Development of a Decision Support Tool for Identifying Appropriate Means and Methods for Locating Underground Utility Assets

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Abstract

The location of utilities buried beneath the built environment has always been a concern for those conducting work that involves excavation or the placement of items into the ground. Whether physically removing material or driving piles, posts, and more, the potential for accidental utility strikes is increasing with the movement of more traditional utilities from above ground to below. Also, the addition of utilities and new technology in underground spaces that hasn't existed in the past, such as fiber optics and more high-speed telecommunication lines, is occupying more space. Traditional methods of surveying, in combination with surface geophysics and the development and improvement of processes and technologies to track the location of buried assets led to the engineering services category termed Subsurface Utility Engineering (SUE). In order to aid utility engineers and consultants who are responsible for the collection of utility data this research aimed to help identify a way to compare the various technologies and incorporate information about the individual project in order to choose the most appropriate locating method for a project with a defined set of parameters. The result was the development of standard evaluation forms that can be sent to technology vendors and consultants to evaluate the performance and limitations of a technology. This data can then be compiled into a database located within an Excel-based program created to compare the technologies. The program, VT PALMS (Virginia Tech Program for Asset Locating Method Selection), consists of the performance and economic databases, a project information

sheet, and the results of the comparison of each technology in the database to the information on the project information sheet. The results are presented in three ways; 1) a speedometer chart with a needle that indicates the percentage of the parameters used in the database that are compatible – also referred to as the Reliability Factor, 2) a matrix view that indicates the parameters where a potential conflict may exist, and 3) an economic indicator that shows the comparable cost of using each technology listed in the database.

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Chapter 1 – INTRODUCTION

1.1 History of Subsurface Utility Engineering

Subsurface Utility Engineering, often shortened to SUE, is the combination of civil engineering, surveying and mapping, and geophysics when working with utility infrastructure to reduce costs, increase safety, and prevent unplanned disruptions of service and costly redesigns once the project is underway. SUE was brought about by the recognition of the amount of money being spent on projects as a result of accidental utility hits, unnecessary relocations, unexpected conditions and the inherent danger with performing utility work in the early 1980s by a utility engineer for an engineering services company in the Washington, DC metro area. This engineer realized that traditional methods of utility locating were insufficient and a new way of thinking was necessary to approach many of the problems being encountered, ironically many of the same problems utility engineers still face today (So Deep, Inc. 1997).

SUE is a service industry that involves a myriad of different professionals that come together as part of a process to identify, locate, map and analyze information to determine the existing conditions of utility infrastructure. Once the existing conditions are known the designer can incorporate this into new projects to avert conflict with utility crossings and determine if relocation is the most feasible alternative versus modification of a projects' scope. Many of the technologies used in subsurface utility engineering are currently in use in: the mining and minerals industry to locate ore bodies, caverns, etc.; environmental engineering to map contaminant plumes and karstic features; and structural engineering for mapping substructure sizes and depths. However, the ability to locate an ore body (very large in size) versus a water line (relatively smaller by comparison) has created some technological lag in the implementation of geophysical methods in the civil engineering community for utility locating (Sirles 2006). According to a report by the National Cooperative Highway Research Program in 2006, ground penetrating radar (GPR) and seismic methods were in use by a number of state transportation departments and federal agencies for things such as pavement condition measuring, bridge substructure evaluation, and construction QA/QC but not utility investigations. This is partially due to a lack of a formal process and guidelines for using geophysical methods to locate buried objects that are shallow in depth, generally less than 100 feet (Sirles 2006). The technologies can also differ significantly leading to difficulties in data reduction and interpretation methods.

In the last 20 years, subsurface utility engineering has been gaining momentum with all state departments of transportation completing at least one trial on a project. Studies have been completed to evaluate the cost benefits of performing SUE on a project and the American Society of Civil Engineers (ASCE), American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), among others, have developed programs, standards, guides, and more to address the growing field. Several of these studies and programs are discussed in Chapter 2.

