular basis, culvert sections can experience joint failures as show in Figure 2.5. A joint failure as bad as this can cause severe water leakage into the surrounding soil.

Figure 2.5: Joint failure in a round concrete culvert [10]

If a culvert is not properly maintained and the soil supporting the highway becomes too saturated with moisture, this could lead to the sudden washout of a highway or other safety hazard as shown in Figure 2.6.

Figure 2.6: Highway washout due to culvert failure [11]

The examples above display a mere fraction of the possible problems and failures that can occur with culverts. Because of the complex nature of culvert failures, a systematic review system and frequent surveillance is necessary.

2.3 Caltrans Culvert Maintenance

Caltrans Division of Maintenance implemented a statewide culvert inspection program in 2005. This program requires a systematic evaluation of the condition of culverts. The results of these inspections are then maintained in a database by the program [12].

The inspection of the culverts uses a ranking system for each major part of a culvert (e.g. headwall, span barrel, etc.). The rankings go from 0 to 4. A rank of 0 means no deficiencies were found while a rank of 4 signifies a significant problem. Workers can then select the urgency factor of the problem to let Caltrans know which culverts need the most work.

Caltrans workers use GPS handheld receivers to record the location and the condition of California's culverts. These receivers allow them to log the location, type, physical dimensions, and material of the culvert. It also allows the workers to conveniently evaluate the condition of the material, joints, shape, alignment, and waterway capacity [13].

Because of this program, Caltrans is able to maintain its knowledge of the state's culvert conditions. So far more than 24,000 culverts have been mapped. 70% are known to be in great shape and more than 10% are in need of major repair [13]. With this knowledge crews can focus on fixing or maintaining the most troublesome culverts. A significant part of culvert maintenance is cleaning for proper flow and to allow access for inspections.

2.4 Culvert Cleaning Equipment Options

Culverts come in a variety of shapes and sizes, which makes cleaning them difficult. Various methods are described in the following section.

2.4.1 Vacuum truck with jetter

The most commonly used equipment for culvert cleaning is a vacuum truck with a jetter, shown in a typical cleaning operation in Figure 2.7. The jetter (sewer jet or rodder) is a nozzle with a circular array of high pressure water streams that break apart debris and flush it out (Figure 2.8). The action of the spray pulls the sewer jet and hose forward as the debris is pushed back to the entrance where the vacuum tube draws the water into a tank.

The jetter system requires a high pressure water pumping system and large tanks (Figure 2.9) to hold the extracted debris and water. These trucks utilize large quantities of water, but they are flexible and can clean many shapes and sizes of culverts. Although very effective in small round culverts, this process is very inefficient in large culverts. In addition to the challenge of moving a large volume of debris and water, the jetter becomes less effective as it tends to dig a narrow channel and then follows it at each pass instead of cutting away at the edges of the channel.

As noted, large amounts of water are required during the operation and the water / debris mixture must be handled and disposed of properly. The water and debris has to be trucked to dedicated settling ponds and the work at the culvert cannot continue during this time.

Figure 2.7: Vacuum truck culvert clearing operation (From Caltrans Maintenance What We Do)

Figure 2.8: Sewer jet flushing debris in a culvert

Figure 2.9: Tank system on vacuum truck with jetter system

2.4.2 Walk-behind loader

There are several walk-behind machines on the market that can be used to clean the larger culverts as seen in Figure 2.10. In the case shown, the culvert is 5 ft tall which forces the operator to lean over. Many similar box culverts are only 4 ft tall which precludes the use of this type of machine.

The most significant problem is that this work environment qualifies as a Confined Operating Space. This requires special training and procedures to avoid the hazards associated with bad air quality in confined spaces. Finding alternate solutions to this practice is a high priority for Caltrans.

Figure 2.10: Using a walk-behind loader to clean the culvert

2.4.3 Dragline system

Historically culverts have even been cleaned with shovels and wheel barrows. Several Caltrans workers recalled that this used to occur in prior decades. Another historical cleaning method is the use of a specialized bucket and cable system called a dragline. Figure 2.11 is a generic representation of such a setup described by workers at a site where the mucker was tested. Equipment would be coordinated to pull a bucket back and forth through the culvert. Setting up the dragline with the necessary cable and pulleys is a task that requires significant experience and training. Workers typically developed this experience in mining operations. In discussions with crews, few were familiar with this type of operation. The manual and dragline systems can takes large amounts of time and manpower.

In many cases the access to the ends of the culvert are obstructed and the positioning of the cable system with pulleys and equipment is difficult. In the example, the boom truck is being used to position a pulley below grade level. The trucks are used to anchor the pulleys. If the level of debris is close to the top of the culvert, the bucket cannot be passed through to make its first cut and rigging a cable through the culvert can be very difficult.

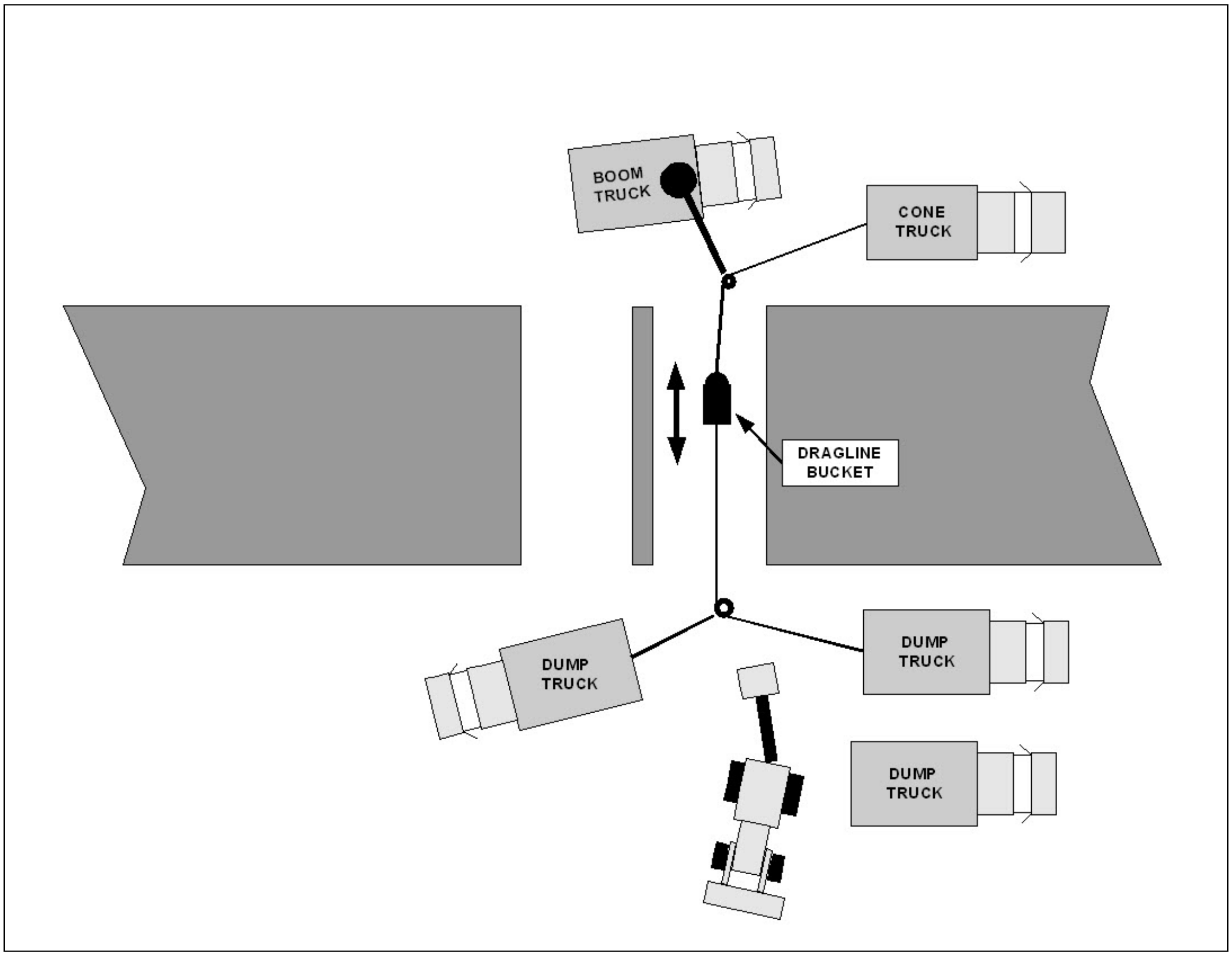

Figure 2.11: Example of dragline bucket operation under a 2-lane highway.

2.4.4 Horizontal drilling

Another solution for cleaning culverts is to use a horizontal directional drill. Hurk Underground Technologies produces a horizontal directional drill for the purpose of cleaning culverts. It has multiple attachments that allow it to clean culverts with a variety of shapes and sizes. A few attachments are shown in Figure 2.12 (a-d). This system appears to be developed by the company for use in its culvert servicing work and is not generally available.

Figure 2.12: Drill attachments (a) Barrel reamer (b) Push bucket (c) Brush (d) Box tool [14]

2.4.5 Tunnel mucker

A tunnel mucker is an excavating machine designed to remove particulate material from within a tunnel or mine. This type of machine can potentially be used to clean culverts and the one tested as part of this evaluation was designed for this purpose.

The Rohmac Microtraxx SL436 tunnel mucker is a unique remote controlled tunnel mucker that is designed and marketed for use in rectangular culverts measuring at least 48 inches by 48 inches or circular culverts at least 60 inches in diameter. Rohmac, a West Virginia company, originally developed this machine for use in the coal mine industry. It was selected for evaluation in Caltrans culverts and is seen in Figures 2.13.

In this operation the mucker is driven into the culvert to collect the debris and bring it to the culvert entrance where a full sized loader then transfers it to a dump truck or other collection point. Figure 2.14 shows the mucker and support vehicles. This is a novel and highly effective method for cleaning the larger culverts.

Figure 2.13: Deploying the tunnel mucker

Figure 2.14: Microtraxx tunnel mucker and support equipment

CHAPTER 3
TUNNEL MUCKER OPERATION

This chapter describes the details of a specific culvert clearing operation at which the mucker was used. It was the third field test of the machine and represents a typical operation. Researchers made a field visit to this site and observed the operations on the first day of the two day operation. The last sections include information on the rate of clearing and include pictures and examples from other sites

3.1 Field Test Operation at Sierraville

The site was located on California Hwy 89 at Fletcher Creek, a few miles north of Sierraville. The crew operating the mucker was trained the previous day in Sacramento and had then transported it to the Sierraville yard. Figure 3.1 shows the staging area the day of the mucker operation.

Figure 3.1: Staging of the culvert cleaning operation at Sierraville CA

On days prior to use of the mucker, crews had cleared the waterway both upstream and downstream. The area was heavily overgrown and a large amount of material was moved. Usually the mucker will easily work concurrently with any other stream bed work since it only requires access to the culvert and a small flat staging area at the entrance of the culvert to start work. This staging area serves as a transfer point where the debris removed from the culvert is then collected by a full sized loader or back hoe for transfer to a dump truck or other point of collection. The transfer loader will easily operate at other tasks while periodically returning to collect the debris removed by the mucker. On the day of this test, the mucker was supported by a loader and dump truck. Technically a bridge, this culvert system consisted of three 8 ft by 5 ft box sections approximately 45 ft long.

3.1.1 Sequence of Operation

The mucker was transported on its dedicated trailer to the job site. It was simply driven off the trailer and then into the culvert. The time required to unload and begin work is about 15 minutes. Figures 3.2, thru 3.4 show the basic steps of culvert mucking. In this case the culvert sections were worked from one end only and cleared right to left.

Figure 3.2: Mucker enters to collect a bucket full

In Figure 3.2 the operator is shown controlling it from a location where he is not breathing the exhaust fumes and is removed from the work area. Because the culvert was relatively short, the operator had good visibility while standing back.

In Figures 3.3 and 3.4 the sequence of backing out with a bucketful of material and setting it to the side is shown. The speed of the operation is greatly affected by the length of the culvert since the machine drives in and out for each bucketful. Taking extra time to ensure that the loader bucket is full before backing out is important for an efficient operation.

The ability of the bucket to slew (rotate) about the tracked base is an important feature. The lateral action of steering the track assembly causes the machine to churn the ground and dig itself into a depression that then has to be smoothed over periodically. This slows the operation and causes additional stream bed erosion.

Figure 3.3: Slews to dumps material at the base of ramp

Figure 3.4: Loader moves debris from mucker staging area to dump truck

In all cases the culvert floor was a smooth concrete surface but the channel is often a natural stream bed as shown here. To avoid pitching motion at the entrance to the culvert, the transition between the sill of the culvert floor and the stream bed needs to be kept relatively even. If not, the mucker pitching action can cause part of the load to be spilled or cause the machine to impact the roof of culverts with low clearance. Typically the surface at the entrance had to be groomed periodically. At this site the soil was very sandy and the water table was very close to the surface. The mucker path had to be groomed a few times an hour but since the debris was easy to scoop with the bucket, the removal rate remained high.

3.2 Measuring Operational Rates

Although the primary expected advantage of using the mucker is to remove the operator from the Confined Operating Space environment, it is also important that the machine improves the work output compared to the present day standard operations. At this site, the material removal quantities were measured directly by measuring material depth and culvert width and length dimensions. An on board data logger recorded the engine run time which was then used to define the removal rates.

Clearing of the first barrel was witnessed by the researchers. It was excavated in 2.5 hours of continuous operation, a rate of 11.7 yd^3 per hour of engine run time (per engine hr). The complete job removed 80 yd^3, took a day and a half, and the removal rate averaged 9.9 yd^3/engine hr.

The data logger recorded machine location approximately every 2 minutes and the on/off status of the engine was clearly indicated. Defining a rate based on engine run time ignores factors such as stopping for refueling, equipment breakdowns, personnel breaks, and similar activities. At this site engine overheating and radio disconnect problems caused the machine to be shutdown periodically. These issues were resolved later but would not have reflected negatively on the removal rates based on engine run time. The additional measure of ‘clock time’ was defined to capture a more realistic representation of production rates. The clock time was defined as the period beginning at 15 minutes before the engine is first turned on and ending 15 minutes after the last shutdown of the day. The removal rate based on clock time was 6.7 yd^3 per hour.

A good example of differing work conditions that affect production can be seen when comparing the 11.7 yd^3/engine hr rate of cleaning barrel 1 to the 8.2 yd^3/engine hr rate of cleaning barrel 3. Barrel 3 was cleaned at the slower rate because the mucker was driven further to deposit the material. The reason for this is that the ramp the loader was using to access the staging area was removed and relocated upstream in order to access the culvert opening. The mucker travel distance outside the culvert was increased, adding significant time to the operation and reducing the production rate.

A wide variety of issues affect production rates and some are presented here. Figures 3.5 and 3.6 are collages of images that show the wide variety culvert cleaning scenarios. Production rates were tracked for the project and the results are provided in Chapter 4 along with a discussion of the issues affecting operations.

Figure 3.5: Assorted pictures of operations using mucker (Set A)

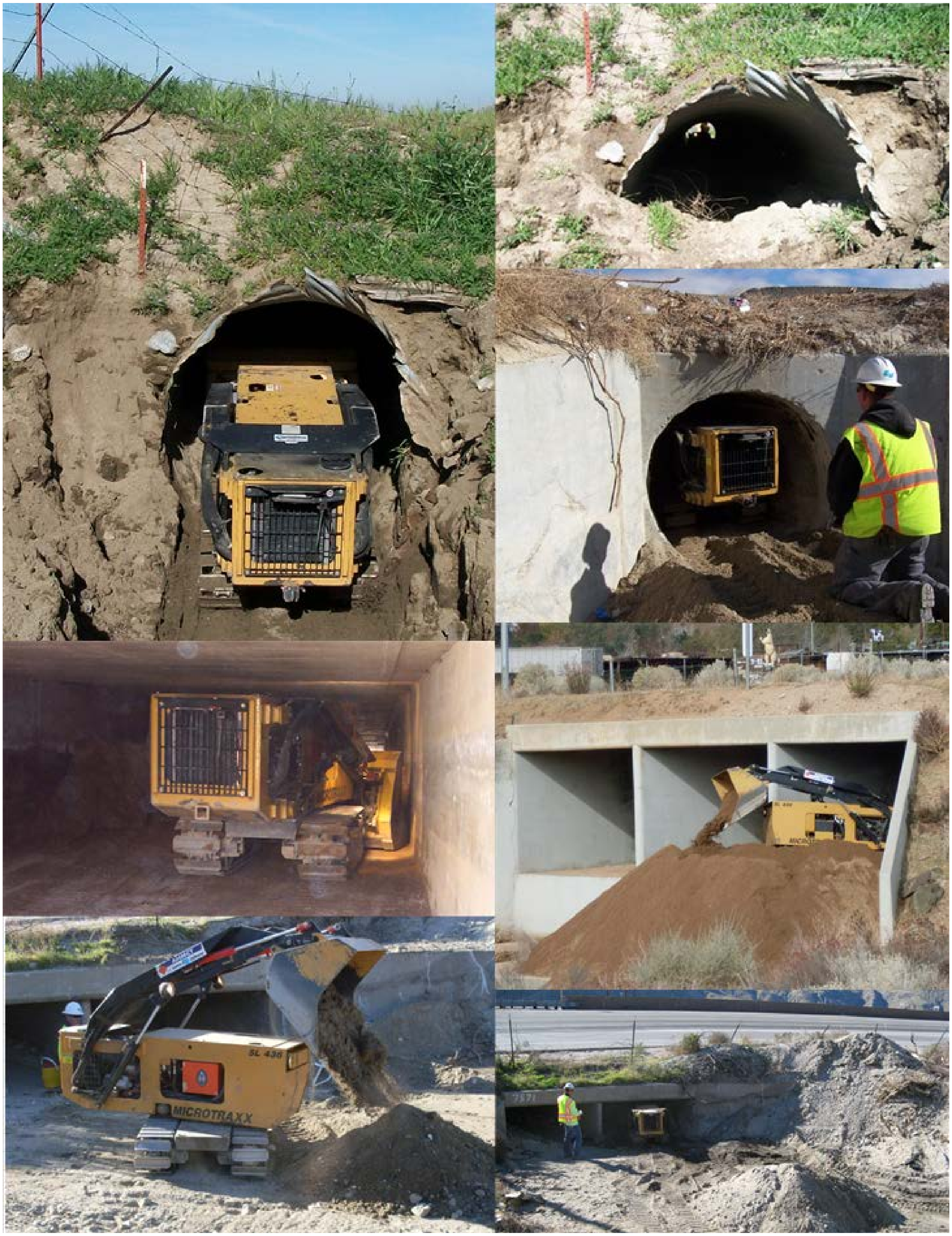

Figure 3.6: Assorted pictures of operations (Set B)

CHAPTER 4
MEASURE OF EFFECTIVENESS

The mucker was deployed by Caltrans headquarters to the various districts on a 4 to 6 week rotation. The researchers and Caltrans monitored its use and collected feedback from the field. This chapter describes the methods used to monitor and quantify the usage and value of the machine. A cost comparison between the mucker and the vacuum truck is made and the results are presented along with a brief discussion of the issues affecting effectiveness.

4.1 Monitoring Machine Usage

The mucker was deployed to Districts 3, 4, 5, 6, 7, 8, 9 and 11 and monitored by the equipment managers, maintenance crews and AHMCT researchers. Information was collected from site visits, notations in the IMMS system, pictures from the crew and the use of a data logger that logs and maps GPS location and time of machine operation. These methods were used to track the machine as follows:

Site visits allowed direct observation and communication with users. Direct measurements of material removal rates were done at these times but observations were limited to a day or less at any particular site. The removal rates were measured over short durations and detailed debris depth measurements were possible. Since most jobs extended over several days and most were not visited, additional information was required to develop removal rates.

IMMS data was of help when the notes describing the operation were of sufficient detail. Crews named the machine WALLE and, as of January 2010, it was used as the IMMS Project Code assigned to mucker operations. Supervisors were encouraged to enter operational details including removal rates in the "notes" field. The IMMS production unit for culvert cleaning (C61050) is 'each culvert cleaned' which cannot be used to compare the material removed.

Photographs were collected and are a useful source of information. A camera was included with the machine and some crews used it extensively to document their work. Pictures of the debris can be used to estimate the material removed by scaling to the size of the machine or known culvert dimensions. This proved to be a very useful tool.

Data logger monitoring was used to provide detailed measurement of machine run time and location. The collected data was available for most of the work and was very valuable. Work locations were mapped onto Google Earth using the GPS coordinates and run time data collected by the data logger system. Hours of operation and location were tabulated along with calculations and reports of how much material was removed. The pictures from the crews were correlated using the date and time stamps.

4.2 Comparing Vacuum and Mucker Operations

In order to compare effectiveness of the operations, it is necessary to define the quantity of work performed and the manpower and equipment required to complete the work. For culvert cleaning with the tunnel mucker, a measure of the debris removed rate is the simplest quantification of its effectiveness. As part of the evaluation process, the debris removal rate was tracked closely on a number of cleaning jobs.

For comparison, the basic equipment and workers required for each of the two configurations is described in Table 4.1. The equipment and crew is similar except for the fact that the tunnel mucker and trailer is substituted for the vacuum truck and tanker. This is a significant reduction in equipment cost.

Table 4.1 - Equipment and Crew in Vacuum and Mucker Operations

	<u>VACUUM TRUCK OPERATION</u> Vacuum Truck with Jetter Tanker 3000 gallons Front End Loader or Backhoe 10 Ton Trailer for loader Dump Body, 2 axle, 4 yd^3 Crew with 3 workers
	<u>MUCKER OPERATION</u> Tunnel Mucker Trailer for mucker Truck to tow mucker trailer Front End Loader or Backhoe 10 Ton Trailer for loader Dump Body, 2 axle, 4 yd^3 Crew with 3 workers

Based on input from Caltrans, the mucker operation is at least four times as fast as the vacuum truck operation. Alternatively it was reported that the vacuum truck operation would clean at 5 cubic yards a day. These factors are the basis for the cost comparison.

4.3 <u>Defining Mucker Usage and Debris Removal Rates</u>

Figure 4.1 shows the website presentation of data from the data logger. By zooming in on the squares in the map, individual data points represented by circles are displayed and details of time and location are displayed. The first and last points for each time period the engine is running were found and used to define the work pattern. A detailed description of the work flow can be determined by finding when the engine was turned on or off and where it was operating.