1.2 Current State of Practice

Buried utilities lie beneath streets, sidewalks, open fields, and every point in between forming a framework that sustains life in the United States. This intricate network includes pipes, cables, telecommunication lines, electrical conduits, and duct banks, and forms a complex infrastructure system. These systems carry potable water, stormwater, wastewater, gas, power, cable, data, and more to millions of people who rely on the uninterrupted supply to accomplish various tasks in every region of the country. The disruption of these utilities during construction activities creates a strain on the local residents by cutting off these services and potentially creating dangerous conditions at the jobsite for contractors and their personnel. In addition to discomforting residents, the re-engineering of new utilities and roadways to accommodate undiscovered utilities is costly and can delay a project substantially (Zembillas 2008). To prevent the accidental disruption of utilities an increasing number of owners, specifically state transportation agencies, are requiring subsurface utility engineering as part of the planning phase for transportation projects. Previous work has defined the quality levels (A, B, C, and D) and their impacts on cost but has not distinctly defined the applicable methods for each level (Jung 2007). In order to implement methods to obtain the required amount and detail of data for a project, a contractor or designer needs to have the appropriate tools necessary to determine which method is suitable and the most cost effective.

Many utilities are located adjacent to or within a public right-of-way typically owned by state transportation departments. This co-location creates of utilities can create challenges when designing relocates and new installs or when completing transportation and infrastructure projects. (Note: This paper focuses on utilities in the public right of way but much of the concepts and the end results can be applied to private utility networks and utilities not located within public right of ways.) According to a survey conducted by Thomas and Ellis in 2002, both contractors and state highway agencies (SHA) ranked utility problems as the main cause of delays on projects (Thomas and Ellis 2002). The top ten reasons determined by the survey are listed below in Table 1.1.

Table 1.1 – Reported Reasons for Delay

Rank	SHA Ranking of Delay Causes	Rank	Contractor Ranking of Delay Causes
1	Utility Relocations Delayed	1	Utility Relocations Delayed
2	Differing Site Conditions (Utility Conflicts)	2	Errors in the Plans or Specifications
3	Errors in the Plans or Specifications	3	Differing Site Conditions (Utility Conflicts)
4	Weather	4	Weather
5	Permitting Issues	5	Owner Requested Changes
6	Delays in Right of Way Acquisition	6	Differing Site Conditions (Other Causes)
7	Delays in Environmental Planning	7	Permitting Issues
8	Insufficient Work Effort by Contractor	8	Delays in Environmental Planning
9	Differing Site Conditions (Other Causes)	9	Delays in Design
10	Poor Coordination of Work by Contractor	10	Pay Items Do Not Match Scope of Work

1.3 Research Purpose and Objectives

Subsurface utility engineering was chosen as the area of focus for this research project due to the ability to combine several disciplines of civil engineering – geotechnical, transportation, and construction engineering, into a single topic area that was at the forefront of an emerging market. The opportunity to conduct research in the SUE field would allow exploration of new areas where the potential exists to positively impact the profession. The overall purpose of the research was to identify an area in civil engineering where a problem existed relating to transportation projects and come up with a solution that was economical to implement, easy to use, and readily available. After looking at the amount of money spent on utility relocations, the amount of accidental utility strikes, and incorrect as-built documents that lead to not knowing where utilities are located, the idea of creating a tool to help state utility engineers, consultants, and utility providers to be able to apply a correct locating technology was chosen. The objectives of the research project specifically were:

- Help reduce the cost of utility incidents on highway projects regardless of project size.
- Develop a simple way to compare technologies from multiple vendors.
- Centralize the data for each technology so it could be readily available to anyone.
- Compare costs of using each technology in conjunction with their limitations to determine a "best fit."
- Ensure the tool could be used by anyone, anywhere, without the expense of completing costly and time-consuming training.
- Ensure the tool could be adapted as more technologies are developed or used as part of the SUE process.

The decision support tool would need to be based on facts while also being able to take into account proven results from the various technologies. In order to accomplish this, a questionnaire was developed in order to evaluate the technologies before incorporating the data into the decision support tool. Such factors that were considered and included are

- The surrounding environment.
- The type of utility being located.
- The location and access to the location of the utility.
- The type of soils and groundcover present.
- The presence of depth of groundwater, and

- The proximity to other structures or objects that may cause interference with the testing equipment.

This project assumed that the end user had already performed an analysis to determine if subsurface utility engineering was required for the project and builds upon research conducted by Yeun Jae Jung and Dr. Sunil Sinha at the Pennsylvania State University. The purpose of their research was to develop a utility impact score based on the answers to a standardized set of questions. This utility impact score (UIS) was then correlated to the ASCE quality levels. Because of this, only SUE methods that produced data related to ASCE Quality Levels A and B were examined. The ASCE quality levels are outlined in Chapter 2. Technologies included were

- Ground penetrating radar
- Electrical resistivity
- Seismicity
- Terrain conductivity and
- Excavation (such as vacuum methods)

Further explanation of each technology can be found in Chapter 3.