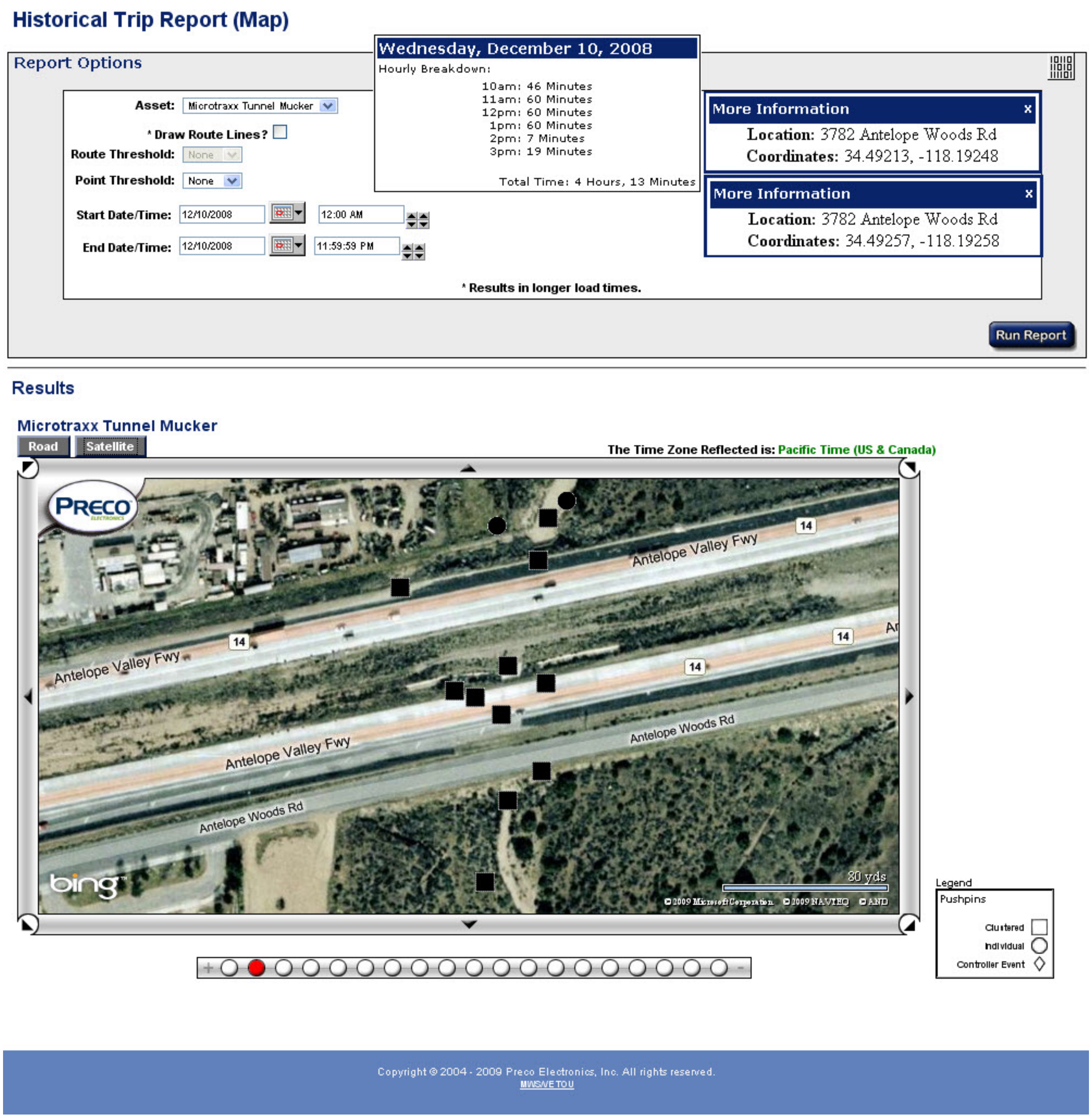

Figure 4.1: Example of output from data logger system

A previously noted, the term 'clock time' is defined to represent the time at the job site. The clock time period begins 15 minutes before the engine is first turned on and ends 15 minutes after it is turned off. The time before and after would be assigned to required tasks such as tie down and packing of the radio, etc. This ignores other work that will occur at a job such as clearing of the channel and preparing the working area in front of the culvert for the mucker to transfer material. It will encompass times for breaks and lunch. The tabulation includes shifts in which breakdowns or other work interruptions occurred.

Details of material removal are correlated with the engine run time by using data from field visits and pictures taken by the crews. Appendix B contains the tabulation of usage and the material removal rates from August 5, 2008 thru March 26, 2010, a period of 599 days, about 20 months.

4.4 Production Data

A detailed investigation on the use of the tunnel mucker was made for the first 41 jobs during the 599 day period. These jobs were identified as WALLE#01 on August 5, 2008 thru WALLE#42 on March 26, 2010 (two jobs were combined). A typical job would have a culvert with several barrels from as short as 35 ft to over 285 ft without a break. Culvert lengths listed in Appendix B under multiple lane highways were not necessarily continuous and typically had breaks in medians areas.

The following is a list of counts and quantities that summarize the work rates during this 20 month period.

- *Total of 41 jobs* – A job represents work at a site which often occurs over a sequential set of dates and it typically includes several culvert barrels. WALLE#19 and WALLE#34 were finally counted as one job because it was the same culvert although operations were separated by several months.
- *129 days of work* – Total count of calendar days (one shift per day) at culvert clearing work. Does not include training, maintenance days, etc. Information was available to calculate the amount of material removed for 98 out of the 129 days.
- *Usage was 79 days per year* for the first 20 months.
- *457 total engine hours of runtime* at the job sites.
- *3.54 engine hours runtime per day/shift* (457 hours/129 days)
- *615 total clock hours at 4.77 clock hours per day/shift* (615 hours/129 days)
- *Usage was 59 days per year* calculated for the 4 year period from Aug 2008 to July 2012.
- *Average daily production = 26.7 yd^3 per day* (maximum 43.5 yd^3 per day)
- *Average hourly production = 7.49 yd^3/engine hr* (maximum at a job 11.4 yd^3 /engine hr)
- *Annual removal rate is 1560 yd^3 per year at 59 days per year over 4 years*
- *Annual removal rate is 2088 yd^3 at 79 days per year during the first 20 months*

4.5 Calculating Mucker Cost Savings

These calculations are presented in Table 4.2. The cost of equipment was calculated by determining an annual cost for each item and assuming a daily rate by dividing the annual cost by an estimated annual usage. This was 100 days for the specialized equipment like the tunnel mucker, trailer, vacuum truck and tanker. The more commonly used equipment was assigned a usage of 150 days a year.

Annual costs in 2009 dollars were first determined by using Caltrans data from 2005 and factoring in a 10.6% increase for inflation. A cost of $1087.38 per day was assigned for the three crew members. This included a 15% overhead rate.

For comparison and as a check, annual costs were also calculated by assigning capital costs and assuming a 5 or 10 year amortization to $0 and an annual 7% maintenance cost. The Caltrans based values are used in the results.

Table 4.2 - Comparison of Material Removal Costs

	USING CALTRANS DATA				ASSIGNING A CAPITAL COST				
COST CALCULATION	**2005-06 CALTRANS ANNUAL COST**	**CALTRAN COST ADJUSTED CPI (10.6%)**	**EST. ANNUAL USAGE DAYS**	**CALC. DAILY COST**	**CAPITAL COST**	**AMORT Years**	**Cost Maint %**	**CALC ANNUAL COST**	**CALC. DAILY COST**
VACUUM TRUCK CREW									
Catch Basin Cleaner	$ 35,420	$ 39,175	100	$ 391.75	$ 500,000	10	7	$ 85,000	$ 850.00
Tanker 3000gal	$ 20,593	$ 22,776	100	$ 227.76	$ 100,000	10	7	$ 17,000	$ 170.00
Loader Front End 1-1/2 CY	$ 17,392	$ 19,236	150	$ 128.24	$ 97,000	5	7	$ 26,190	$ 174.60
Trailer Equipment 10 Ton	$ 2,453	$ 2,713	150	$ 18.09	$ 8,000	10	7	$ 1,360	$ 9.07
Dump Body, 2 axle 4 cu yd	$ 14,355	$ 15,877	150	$ 105.84	$ 60,000	10	7	$ 10,200	$ 68.00
Total Equipment				$ 871.67					$1,271.67
Crew with 3 workers				$1,087.38					$1,087.38
DAILY COST		(Using annual costs)		**$1,959.05**				(Using capital costs)	**$2,359.04**
Cost per cuyd @ 5 CuYd/day				**$ 391.81**					**$ 471.81**
MUCKER CREW									
Mucker	$ 19,185	$ 21,219	100	$ 212.19	$ 107,000	5	7	$ 28,890	$ 288.90
Trailer, 6 ton	$ 3,668	$ 4,057	100	$ 40.57	$ 12,000	10	7	$ 2,040	$ 20.40
Cone setter, Super 1 ton	$ 9,691	$ 10,718	150	$ 71.45	$ 50,000	10	7	$ 8,500	$ 56.67
Loader Front End 1-1/2 CY	$ 17,392	$ 19,236	150	$ 128.24	$ 97,000	5	7	$ 26,190	$ 174.60
Trailer Equipment 10 Ton	$ 2,453	$ 2,713	150	$ 18.09	$ 8,000	10	7	$ 1,360	$ 9.07
Dump Body, 2 axle 4 cu yd	$ 14,355	$ 15,877	150	$ 105.84	$ 60,000	10	7	$ 10,200	$ 68.00
Total Equipment				$ 576.38					$ 617.63
Crew with 3 workers				$1,087.38					$1,087.38
DAILY COST		(Using annual costs)		**$1,663.75**				(Using capital costs)	**$1,705.01**
Cost per cuyd @ 20 CuYd/day				$ 83.19	**Cost per cuyd @ 20 CuYd/day**				$ 85.25
Cost per cuyd @ 26.7 CuYd/day				**$ 62.31**	**Cost per cuyd @ 26.7 CuYd/day**				**$ 63.86**

By assuming a removal rate of 5 yd^3 per day for the vacuum truck and conservatively using 20 yd^3 per day for the mucker the resulting debris removal costs are calculated to be:

- Vacuum truck operation at 5 yd^3 per day = $392 per yd^3

- Tunnel mucker operation at 20 yd^3 per day = $83 per yd^3

Using the mucker reduces material removal costs by $309 per yd^3 a 79% reduction in cost. Assuming the annual material removal rate of 1560 yd^3 per year, the cost saving is $463,500 per year, well over 4 times the cost of the mucker.

4.6 Factors Affecting Production

Generally the mucker is clearly the most cost effective equipment for the cleaning of culverts that it can access. Removal rate is highest under the following conditions:

- Culvert is short and the staging area is close to the culvert entrance.
- Debris is deep
- If a long culvert, it is accessible from each end
- Staging area is a solid flat surface continuous with the culvert bottom

Even in the least ideal conditions tested the removal rates was 4.8 yd^3/engine hr. The lower more conservative clock time rate averaged 5.7 yd^3/clock hr (lowest was 3.1 yd^3/clock hr) making it extremely effective.

The mucker is able to access a wide variety of culvert entrances and can even be lowered by a chain to the entrance. It does require a staging area at the culvert entrance where it can drop the buckets of debris to the side or behind it and move back into the culvert. The mucker spends most of the time moving forward or backward and the less time spent doing so, the more effective it is.

Because creating and accessing the staging area typically requires parking access for the support equipment such as trailers and the loader and dump truck, many of the longer culverts were accessed from one end only. At distances over 250 ft, visibility of the machine and radio drop out begin to limit the ability to control the machine.

In most cases, the stream and culvert beds were dry and the fact that no water was used to collect the debris was a significant advantage. The dust kicked up by the operation was minimal and no dust control was required.

An added advantage that was not determined is the fuel savings. The vacuum truck will typically require operation of the main engine to power the pump and operation of a secondary engine powering the vacuum. This represents 200 hp of continuous engine power that needs to be compared to the less than 40 hp used by the mucker (not including the intermittent power consumed by the loader supporting the mucker).

CHAPTER 5
MACHINE DETAILS

The machine specification, recommended support equipment, ergonomic and mechanical issues are presented in this chapter.

5.1 Mucker Specification

The Microtraxx SL436 is a radio remote controlled front end loader measuring 42 in high, 42 in wide and 120 in long. It weighs approximately 5600 lbs and has a 1/3 yd^3 loader bucket with a lifting capacity of 1550 lb. It is controlled by a commercially available seven-function wireless remote control with industry standard safety top features. It was provided with an Isuzu diesel engine that met the current tier 4 emissions requirements. The hydraulic system oil and grease are biodegradable. A specification sheet in Appendix A contains additional details.

5.2 Support Equipment

The mucker was operated throughout the state and moved every 4-6 weeks between maintenance yards. Caltrans dedicated a 6 ton tilt trailer (Figure 5.1) to the project which made the logistics of deploying the mucker much simpler. Various items were carried with the mucker in a tool box permanently attached to the trailer. Additionally a carrying case was purchased for the radio unit and its charger.

Figure 5.1: Mucker on dedicated trailer

The trailer tool box (Figure 5.2) was not large enough to contain all the items that crews were using to support the machine. The radio case (Figure 5.3) was handled separately and kept in an office where the supervisor would make sure it was charged before going into the field. The case contained the radio controller, emergency manual controller, battery charging unit, spare batteries, camera, keys, and fuses.

Items kept with the machine included:

- Grease gun with special biodegradable grease
- Biodegradable hydraulic oil (not compatible with petroleum based oils)
- Lifting clevis and pintle hook for rear of machine
- Air filters, lamp bulbs, vest for radio controller, tools
- Log books and operator manuals
- Chain down hardware

Figure 5.2: Tool box attached to the mucker trailer

Figure 5.3: Hardened case used to carry radio components

5.3 Ergonomic and Safety Recommendations

5.3.1 Controller strap

The mucker control unit was originally supplied with a waist strap which was cumbersome to use because it required repeated adjustments as the controller was passed between the various operators during training sessions. Some operators could not use it at all and at times the operators chose to hold the controller without any strap. They also began wearing the belt as a neck or shoulder strap.

A neck strap was purchased and used in the field but this proved to be unsuccessful. Although the controller weighed only a few pounds, supporting it with the neck strap was not comfortable after using it for an extended time. The operator‘s hands would rest on the controller adding weight to the neck. Additionally when bent over to peer into the culvert, the weight was transferred to the operator’s lower back muscles. The controller was also likely to swing away from the body especially when bent over. Caltrans suggested the use of a vest which distributes the weight of controller on the shoulders and keeps the controller close to the waist. Using the vest shown in Figure 5.4 resolved all the issues.

Figure 5.4: Controller carrying options: Vest (a) is much preferred over alternatives (b)

5.3.2 Body positioning

Generally when operating the mucker, it was most convenient to stand. Often when working in the 4 ft tall culverts or the long ones, it was more comfortable to kneel or be seated. Figure 5.5 shows examples of operators in various body configurations as they are looking into the culvert.

Operators were required to stay back from the mucker at least 10 ft when running the machine. The operators would usually stand up and back away from the entrance as the mucker was backing out to dump a load of debris. The use of a chair made it easier for some operators but others were hesitant to use one. When working on long low culverts, a large amount of the operator's time will be spent in the lowered position. There was no specific recommendation resulting from the field deployment but it is recommended that the operator be encouraged to find a comfortable configuration that will not strain muscles and joints.

5.3.3 Safe Operation

Caltrans incorporated the training of operators into its formal program from the beginning. A list of safe practices is included in Appendix C. Training emphasized the need to stay out of the machine's reach and its speed was low enough to always be controllable. The fact that the operator can easily position himself in the path of the machine is a hazard that needs to be noted in regular safety reminders to operators.

Figure 5.5: Operators in various body configurations

A primary safety advantage to using the mucker is that it avoids the hazards of the confined space environment. Additionally operating the mucker is less physically strenuous than handling the water hose and vacuum tube of the vacuum truck. The ability to stand back away from the machine and the work area is a distinct advantage of the remote control system.

5.4 Lighting

The original lighting consisted of 12V incandescent lamps. The three forward facing lamps (one on the front and one on each side) were 35W Par 36 tractor lamps (Figure 5.6) and the rear lamp was a lower wattage backup type lamp. Crews struggled with the low lighting condition when working within the long culverts. This was particularly problematic on sunny days in the desert landscapes where the contrast between inside and outside the culvert was extreme.

The single forward front lamp was replaced with two LED lamps that were selected based on the space available (Figure 5.7). A relay was added to avoid overloading the light switch. Each LED lamp was rated at 20W and 1,800 lumens. The need for strong lighting was requested repeatedly and it is recommended that the lights on the sides and rear also be replaced with high quality LEDs.

Operators controlled the machine at distances up to 285 ft. Typically at these distances the mucker was guided by sliding the bucket along one of the culvert walls. The sound of the engine bearing down indicated that it had reached the debris and was digging into it. Usually, the operator had to drive the mucker back and forth into the debris to loosen it up before being able to take a full bucket scoop. After some practice, it was possible to tell by the sound of the machine when the machine was scooping up a full bucket. Moving full buckets of material was important for improving overall efficiency. Being able to see the orientation of the bucket was the most difficult. When empty, the sound of it impacting the floor could be used to discern that it was oriented close to level. Never the less, it was at these extremes of distance that the lighting was most critical.

Figure 5.6: Original 3 forward facing lamps (right side hidden)

When working in long culverts, it was sometimes difficult to see if the machine was responding immediately to commands. A red LED was added to the rear to indicate that the radio communication was connected. Since the link would sometimes drop when in the longer culverts, it was very helpful to have a positive indication that it was connected. A discussion of the radio link is discussed further in Chapter 6.

Figure 5.7: Lighting modifications:2 LED lamps in front and red LED radio link indicator in rear

5.5 Antenna Locations and Data Logger Installation

As originally delivered, the main antenna was mounted to the top deck of the mucker. Although ideal for transmitting the signal, it had to be relocated to the rear as seen in Figure 5.8. Although more protected, the antenna was still broken off periodically. Additional investigation of the antenna configuration is discussed in Chapter 6.

Figure 5.8: Relocation of radio control antenna from top (a) to rear (b)

To support the research evaluation, a data logger (PreCise InfoX GSM/GPRS unit) was installed to track the location of the machine when it was running. In addition to the power circuit, an engine running signal was taken from the hour meter circuit to indicate the engine run time. It was installed in a customized sealed enclosure that was mounted in the body of the mucker as seen in Figure 5.9.

Figure 5.9: Data logger placed in custom enclosure in mucker

The antenna for the data logger GSM system was placed just within the open side of the engine compartment (not shown) and the GPS antenna was located on the top deck as shown in Figure 5.10. Placed on the top to maximize the signal reception, it was installed onto a flexible mount to minimize the chance that it would be damaged.

Figure 5.10: Locating the GPS Antenna

5.6 Miscellaneous Recommendations

Based on AHMCT repairs and experience with the machine and also Caltrans crew observations, various recommendations are compiled below.

The operating environment in the culverts is harsh due to the excessive grit and vibrations. Chafing of hoses and electrical lines occurred regularly and required monitoring. Electrical switches and blade fuses failed due to the grit build up. Hardening and or monitoring of these components is recommended.

Rocks and dirt would fall into the machine interior through the access openings on the top deck especially at the forward end. Crews installed covers on the openings at the front end. All exterior surfaces were eroded by abrasion at edges and corners. Rocks would get wedged into pockets of space between components. Covering access holes at the front and monitoring intrusion of rocks etc. is recommended.

Power and weight of the unit are important. The crews expressed the opinion that the machine is surprisingly effective, given its small size. They identified the weight and power as important factors.

Crews expressed various solutions to improve the controller functions which drove a series of on-off hydraulic functions. Most quickly adapted to the controller and the simplest commercial off the shelf system is preferred. It was repeatedly recommended that the boom action of the main arms be slowed and be cushioned. They also expressed a desire for a control function to adjust the engine speed remotely.

Tracks are steel and provide good traction. Crews expressed the opinion that the steel tracks add to the robustness of the machine. Compared to a rubber tracked vehicle, the steel track is less likely to slip off, and it has better traction. Tracks, sprockets and associated wear components required replacement at about 1000 hrs. Operating the tracks on the dry concrete surface of culvert floors caused high wear rates.

The front corners of the bucket and the cutting edge of the bucket wore quickly. Hardening the edges and making them replaceable is recommended. The option of teeth on the bucket edge is required for breaking up the hard packed debris found in most culverts.

As noted previously, the ability to slew the body around the track base is very important. By incorporating hydraulic slip joints, the Rohmac mucker is able to slew without limitation. A slew of ¾ revolution in both directions would be a minimum ideal.

CHAPTER 6
RADIO COMMUNICATIONS

During the first days of tunnel mucker testing, a sequence of radio operation problems had to be resolved. Replacement of some electronic components eventually solved most of the problems but the mucker continued to have radio communication failures when operating at about 200 ft in the narrower culverts. This led into an investigation of the problem of signal attenuation in the culvert which is reported on in this chapter. Although not fully resolved, the problem did not occur often enough in the field testing to warrant further action.

6.1 Introduction

In the early days of mucker testing, the radio would disconnect (dropout) at random times and distances. Drop out was evidenced by the mucker going to ‘safe mode’ where hydraulics are idled while the engine continued to run. When this occurred, radio communication had to be reinitiated by resetting the transmitter. Although somewhat frustrating, it was not a regular occurrence on most days and the problem was eventually resolved by replacing electronic components.

During this time period of intermittent dropout, the antenna was destroyed while working in a 4 ft tall culvert that measured 6 ft wide and 204 ft long (Job#5). Although not clearly independent of the random dropout, a more consistent dropout seemed to occur at about 200 ft but the antenna had already been damaged. The previous culverts cleaned had measured 65 ft or less in length so it was suspected that there may be a limitation due to culvert length. Not all the potentially defective radio components had yet been changed out at that time.

Once the radio electronics had been changed out and the antenna relocated to the rear, the mucker was used at several long culverts including one measuring 5 ft tall 10 ft wide and 283 ft long. The drop out problem did not occur at this point and appeared to be resolved.

Drop out at distance did reoccur in some culverts and it was reconfirmed by operating it in the culvert #5 referenced above. The issue was then investigated.

6.2 Radio Wave Propagation Theory Overview

A brief literature review in the area of radio wave propagation theory led to an IEEE journal paper titled “Theory of the Propagation of UHF Radio Waves in Coal Mine Tunnels” [15]. This particular paper presents a theoretical study of UHF radio communication in the context of long, narrow, and shallow coal mines. The study covers many aspects of radio communication in this scenario, focusing specifically on the effects that the geometry of the mine has on radio signal attenuation.

There exist a variety of different losses that contribute to the total signal attenuation. The first documented losses are referred to as propagation losses, specifically due to refraction, wall roughness, and wall tilt. Refraction losses occur when a part of the wave that impinges on a wall of the tunnel is refracted into the surrounding dielectric. This refracted part propagates away from the waveguide (in this case, the walls of the mine or culvert) and represents a power loss. In the case of a coal mine tunnel, it is shown that refraction losses are minimized as transmission frequency increases. This relationship is a function of tunnel geometry, and material dielectric properties. Both the roughness (surface level variation) and tunnel wall tilt contribute to increased loss rates. Roughness associated losses increase with wavelength, while tilt is most significant at high frequencies. These qualities result in scattered power that is regarded as a diffuse radiation component.

Another type of loss is referred to as insertion losses. These losses are the result of inefficient coupling between the transmission and receiving antenna and the waveguide mode. The inefficiencies result from mismatches between the impedance seen by the antenna in air and the impedance of the waveguide. This is a significant loss that occurs at both the transmitter and receiver that decreases rapidly with increasing wavelength. Additionally, excitation of the antenna in the waveguide is dependent on its physical location, both relative to the transmitting antenna, and other objects that may exist in the waveguide. As a result, the transmission and receiving antenna location and orientation are important considerations in minimizing signal loss. The paper presents a horizontal-horizontal orientation for the transmission and receiving antenna as the lowest loss reference configuration relative to other configurations. If one antenna is rotated to become orthogonal to the other, the losses increase by 3 dB. This is referred to as polarization loss. Other contributing factors include antenna efficiency, and fade margin to account for the effect of destructive interference.

The paper presents several plots and tables that contain power loss data for a range of transmission frequencies. When propagation and insertion losses are combined, a frequency of 415 MHz is shown to have the smallest overall power loss in a long coal mine environment. Culverts demonstrate many similarities to coal mines because they both represent poor waveguides. The mucker radio operates at 450 MHz, a frequency quite close to 415 MHz which was shown to be optimal in the coal mine scenario. As a result, much of the above theory remains relevant to the mucker application. Refraction losses remain significant for the mucker, however culvert walls are typically smooth and do not have a tilt angle. Insertion losses will affect the mucker, and antenna configuration is likely an important factor in minimizing power loss. Similarly, the distance from the large metallic body of the vehicle to the receiving antenna is expected to have a large effect on signal strength.

Based on the literature review and current radio configuration, a large improvement in signal strength is expected to occur based on the following changes:

1. Addition of a custom ground plane to the receiving antenna
2. Moving the antenna away from the body of the vehicle
3. Orienting the receiving antenna horizontally to match the polarity of the transmitting antenna

6.3 Testing Procedure

The literature suggested that the antenna configuration including location and orientation within the waveguide had significant influence over the power loss. As a result the manufacturer of the mucker was contacted regarding the issues encountered in the culvert. They responded with a modified version of the receiving antenna that included a ground plane that was anticipated to improve radio reception. At this point, three separate tests were performed to evaluate the performance of the radio system. A variety of different antenna configurations were utilized for each test. Configurations included testing both with and without the ground plane, horizontal and vertical antenna orientation, and placement both close to, and away from the vehicle. Examples of some of these configurations are shown in Figures 6.1 thru 6.4.

Figure 6.1: Antenna Configuration 1: Vertical, Center Offset, Close

Figure 6.2: Antenna Configuration 2 : Vertical, Center Offset, Close, Ground Plane

Figure 6.3: Antenna Configuration 3: Vertical, Centered, Far, Ground Plane

Figure 6.4: Antenna Configuration 4: Horizontal, Centered, Far, Ground Plane

6.3.1 Test 1: Open Air Range Test

For this test, the mucker was parked in open air, far from the influence of buildings and other vehicles. For each antenna configuration, the transmitter was connected with the vehicle. The operator progressively moved away from the vehicle, and the distance that communication was lost was recorded.

6.3.2 Test 2: Quantitative Open Air Test

For this test, a spectrum analyzer (Figure 6.5) was connected to the receiving antenna. The transmitter was placed 100 ft from the vehicle and its signal strength was measured with the spectrum analyzer. This arrangement is shown in Figure 6.6. For each antenna configuration that was tested, the analyzer output was exported to a spreadsheet for later analysis.