1.4 Terms & Vocabulary

Throughout this paper there are several terms that can be used interchangeably and common names or phrases referred to that may be have multiple meanings or are general in nature. For this reason, several of those terms are clarified in this section below.

- *Designating* – a term generally used to describe ASCE Quality Level B activities that are used to determine the position of buried objects. In this paper, it is referred to as any activity that produces the location of a buried asset using ASCE Quality Level A or B Methods.

- *Evaluation(s)* – either one of the two 'questionnaires' developed to collect data on technologies for use in the database within VT PALMS.
- *Locating* – a term generally used to describe ASCE Quality Level A activities that are used to determine the position of buried objects. In this paper, it is referred to as any activity that produces the location of a buried asset using ASCE Quality Level A or B Methods.
- T*echnology/Technologies* – any device or method used as part of an activity that produces the location, either vertical or horizontal, of a buried object.
- *Testing* – in the area of SUE, the act of performing an activity that produces the location of a buried asset; used interchangeably with *Locating*.
- *Tool* – in the context of this paper, the word tool refers to the final result of the research project, VT PALMS.
- *User* – anyone who chooses to enter data into the project databases, project information sheet, or view and use the results of the VT PALMS program.
- W*orkbook* – a term used to describe a set of worksheets in Microsoft Excel. In this instance, workbook will refer to the worksheets that comprise VT PALMS.

Chapter 2 – Literature Review

Subsurface utility engineering is not a new concept and has been gaining momentum recently with the amount of infrastructure projects taking place and available funds decreasing. The need for upfront engineering in regards to utilities has been proven to save substantial amounts of money while reducing project delays and costs as shown in studies conducted by Purdue University and by several State DOTs (Purdue 1999, Sinha, et al. 2008).

2.1 The Need for Accurate Utility Data

As with any engineering discipline, a good analysis can only begin once sufficient and quality data is obtained in order to progress into the design stage of a project. This is no different in civil engineering when it comes to utilities on transportation projects. In years past the data has not always been so accurate, yet has been accepted as a common practice. Currently, the state one call systems such as Miss Utility in Virginia are the only required means of locating utilities according to the Virginia Damage and Prevention Act. State one-call systems have been the status quo for many years and may be appropriate for projects that have low risk, low complexity, and minimal utilities. For these projects the one call operator generally notifies all suspected utility providers that a project is to take place in a certain area and it is the responsibility of the utility owner to mark the location themselves or contract it out. For clarity and continuity between projects, the APWA developed a standard color guide for utility markings. The ASCE also devised a standard for the collection and depiction of utility data and defined the generally accepted quality levels for subsurface utility engineering. In 2002 the *Standard Guideline for the Collection* *and Depiction of Existing Subsurface Utility Data*, also known as ASCE/CI 38-02, was published describing the different levels. Quality level "D" involves asking individuals their thoughts and memories of projects that they were associated with to determine the likely size, type, and location of utilities. The most common quality level, "C," is the cheapest and easiest to implement. This typically utilizes the state One-Call system to notify utility owners who have systems in the area to be affected. In turn, utility owners usually have someone contracted out to perform such tasks and when they are done, the paint or flags marking the approximate location of the utilities are often very visible. The color codes are based on the APWA Uniform Color Code so that a standard exists to alert workers of what is potentially below. The complete description of each quality level is listed below. (Ellis and Lee 2005, FHWA 2009, ASCE 2002)

<u>Quality Level D</u>: Information comes solely from existing utility records. It may provide an overall "feel" for the congestion of utilities, but it is often highly limited in terms of comprehensiveness and accuracy. Its usefulness should be confined to project planning and route selection activities.

<u>Quality Level C</u>: Involves surveying visible above-ground utility facilities, such as manholes, valve boxes, posts, etc., and correlating this information with existing utility records. When using this information, it is not unusual to find that many underground utilities have been either omitted or erroneously plotted. Its usefulness, therefore, should be confined to rural projects where utilities are not prevalent, or are not too expensive to repair or relocate.

Quality Level B: Involves the use of surface geophysical techniques to determine the existence and horizontal position of underground utilities. This activity is called "designating." Two-dimensional mapping information is obtained. This information is usually sufficient to accomplish preliminary engineering goals. Decisions can be made on where to place storm drainage systems, foundations, and other design features in order to avoid conflicts with existing utilities. Slight adjustments in the design can produce substantial cost savings by eliminating utility relocations.