Figure 6.5: Spectrum analyzer

Figure 6.6: Open Air Testing transmitter configuration

6.3.3 Test 3: Quantitative Culvert Test

This test is similar to Test 2, except the vehicle was located 100 ft inside of the culvert and the transmitter was placed at the culvert entrance (Figure 6.7), approximately where an operator would stand.

Figure 6.7: Culvert Testing transmitter configuration

6.4 <u>Testing Results and Analyses</u>

6.4.1 Test 1: Open Air Range Test

The data presented in Table 6.1 corresponds to the results acquired from open air range test. Distances were recorded at the point where the mucker no longer responded to remote transmitter commands. The information presented in Table 6.1 is also presented visually in Figure 6.8.

Table 6.1 - Open Air Range Test Results

Antenna Configuration	Maximum Range
Configuration 1: Vertical, Center Offset, Close (Figure 6.1)	2365 ft
Configuration 2: Vertical, Center Offset, Close, Ground Plane (Figure 6.2)	3022 ft
Configuration 3: Vertical, Centered, Far, Ground Plane (Figure 6.3)	3103 ft
Configuration 4: Horizontal, Centered, Far, Ground Plane (Figure 6.4)	3304 ft

Figure 6.8: Open Air Range test results

<u>Analysis:</u> The results from this test align with expectations based on the theory presented in Section 6.2. For all antenna configurations evaluated in this section, the maximum range significantly exceeded typical operating ranges for culvert operations. The range limitations

previously reported by operators were not expected to occur for this test. Instead, this test was designed to evaluate the governing radio communication theory. The results present a significant increase in range (200 ft) by adding the ground plane between the first two trials. Range was further improved by centering the antenna and moving it further away from the body of the vehicle. This improvement suggested that the large metallic body of the vehicle likely introduced unaccounted wave guide effects on the radio signal. The best results however, occurred when the orientation of the antenna was changed from vertical to horizontal. This result is not surprising as the literature suggested that both the transmitting and receiving antenna should be oriented the same way. The mucker transmitter has a horizontally mounted dipole antenna (Figure 6.9), suggesting that the receiving antenna should also be horizontal.

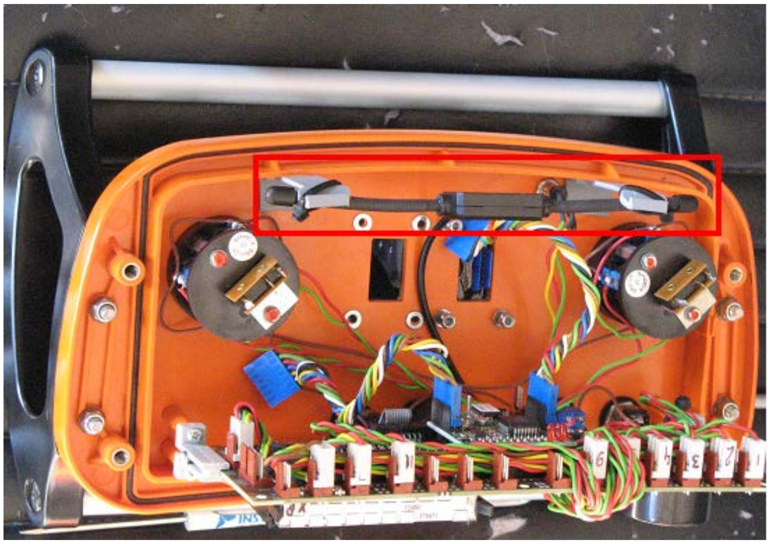

Figure 6.9: Horizontally mounted transmitter antenna

6.4.2 Test 2: Quantitative Open Air Test

For this test, the spectrum analyzer was used to collect information about the received signal. Screen captures were taken and signal data was exported to an excel file and saved to a computer for further analysis. An example of a screen capture is shown in Figure 6.10 where the peak corresponds to the detected transmitter frequency and associated power. It is important to note that there was considerable fluctuation in measured peak power over the course of data collection, occasionally as large as 2-3 dBm. To overcome this limitation, several captures were acquired for each antenna configuration, and the averages are presented in Table 6.2. Similarly, these same results are illustrated as bar graphs in Figure 6.11.

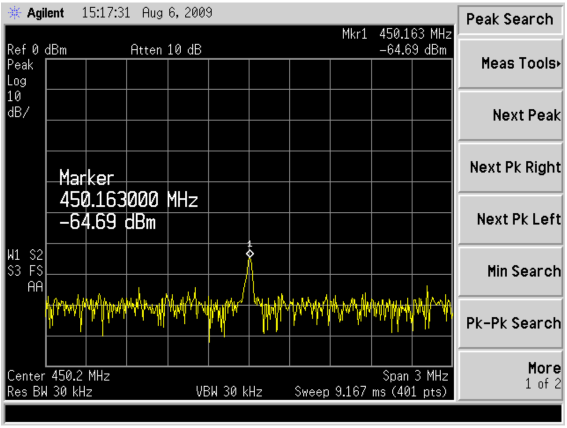

Figure 6.10: Sample spectrum analyzer screen capture

Table 6.2 - Open Air Test Results

Antenna Configuration	No Ground Plane (dBm)	With Ground Plane (dBm)
Configuration 1: Vertical, Center Offset, Close (Figure 6.1)	-62.30	-61.27
Configuration 3: Vertical, Centered, Far, Ground Plane (Figure 6.3)	-64.44	-58.87
Configuration 4: Horizontal, Centered, Far, Ground Plane (Figure 6.4)	-62.94	-66.50

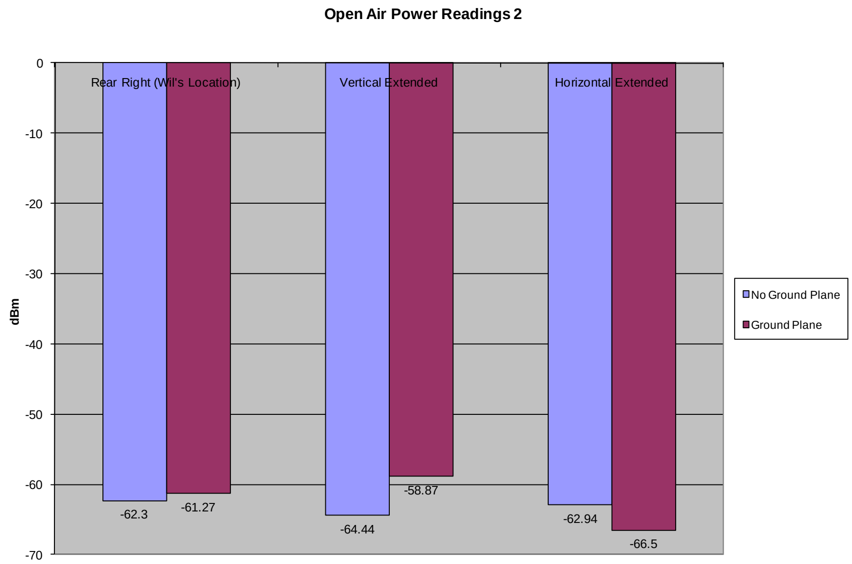

Figure 6.11: Quantitative Open Air Test results

Analysis: The results from this test have some correspondence to the discussed theory, but also demonstrate some deviations. To better understand the data, it is important to note that a smaller quantity in dBm is most desirable. The first configuration that is illustrated in Figure

6.11 shows a slight increase in power with the addition of the ground plane. The same relationship is seen in the second configuration to a greater extent, however it was expected that the vertical extended configuration would outperform the original configuration both with and without the ground plane. The third configuration presented the most puzzling results. It was anticipated that the horizontally oriented antenna with the ground plane would have the best performance of all; however the spectrum analyzer reported the worst performance for this configuration. This result does not align with the results of Test 1, since the longest communication range was attained with this configuration.

6.4.3 Test 3: Quantitative Culvert Test

Table 6.3 - Culvert Test Results

Antenna Configuration	No Ground Plane (dBm)	With Ground Plane (dBm)
Configuration 1: Vertical, Center Offset, Close (Figure 6.1)	-62.11	-62.74
Configuration 3: Vertical, Centered, Far, Ground Plane (Figure 6.3)	-62.27	-63.68
Configuration 4: Horizontal, Centered, Far, Ground Plane (Figure 6.4)	-61.61	-57.92

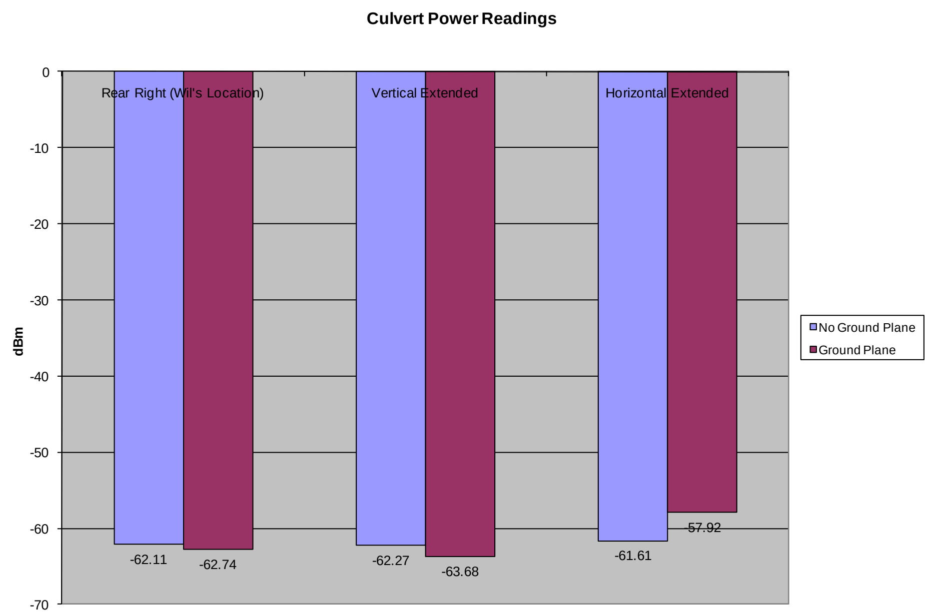

Figure 6.12: Quantitative Culvert Test results

<u>Analysis:</u> The results from this test are presented in Figure 6.12. They were significantly different than that of Tests 1 and 2, however still did not align directly with the expected theory. For the first two configurations, the spectrum analyzer actually reported worse performance with the addition of the ground plane. Furthermore, the results indicated inferior performance by moving the antenna away from the body of the vehicle. The third configuration demonstrated behavior that was closest to what was expected. Both with and without the ground plane, this configuration outperformed the other two. It is important to note however, that the performance was only better by a small margin.

6.5 Conclusions

Based on a literature review, several tests were designed to help identify limitations of the current design and operation of the remotely controlled mucker. Each of these tests was used to determine different aspects of the remote control functionality.

The first test, a simple range test, was designed to determine the maximum open air operating range of the vehicle. The results from this basic test aligned well with the concepts presented in the theory. Additionally, they provided insight into the open air operating limitations.

The second test was designed to quantitatively evaluate the signal strength from the transmitter at the receiving end in open air. The results from this test did not directly support the theory presented in the literature. A variety of factors can be used to explain this, however it should be noted that the theory presented in the literature was derived specifically for radios functioning in environments with tunnel type wave guides. It is likely that variations of the theory exist specifically for open air environments. A second consideration is the fact that the spectrum analyzer presented constant measurement fluctuation. This made it very difficult to accurately attain a power reading. Even though several data points were collected and averaged for each test, utilization of a real time averaging function would have likely produced more useful results.

The third test was used to most directly test the concepts presented in the coal mine radio communication theory. Though the third antenna configuration did produce the best results as predicted, the other two configurations did not perform as expected. This is most likely explained again by the heavy fluctuations in spectrum analyzer readings.

Overall, the tests conducted in this study are believed to be robust and useful for further research in the area of improving radio communication with the mucker while working in culverts. It would be valuable to implement real time averaging on the spectrum analyzer to acquire more meaningful results. The results loosely demonstrate that best radio range is attained by orienting the receiving antenna horizontal (same as the transmitter), moving the antenna away from the body of the vehicle, and adding the ground plane. An antenna built and mounted with these features will require changes to the design of the rear of the mucker and protecting it from damage will be more difficult.

CHAPTER 7
CONCLUSIONS AND FUTURE RESEARCH

Crews using the Microtraxx instead of the vacuum truck based system removed debris four times as fast with lower equipment costs, yielding a 79% reduction in debris removal costs for culverts measuring at least 4 ft square or 5 ft in diameter. Almost all personnel that operated the machine and were responsible for its use recommended it for use in the culvert cleaning operation. The crews can stand back from the operation where they are less exposed to potential injuries associated with handling the high pressure hoses and vacuum nozzles or from the hazards of working with a walk-behind machine. Based on the experience with the machine and testing of the antenna, the machine as tested was very well suited for the operation. The use of the tunnel mucker has the potential to significantly improve safety and efficiency of many culvert cleaning operations.

Future work includes evaluation of different machines as they become available. A range of smaller culvert sizes are not accessible with the machine tested but Rohmac offers a smaller version for 3 ft box culverts. The mechanical action of scooping and shoveling material is likely to be much more efficient than the water jetting action if the water has to be collected and transported along with the debris. Other alternatives to the water jetting process should be considered for smaller culverts. Feasibility will depend on the actual number and sizes of culverts and the frequency of cleaning. Establishing a business case for this effort is recommended.

Since culvert mucking in long culverts requires long sequences of traveling back and forth, reducing the amount of time in this part of the operation is important. Various automated functions that guide the machine and higher travel speed options could be implemented to reduce the burden on the operator and increase efficiency. A faster machine will require additional safety features to avoid accidents. Continuing to collect operator input will assist in determining the value of options such as the operator recommended engine speed control and proportional steering control.

The tested machine, and other similar remote control equipment along with additional tools could be applied to other road maintenance operations. The advantage of being able to operate equipment remotely has the potential to greatly improve operator comfort, safety and efficiency in a variety of activities. Continued monitoring of the tunnel mucker and its application with the crews should be made to understand the potential of this type of equipment.

REFERENCES

1. Transportation, C.D.o. *Drain Inlet Cleaning Efficacy Study*. 2003; Available from: http://www.dot.ca.gov/hq/env/stormwater/pdf/CTSW-RT-03-057.pdf.
2. Choctawhatchee, P.a.Y.R.W.M.A. *Recommended Practices Manual: A Guideline for Maintenance and Service of Unpaved Roads*. 2003; Available from: http://water.epa.gov/polwaste/nps/urban/upload/2003_07_24_NPS_unpavedroads_ch3.pdf.
3. Transportation, N.Y.S.D.o. *NYSDOT Culvert Inspection Field Guide*. Available from: https://www.dot.ny.gov/divisions/operating/oom/transportation-maintenance/repository/CULVERT%20INSPECTION%20FIELD%20GUIDE%201-18-06.pdf.
4. Transportation, O.M.o. *A New Era for Gravity Pipes*. Ontario's Transportation Technology Transfer Digest 2010 [cited 16 2]; Available from: http://www.mto.gov.on.ca/english/transtek/roadtalk/rt16-2/.
5. Management, L.S.W. *Drainage Criteria Manual*. Available from: http://stormwater.ci.lubbock.tx.us/drainage/DCM/chapter09.pdf.
6. Engineers, C.C. *Culvert Headwalls*. Available from: http://www.coppard-groundworks.com/culvert-headwalls.html.
7. Inc., S.E. *City of East Point: Storm Water Infrastructure Analysis Survey*. Available from: http://www.seengineering.com/908/projects/city-of-east-point-storm-water-infrastructure-analysis-survey/.
8. Industries, A.C. *Precast Contrete Box Culverts*. Available from: http://www.americanconcrete.com/commercial/box_culverts/box-culverts.htm.
9. Inc., P.T. *Culvert Lining*. Available from: http://www.psitechnologies.ca/index.php?pg=culvert.
10. Transportation, C.D.o. *Caltrans Condition Tables*. Available from: http://www.dot.ca.gov/hq/oppd/culvert/caltrans-condition-tables.pdf.
11. Morse, C. *Roadway Swept Away*. 2008; Available from: http://blog.mlive.com/chronicle/2008/06/roadway_swept_away.html.
12. Transportation, C.D.o. *Design Information Bulletin No. 83-02 Caltrans Supplement to FHWA Culvert Repair Practices Manual*. Available from: http://www.dot.ca.gov/hq/oppd/dib/dib83-02-3.htm.

13. Bisio, R. *Caltrans Culvert Maintenance Program Mitigates Expensive Failures and Repairs*. 2008; Available from: http://www.cenews.com/magazine-article-cenews.com-4-2008-mapping_asset_conditions-5730.html.

14. Technologies, H.U. *Horizontal Directional Drill*. Available from: http://hurkunderground.com/tooling.

15 A. G. Emslie, R. L. Lagace, and P. F. Strong, "Theory of the propagation of UHF radio waves in coal mine tunnels", IEEE Trans. Antennas Propagat., vol. AP-23, pp. 192 - 205, 1975.

APPENDIX A – MACHINE SPECIFICATION

MICROTRAXX

SL 436 Machine Specifications

General:

Basic Dimensions	42"/1067mm (H), 42"/1067mm (W), 120"/3048mm (L)
Basic Unit Weight	5600 lbs / 2540 kg
Lift Capacity	1550 lbs / 703 kg
Controls	7 function Radio Remote Controls.

Power Unit:

Kubota	
or equivalent	35.1 HP / 26.2 kW, 4 Cylinder Diesel
Fuel Capacity	11 Gal. US / 41.6 L
Hyd. Oil Capacity	32 Gal. US / 121.1 L

Traction:

Drive Motors	Planetary Wheel Motors, Dual Speed w/Braking
Tram Speed	Low 80 ft/Min / 24.4 m/Min
	High 160 ft/Min / 48.8 m/Min
Draw Bar Pull	4700 lbs / 20.9 kN
Ground Pressure	7.5 psi / 51.7 kPa (loaded)

Features:

360 Degree Swing Rotation.
Quick Disconnect System (QDS)
Biodegradable Machine Fluids
Provides Safe Access to Hazardous Areas.
Minimizes Operator Exposure.

APPENDIX B – 20 MONTH USAGE DETAILS

WORK RATE CALCULATIONS-FINAL REPORT				**Culvert**				**Material Removal**			
Section I. Work Details 8-08-2008 thru 3-26-2010 (599 Days) - 41 Jobs			**Hwy**	**Length**	**Job**	**Clock**	**Engine**	**Quantity**	**Clk Rate**	**Eng Rate**	**Daily Rate**
ID (Job #-YYYYMMDD-District-County-PM)	**Culvert ID**	**GPS Road Center**	**Lanes**	**ft**	**Days**	**Hours**	**Hours**	**yd3**	**yd3/hr**	**yd3/hr**	**yd3/day**
WALLE#01-20080805-05-SCR-129_007.53	culvert	36.906126, -121.635727	2	35	1	7.0	6.1	32	4.6	5.2	31.8
WALLE#02-20080806-05-MON-068_013.42	culvert	36.579000, -121.723062	3+	65	1	2.7	1.7	12	4.5	7.1	12.0
WALLE#03-20080903-03-SIE-089_022.70	Brdg 13 0016	39.662206, -120.432644	2	45	2	11.9	8.1	80	6.7	9.9	40.0
WALLE#04-20080910-03-GLE-45_019.81	Brdg 11 0040	39.697532, -122.003891	2	36	1	2.3	1.8				
WALLE#05-20080918-03-YOL-005_R007.00	culvert	38.683292, -121.750113	4+	204	2	7.8	5.6	45	5.8	8.1	22.7
WALLE#06-20080922-03-YOL-113R010.55	culvert	38.681884, -121.750968	4+	230	4	20.6	12.8	64	3.1	5.0	16.0
WALLE#07-20080929-03-YOL-113R002.33	Brdg 22 0186	38.681884, -121.750592	6+	283	3	11.9	5.9	52	4.4	8.9	17.5
WALLE#08-20081010-04-SOL-680R010.20	culvert	38.18514, -122.135592	4+	249	2	6.6	2.6				
WALLE#09-20081020-04-NAP-029R002.37	culvert	38.192632, -122.255060	2	52	2	9.9	8.2	87	8.7	10.5	43.3
WALLE#10-20081022-04-NAP-029_022.36	Brdg 21 0105	38.431928, -122.398361	2	47	4	22.6	19.8	122	5.4	6.2	30.5
WALLE#11-20081124-07-LA-014R049.00	Brdg 53 1912	34.492730, -118.192372	6+	372	9	45.2	34.2	331	7.3	9.7	36.7
WALLE#12-20090107-08-RIV-010R017.27	culvert	33.924466, -116.811877	8+	204	1	2.1	1.6				
WALLE#13-20090116-08-RIV-010R019.71	culvert	33.918786, -116.771658	11+	286	10	42.1	32.6	212	5.0	6.5	21.2
WALLE#14-20090124-08-RIV-079_038.56	culvert	33.901062, -116.985581	4	114	6	34.0	28.4	158	4.7	5.6	26.4
WALLE#15-20090127-08-RIV-060_020.98	culvert	33.939293, -117.146156	4+	149	7	36.4	27.2				
WALLE#16-20090302-06-KER-058R106.60	culvert	35.118063, -118.219080	4	143	4.6	22.7	16.0	93	4.1	5.8	20.1
WALLE#17-20090310-06-KER-058R106.20	culvert	35.117367, -118.226000	4	130	3.2	14.1	9.1	72	5.1	7.9	22.6
WALLE#18-20090310-06-KER-058R105.73	culvert	35.114072, -118.233256	5+	244	4.2	25.0	19.7	149	6.0	7.6	35.5
WALLE#19-20090407-06-KER-014_032.81	culvert	35.27232, -118.031470	4+	168	2	14.5	7.1				
WALLE#20-20090423-11-SD-067R001.12	culvert	32.819108, -116.959756	4	89	2	6.4	4.8				
WALLE#21-20090424-08-SD-067R004.16	culvert	32.855665, -116.942794	4+	195	6	27.4	22.5	130	4.8	5.8	21.7
WALLE#22-20090505-11-SD-067R003.29	culvert	32.848529, -116.954429	6+	237	4	25.8	23.2				
WALLE#23-200905-11-SD-067R001.10	culvert	32.818867, -116.959187	4+		1	1.8	1.3				
WALLE#24-20090519-11-SD-094_064.82	culvert	32.66905, -116.290300	2+		1	4.8	2.4				
WALLE#25-20090609-08-RIV-010R019.75	culvert	33.918860, -116.770884	8+	265	6	24.2	20.1	118	4.9	5.9	19.6
WALLE#26-20090622-08-RIV-010R019.94	culvert	33.919346, -116.76770	8+	270	1	5.4	2.7				
WALLE#27-20090909-04-SCL-152_024.05	culvert	36.995814, -121.378076	2	65	3	9.9	6.9	44	4.5	6.5	14.8
WALLE#28-20090921-04-SCL-152R017.91	culvert	36.983146, -121.439767	2	60	1	1.8	0.8				
WALLE#29-20090921-04-SCL-152R014.81	culvert	36.988435, -121.490871	2	75	0.5	2.3	1.8				
WALLE#30-20090924-04-SCL-152R012.71	culvert	37.010374, -121.515601	2		0.5	1.8	1.3				
WALLE#31-20091104-03-YOL-005R019.22	culvert	38.811981, -121.898309	4+	181	1	1.6	1.0				
WALLE#32-20091118-06-FRE-005_036.00	culvert	36.506114, -120.459651	4+	160	4.5	21.4	16.4	96	4.5	5.9	21.4
WALLE#33-20091124-06-FRE-005_042.00	culvert	36.56674, -120.535395	4+	257	5.5	23.5	18.7	203	8.6	10.8	36.8
WALLE#34-20091228-06-KER-014_032.81	see #19	35.272329, -118.031481	#19	168	6	32.6	22.9	261	8.0	11.4	43.5
WALLE#35-20100111-08-SBD-127_31.90	Brdg 54 1170	35.664187,-116.297378	2	70	5	24.9	19.0	157	6.3	8.3	31.4
WALLE#36-20100304-06-KER-058_069.50	culvert	35.294363, -118.757369	4+	135	2	11.9	9.5	70	5.9	7.3	35.0
WALLE#37-20100305-06-KER-178R013.74	culvert	35.437139, -118.800443	2	77	2	10.7	7.3				
WALLE#38-20100309-06-KER-166_003.86	culvert	35.058146, -119.332816	2	35	1	5.5	2.8	31	5.6	11.1	30.8
WALLE#39-20100310-06-KER-166_006.20	culvert	35.057997, -119.291966	2	35	1	6.4	3.2	25	3.8	7.8	24.6
WALLE#40-20100315-06-KER-223_026.40	culvert	35.214006, -118.735172	2	68	2	9.5	7.5	36	3.8	4.8	18.0
WALLE#41-20100317-06-KER-005_016.57	Brdg 50 0381	35.025737, -118.964481	4+	300	3	10.8	8.2				
WALLE#42-20100326-06KER-204_005.61	Brdg 50 0033	35.393267, -119.027864	4		1	5.8	4.7				
Section II - Totals from Section I								**Material Removal**			
					Job	**Clock**	**Engine**	**Quantity**	**Clk Rate**	**Eng Rate**	**Daily Rate**
					Days	**Hours**	**Hours**	**yd3**	**yd3/hr**	**yd3/hr**	**yd3/day**
Category A (CatA) - Data based on culverts with material removal information					98.0	474.5	357.6	2680	**5.65**	**7.49**	27.3
Category B (CatB) - Data based on culverts without material removal information (Grayed out)					31.0	140.8	99.7				
Totals CatA + CatB					**129.0**	**615.2**	**457.3**				
Average Clock and Engine hours per day						4.77	3.54				
Days per Job (41jobs)=	3.1	Clock Hours per Job (41jobs)=				15.0	Ratio - Engine Hours:Clock Hours=				0.74
Section III - Material Removal Totals						**Clock**	**Engine**	**Average**			
Calculated Total Material removed using Total hours and CatA rates 5.65 and 7.49 yd3						3475	3427	**3451**			
Calculated total material removed per day (3451/129) =				**26.7**							
Section IV - Annual Material Removal Rates						Rate based on			4 year period		
						First 599 days (20 mo)			Aug 1, 2008 - July 31, 2012		
Using hour meter and Ratio of		Total engine hours (Hour meter equivalent)				Not applicable			919 from engine hour meter		
Working Engine hrs :Total Engine hrs	0.906	Engine hours per year (working)				279			208		
which exludes engine operations in training,		Material removed per year @ 7.49 yd3/hr				2088			1560		
maintenance etc.		Work days per year @ 3.54 hr/day				79			59		
		Material removed per year @ 3451 yd3 in 599 dy				2103			1571		

CATEGORY A -JOBS WITH INFO ON MATERIAL REMOVED WALLE JOB #		Barrel Identity	Width ft	Height ft	Barrel Length ft	Length Cleaned ft.	Debris Depth ft	Clock Start Time	Clock End Time	Engine Runtime hr:min	Clock Time + 1/2 hr X.XX hr	ENGINE RUNTIME X.XX hr	MATERIAL REMOVED cu yd	REMOVAL RATE CLOCK TIME cu yd/hr	REMOVAL RATE ENGINE TIME cu yd/hr	RATE PER DAY cu yd/day
#01-20080805-05-SCR-129_007.53	8/5/2008	1 arch	7	7	35	35	3.5	8:42	15:09	6:06	6.95	6.10	31.8	4.6	5.2	31.8
	1	**days**									**6.95**	**6.10**	**31.8**	**4.6**	**5.2**	**31.8**
#02-20080806-05-MON-068_013.42	8/6/2008	1 box	5	5	65	65	1	9:24	11:34	1:42	2.67	1.70	12.0	4.5	7.1	12.0
	1	**days**									**2.67**	**1.70**	**12.0**	**4.5**	**7.1**	**12.0**
#03-20080903-03-SIE-089_022.70	9/3/2008	3 box	8	5	45	45	2	7:47	15:04	4:39	7.78	4.65	80.0			
	9/4/2008							7:37	11:13	3:26	4.10	3.43				
	2	**days**									**11.88**	**8.08**	**80.0**	**6.7**	**9.9**	**40.0**
#05-20080918-03-YOL-005_R007.00	9/18/2008	2 box	6	4	204	204	0.5	10:55	12:12	1:04	1.78	1.07	45.3			
16:02-Add 1 hr for 9/22	9/19/2008							10:29	16:02	4:33	6.05	4.55				
Depth from pic 0.5 ft	**2**	**days**									**7.83**	**5.62**	**45.3**	**5.8**	**8.1**	**22.7**
69 cuyd per notes. IMMS?																
#06-20080922-03-YOL-113R010.55	9/22/2008	1 box	10	4	230	230	0.75	10:27	14:42	3:00	4.75	3.00	63.9			
Depth from pic. .75 ft	9/23/2008							9:16	14:11	3:41	5.42	3.68				
78 cuyd per notes. IMMS?	9/24/2008							8:19	14:38	4:02	6.82	4.03				
	9/25/2008							10:58	14:02	2:02	3.57	2.03				
	4	**days**									**20.55**	**12.75**	**63.9**	**3.1**	**5.0**	**16.0**
#07-20080929-03-YOL-113R002.33	9/29/2008	3 box	10	5	283	283	0.25	12:34	14:17	1:17	2.22	1.28	52.4			
Depth from pic .25 for 2 barrels	9/30/2008							8:36	13:51	2:40	5.75	2.67				
94 cuyd per notes. IMMS?	10/1/2008							9:03	12:26	1:58	3.88	1.97				
1 barrel nearly clean. 2 of 3 worked.	**3**	**days**									**11.85**	**5.92**	**52.4**	**4.4**	**8.9**	**17.5**
#09-20081020-04-NAP-029R002.37	10/20/2008	3 box	6	4	52	52	2.5	8:40	13:39	4:18	5.48	4.30	86.7			
Average depth 3,2.5,2 =2.3	10/21/2008							8:37	12:33	3:56	4.43	3.93				
From pics	**2**	**days**									**9.92**	**8.23**	**86.7**	**8.7**	**10.5**	**43.3**
#10-20081022-04-NAP	10/22/2008	2 box	10	6	47	47	3.5	8:16	12:37	3:53	4.85	3.88	121.9			
	10/23/2008							8:12	13:36	5:06	5.90	5.10				
	10/20/2008							7:47	13:08	5:21	5.85	5.35				
	10/21/2008							7:42	13:10	5:28	5.97	5.47				
	4	**days**									**22.57**	**19.80**	**121.9**	**5.4**	**6.2**	**30.5**
WALLE#11-20081124-07-LA-014R049.00	11/24/2008	3 box	8	8	372	372	1.5	11:10	14:26	2:50	3.77	2.83	330.7			
	12/1/2008							10:07	14:55	2:50	5.30	2.83				
From pics.	12/2/2008							9:23	14:04	3:29	5.18	3.48				
2 out of 3 barrels cleaned.	12/3/2008							9:57	14:50	3:53	5.38	3.88				
Assume 3 ft at entrance 0 at far end	12/4/2008							8:32	14:36	5:10	6.57	5.17				
	12/5/2008							8:52	14:35	5:39	6.22	5.65				
	12/9/2008							10:26	14:07	3:40	4.18	3.67				
	12/10/2008							10:14	14:07	3:54	4.38	3.90				
	12/11/2008							10:16	13:57	2:46	4.18	2.77				
	9	**days**									**45.17**	**34.18**	**330.7**	**7.3**	**9.7**	**36.7**
#13-20090116-	1/16/2009	Rt box	8	4	286	286	2	9:35	13:24	3:13	4.32	3.22	169.5			
Banning A	1/17/2009	Lt box	8	4	286	286	0.5	7:41	12:32	4:36	5.35	4.60	42.4			
	1/18/2009							7:01	12:28	5:22	5.95	5.37				
Wil - measured **6.7 cu yd / hour**	1/20/2009							8:52	11:05	2:13	2.72	2.22				
at beginning of culvert clearing.	1/21/2009							7:28	12:19	4:51	5.35	4.85				
	1/22/2009							9:00	10:35	0:34	2.08	0.57				
	2/13/2009							10:36	13:03	2:14	2.95	2.23				
	2/18/2009							9:52	13:53	3:07	4.52	3.12				
	2/19/2009							9:00	13:50	3:50	5.33	3.83				
	2/20/2009							7:26	10:29	2:37	3.55	2.62				
	10	**days**									**42.12**	**32.62**	**211.9**	**5.0**	**6.5**	**21.2**
#14-20090124-	1/24/2009	1 box	10	5	114	114	3.75	7:01	12:27	4:16	5.93	4.27	158.3			
Lambs canyon	1/25/2009							7:05	14:04	6:00	7.48	6.00				
Depth - 3.25 from photo	1/26/2009							8:36	14:57	5:37	6.85	5.62				
Assume average of 5 and 2.5 ft.	2/3/2009							9:39	14:25	4:10	5.27	4.17				
	2/4/2009							9:34	13:17	4:33	4.22	4.55				
	2/4/2009							8:44	12:28	3:49	4.23	3.82				
	6	**days**									**33.98**	**28.42**	**158.3**	**4.7**	**5.6**	**26.4**
#16-20090302-	3/2/2009	1 box	10	4	143	143	1.75	14:04	14:43	0:39	1.15	0.65	92.7			
Rockhouse	3/3/2009							7:18	15:15	5:10	8.45	5.17				
Depth - 3.5 ft / 2 from photo	3/4/2009							8:56	15:01	5:07	6.58	5.12				
Assume average of 3.5 and 0 ft.	3/5/2009							7:30	10:36	2:54	3.60	2.90				
	3/10/2009							8:55	11:19	2:10	2.90	2.17				
	4.6	**days**									**22.68**	**16.00**	**92.7**	**4.1**	**5.8**	**20.1**
#17-20090310-	3/10/2009	1 box	10	4	130	130	1.5	11:38	13:20	0:28	2.20	0.47	72.2			
Next site West	3/11/2009							7:53	15:29	6:01	8.10	6.02				
Depth est. 1.5 ft	3/12/2009							7:20	9:41	2:12	2.85	2.20				
	3/24/2009							7:06	7:32	0:26	0.93	0.43				
	3.2	**days**									**14.08**	**9.12**	**72.2**	**5.1**	**7.9**	**22.6**

#18-20090310-	3/10/2009	1 box	10	4	244	244	1.65	13:40	14:09	0:14	0.98	0.23	149.1			
Depth-3.3 ft to 0 from marks on wall	3/17/2009							10:16	14:36	4:14	4.83	4.23				
Depth is 1.65. Avg of 3.3 and 0	3/18/2009							7:31	14:29	5:50	7.47	5.83				
38.7 cuyd Dirt pile collected on 3/24.	3/24/2009							7:19	13:29	5:46	6.67	5.77				
6.7 cuyd/hr (38.7 in 5.77hr)	3/25/2009							10:37	15:07	3:39	5.00	3.65				
Walle had trouble shifting to HIspeed.	**4.2**	**days**									**24.95**	**19.72**	**149.1**	**6.0**	**7.6**	**35.5**
WALLE#19-20090407-06-KER-014_032.81	4/7/2009	2 box	8	6	168	168	3.5	8:17	14:16	2:34	6.48	2.57	0.0			
WALLE#34-20091228-06-KER-014_032.81	4/8/2009							7:33	15:01	4:34	7.97	4.57				
2 sections accessible from median	**2**	**days**									**14.45**	**7.13**				
12/29 Breakdown of motherboard																
Assumed density 2.7 tons per cu yd	12/28/2009							13:28	15:34	2:06	2.60	2.10	*12.0*	**4.6**	**5.7**	**12.0**
From IMMS notes 12/28 - 2/24 *261cuyd*	12/29/2009							7:41	15:02	5:15	7.85	5.25	*90.0*	**11.5**	**17.1**	**90.0**
	2/16/2010							12:36	15:02	2:35	2.93	2.58				
	2/17/2010							7:49	14:40	3:01	7.35	3.02	*74.0*	**10.1**	**24.5**	**37.0**
	2/23/2010							7:58	16:15	7:41	8.78	7.68	*55.6*	**6.3**	**7.2**	**55.6**
	2/24/2010							7:27	10:02	2:13	3.08	2.22	*29.6*	**9.6**	**13.4**	**29.6**
	6	**days**									**32.60**	**22.85**	**261.2**	**8.0**	**11.4**	**43.5**
CHECK FOR REASONABLENESS																
ALTERNATE CALC #19 & #34 Combined	**8**	**days**	8	6	168	168	3.5				**47.05**	**29.98**	**348.4**	**7.4**	**11.6**	**43.6**
From Pics - 1 pair at 3 ft, 1 pair at 4 ft																
Average 3.5 depth																
#21-20090424-	4/24/2009	2 box	6	4	195	195	1.5	12:28	14:07	1:38	2.15	1.63	130.0			
1.5 ft depth from pics	4/27/2009							8:52	14:21	5:20	5.98	5.33				
	4/28/2009							7:48	13:42	5:54	6.40	5.90				
	4/29/2009							13:24	14:29	0:56	1.58	0.93				
	4/30/2009							8:05	14:57	5:26	7.37	5.43				
	5/1/2009							9:24	12:47	3:14	3.88	3.23				
	6	**days**									**27.37**	**22.47**	**130.0**	**4.8**	**5.8**	**21.7**
#25-20090609-08-RIV-010R019.75	6/9/2009	2 box	8	4	265	265	0.75	10:00	13:23	3:22	3.88	3.37	117.8			
50% full, 20 cy yd /day per Darryl	6/10/2009							8:45	13:36	4:08	5.35	4.13				
Used the lower figure, 20 cu yd	6/15/2009							9:31	13:45	3:05	4.73	3.08				
Equivalent to .75 ft deep	6/16/2009							8:37	13:21	2:56	5.23	2.93				
Both barrels cleaned.	6/17/2009							13:15	13:15	3:30	0.50	3.50				
	6/19/2009							8:48	12:47	3:06	4.48	3.10				
	6	**days**									**24.18**	**20.12**	**117.8**	**4.9**	**5.9**	**19.6**
#27-20090909-04-SCL-152_024.05	9/9/2009	1 box	8	4	65	75	2	13:27	14:56	1:23	1.98	1.38	44.4			
From pics 2 ft	9/10/2009							9:18	14:23	3:47	5.58	3.78				
Additional work at entrance	9/11/2009							9:45	11:36	1:41	2.35	1.68				
Added 10 ft to nominal 65 ft culvert	**3**	**days**									**9.92**	**6.85**	**44.4**	**4.5**	**6.5**	**14.8**
WALLE#32-20091118-06-FRE-005_036.00	11/18/2009	1round	4.7		160	160	95%	9:26	13:58	4:16	5.03	4.27	*96.2*			
56 in dia single barrel.	11/19/2009							9:21	13:14	3:32	4.38	3.53				
N bound-80 ft S bound 80ft	11/20/2009							9:23	13:37	3:38	4.73	3.63				
Filled 95%	11/23/2009							9:29	13:36	3:45	4.62	3.75				
	11/24/2009							9:31	11:41	1:10	2.67	1.17				
	4.5	**days**									**21.43**	**16.35**	**96.2**	**4.5**	**5.9**	**21.4**
WALLE#33-20091124-06-FRE-005_042.00	11/24/2009	1box	8	6	257	120	5.7	12:41	13:44	1:03	1.55	1.05	202.7			
95% blockage	11/25/2009							9:26	12:32	2:50	3.60	2.83				
	11/30/2009							8:48	13:36	4:48	5.30	4.80				
	12/1/2009							9:35	13:42	3:16	4.62	3.27				
	12/2/2009							10:07	13:38	2:49	4.02	2.82				
	12/3/2009							9:18	13:14	3:56	4.43	3.93				
	5.5	**days**									**23.52**	**18.70**	**202.7**	**8.6**	**10.8**	**36.8**
WALLE#34 located at WALLE#19																
WALLE#35-20100111-08-SBD-127_31.90	1/11/2009	9	8	4	70	5	2	14:14	15:22	1:07	1.63	1.12	3.0			
1/11 Crew stopped at site after											**1.63**	**1.12**	**3.0**	**1.8**	**2.7**	**3.0**
driving from Bishop. Site prep.																
Witnessed by Wil 1/12	1/12/2009	9	8	4	70	65	3						57.8			
		8	8	4	70	5	2	7:24	15:17	6:27	8.38	6.45	3.0			
											8.38	**6.45**	**60.7**	**7.2**	**9.4**	**60.7**
Reported that on these 3 days	1/13/2009	5	8	4	70	35	3	07:13	10:50	2:45	4.12	2.75	31.1			
half of 4 barrels were cleaned.	1/14/2009	6	8	4	70	35	2	07:46	15:28	6:40	8.20	6.67	20.7			
Assume this was done	1/15/2009	7	8	4	70	35	2	07:29	09:33	2:03	2.57	2.05	20.7			
on barrels #5,6,7,8		8	8	4	70	35	2						20.7			
Valve orings blew on 1/13											**14.88**	**11.47**	**93.3**	**6.3**	**8.1**	**31.1**
	5	**days**							**JOBSITE TOTALS**		**24.90**	**19.03**	**157.0**	**6.3**	**8.3**	**31.4**
WALLE#36-20100304-06-KER-058_069.50	3/4/2010	1 Box	6	6	135	135	2.2	8:30	13:55	4:37	5.92	4.62	*70.0*			
70 cu yd per IMMS	3/8/2010							8:19	13:49	4:55	6.00	4.92				
	2	**days**									**11.92**	**9.53**	**70.0**	**5.9**	**7.3**	**35.0**
WALLE#38-20100309-06-KER-166_003.86	3/9/2010	1 squash	9.5	6.5	35	35	2.5	9:14	14:13	2:47	5.48	2.78	30.8			
	1	**days**									**5.48**	**2.78**	**30.8**	**5.6**	**11.1**	**30.8**
WALLE#39-20100310-06-KER-166_006.20	3/10/2010	1 squash	9.5	6.5	35	35	2	8:37	14:32	3:09	6.42	3.15	24.6			
	1	**days**									**6.42**	**3.15**	**24.6**	**3.8**	**7.8**	**24.6**
WALLE#40-20100315-06-KER-223_026.40	3/15/2010	1round	6		68	68	3	9:27	13:33	3:19	4.60	3.32	*36.0*			
IMMS Notes WO#2153989 36cuyd	3/16/2010							9:23	13:48	4:12	4.92	4.20				
6ft dia, 68 ft, half full.	**2**	**days**									**9.52**	**7.52**	**36.0**	**3.8**	**4.8**	**18.0**

CATEGORY B																
NO INFO ON MATERIAL REMOVED																
WALLE#04-20080910-03-GLE-45_019.81	9/10/2008				36			14:19	16:07	1:48	2.30	1.80	0.0			
	1	**days**									**2.30**	**1.80**	**0.0**	**0.0**	**0.0**	**0.0**
#08-20081010-04-SOL-680R010.20	10/10/2008				249			10:27	13:14	0:55	3.28	0.92	0.0			
	10/17/2008							9:08	11:59	1:39	3.35	1.65				
	2	**days**									**6.63**	**2.57**	**0.0**	**0.0**	**0.0**	**0.0**
#12-20090107-08-RIV-010R017.27	1/7/2009				204			8:45	10:20	1:35	2.08	1.58	0.0			
	1	**days**									**2.08**	**1.58**	**0.0**	**0.0**	**0.0**	**0.0**
#15-20090127-08-RIV-060_020.98	1/27/2009				149			8:23	14:19	5:37	6.43	5.62	0.0			
	1/28/2009							8:30	13:56	4:37	5.93	4.62				
	1/29/2009							8:34	13:45	5:01	5.68	5.02				
	1/30/2009							6:14	11:01	4:16	5.28	4.27				
	1/31/2009							6:17	10:38	3:26	4.85	3.43				
	2/1/2009							6:32	10:16	2:46	4.23	2.77				
	2/2/2009							8:29	11:57	1:26	3.97	1.43				
	7	**days**									**36.38**	**27.15**	**0.0**	**0.0**	**0.0**	**0.0**
#20-20090423-11-SD-067R001.12	4/23/2009				89			12:45	14:58	2:08	2.72	2.13	0.0			
	4/24/2009							8:11	11:21	2:37	3.67	2.62				
	2	**days**									**6.38**	**4.75**	**0.0**	**0.0**	**0.0**	**0.0**
#22-20090505-11-SD-067R003.29	5/5/2009				237			8:04	14:15	6:10	6.68	6.17	0.0			
	5/11/2009							8:16	14:30	5:55	6.73	5.92				
	5/12/2009							8:15	14:19	5:49	6.57	5.82				
	5/13/2009							8:42	13:58	5:16	5.77	5.27				
	4	**days**									**25.75**	**23.17**	**0.0**	**0.0**	**0.0**	**0.0**
#23-200905-11-SD-067R001.10	5/18/2009				na			8:41	10:01	1:19	1.83	1.32	0.0			
	1	**days**									**1.83**	**1.32**	**0.0**	**0.0**	**0.0**	**0.0**
#24-20090519-11-SD-094_064.82	5/19/2009				na			10:08	14:25	2:24	4.78	2.40	0.0			
	1	**days**									**4.78**	**2.40**	**0.0**	**0.0**	**0.0**	**0.0**
#26-20090622-08-RIV-010R019.94	6/22/2009				270			9:12	14:05	2:43	5.38	2.72	0.0			
	1	**days**									**5.38**	**2.72**	**0.0**	**0.0**	**0.0**	**0.0**
#28-20090921-04-SCL-152R017.91	9/21/2009				60			10:58	11:19	0:21	0.85	0.35	0.0			
	9/24/2009							10:48	11:17	0:29	0.98	0.48				
	1	**days**									**1.83**	**0.83**	**0.0**	**0.0**	**0.0**	**0.0**
#29-20090921-04-SCL-152R014.81	9/21/2009				75			8:41	10:27	1:46	2.27	1.77	0.0			
	0.5	**days**									**2.27**	**1.77**	**0.0**	**0.0**	**0.0**	**0.0**
#30-20090924-04-SCL-152R012.71	9/24/2009				na			13:13	14:29	1:16	1.77	1.27	0.0			
	0.5	**days**									**1.77**	**1.27**	**0.0**	**0.0**	**0.0**	**0.0**
#31-20091104-03-YOL-005R019.22	11/4/2009				181			9:27	10:30	1:02	1.55	1.03	0.0			
	1	**days**									**1.55**	**1.03**	**0.0**	**0.0**	**0.0**	**0.0**
WALLE#37-20100305-06-KER-178R013.74	3/5/2010				77			7:48	13:23	4:08	6.08	4.13	0.0			
	3/12/2010							8:49	12:58	3:11	4.65	3.18				
	2	**days**									**10.73**	**7.32**	**0.0**	**0.0**	**0.0**	**0.0**
WALLE#41-20100317-06-KER-005_016.57	3/17/2010				300			10:14	13:53	3:24	4.15	3.40	0.0			
IMMS WO#2155646	3/18/2010							12:35	13:56	1:22	1.85	1.37				
	3/23/2010							9:38	13:58	3:26	4.83	3.43				
	3	**days**									**10.83**	**8.20**	**0.0**	**0.0**	**0.0**	**0.0**
WALLE#42-20100326-06KER-204_005.61	3/26/2010				na			7:53	13:10	4:42	5.78	4.70	0.0			
	1	**days**									**5.78**	**4.70**	**0.0**	**0.0**	**0.0**	**0.0**

APPENDIX C – EXAMPLE OF SAFE PRACTICE RULES

Microtraxx SL 436
(Tunnel Mucker)

1. Pre-op equipment. Read and be familiar with Operating Instructions as supplied by the manufacturer.

2. Do not make any changes to the system that have not been approved by the manufacturer.

3. Do not power the system other than with the specified power supply.

4. Strictly follow the manufacturer's Operating Instructions for the Microtraxx machine and the User's Manual for the Cervis Control System.

5. Keep the transmitter out of reach of unauthorized personnel.

6. Remove the transmitter key when the system is not in use.

7. Before starting work each day, make certain the STOP button and all other safety measures are working

8. Do not use the system if failure is detected

9. Always attach transmitter to belt and secure around operator's waist before attempting to start the machine.

10. Follow System Start Procedure as outlined in the Operating Instructions to be sure transmitter is functioning correctly before attempting to start machine engine.

11. Do not use the system if any failure is detected.

12. When the transmitter is powered up, be sure that all persons are clear of the machine before starting engine.

13. Remember that this machine is a remotely controlled piece of machinery and will move as the switches are activated on the transmitter.

14. Do not use the machine when visibility is limited.

15. If the machine is being used in a confined space, be sure to follow the C.O.S.P. for Confined Spaces when entering the area to retrieve or work on the machine.

16. After use, never leave the system ON. Always use the STOP button or turn off the transmitter key.

17. When in doubt, press the STOP button.