Quality Level A: Involves the use of nondestructive digging equipment at critical points to determine the precise horizontal and vertical position of underground utilities, as well as the type, size, condition, material, and other characteristics. This activity is called "locating." It is the highest level presently available. When surveyed and mapped, precise plan and profile information are available for use in making final design decisions. By knowing exactly where a utility is positioned in three dimensions, the designer can often make small adjustments in elevations or horizontal locations and avoid the need to relocate utilities. Additional information such as utility material, condition, size, soil contamination, and paving thickness also assists the designer and utility owner in their decisions.

2.4 Benefits of Utilizing A Formal SUE Process

A study conducted by Purdue University's Department of Building Construction Management analyzed 71 projects with an aggregate value of over $1 billion. Four state transportation departments were used in the study – Virginia, Texas, North Carolina, and Ohio, and the project sites varied from urban to suburban to rural encompassing arterial roads, interstates, and smaller roads. The study only examined these projects due to their involvement of a formal SUE process. The results showed that an average savings of $4.62 for every $1.00 spent on subsurface utility engineering during the up-front stages of a project. The actual savings varied from greater than $200 per $1.00 spent to a negative return on two projects. These projects were deemed to have other contributing factors that caused the figure to be negative however, they were included in the study in the beginning and therefore must be included in the average (Purdue 1999). A separate review of projects with an SUE program, also using the Virginia DOT, by Brown and Mckim found a substantially higher number. They quantified the savings to the Virginia DOT, who has been refining their SUE processes since the 1980s and held the first SUE contract in the United States, at $7.00 for every $1.00 spent (Brown and Mckim 2002).

Since the years 1997 – 1998, when nearly half of all highway and bridge projects involved utility relocations, the number of utility lines being placed underground is increasing due to aesthetics, ease of maintenance, and so forth. This naturally increases the risk of utility strikes, relocations, and conflicts unless accurate data on their position is obtained. (Goodrum, et al. 2008, Jeong, Abraham and Lew 2004). This fact, along with the increased dependence on information and services (such as telecom) has created an atmosphere where prevention and problem solving in the beginning stages of a project can create a substantial savings and lead to a more successful project.

Chapter 3 – Current Locating Methods

Several common methods associated with shallow or environmental geophysics used to detect buried utilities are described in this section. The descriptions below are not a critical review of the technology's capabilities but merely a summary of the how the devices operate and a brief explanation of the science behind them. A majority of technologies operate by introducing energy into the ground and measuring the amount of return energy generated by a buried object. Several technologies being researched for utility locating, such as RFID (radio frequency identification) tags, marker balls, and other embedded sensors are not included in this section. They are often placed during new construction and while their use is growing, they have not been in service long enough to be placed on a substantial amount of utilities so their use in finding existing utilities is minimal at this point.

3.1 Ground Penetrating Radar

Ground Penetrating Radar, typically referred to as GPR, is a method that introduces pulses of radar waves into soil and rock. Once the waves are in the ground the device on the surface is used to detect a returned wave. Return waves are generated when the introduced wave comes in contact with an object and reflects back to the surface. The measurement of the return wave is based on soil conductivity and the dielectric constants of the materials. Differing materials have various electric constants and the return wave may be generated at slightly different times and speeds. This difference produces an 'echo' and is measured to create an image of the utility asset.

Ground penetrating radar typically operates in the VHF (very high frequency) and UHF (ultra high frequency) ranges. The lower the frequency the further into the ground the wave will travel and allow for deeper imaging. However, the lower the frequency means that less scans are conducted over a given time and the size of the detectable object diminishes. GPR that uses the higher frequencies is more often used in shallow or environmental geophysics (Doolittle and Collins 1995, Daniels 2004). A sample image based on the results of GPR is shown in Figures 3.1 to 3.3.

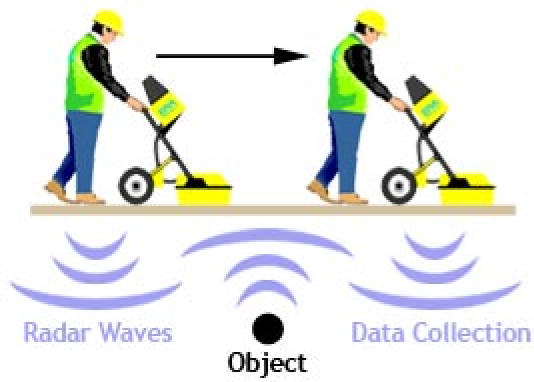


Figure 3-1 – Depiction of GPR Use
Source: Worksmart, Inc.

Figure 3-2 – GPR in Use at the USGS
Source: US Geological Survey

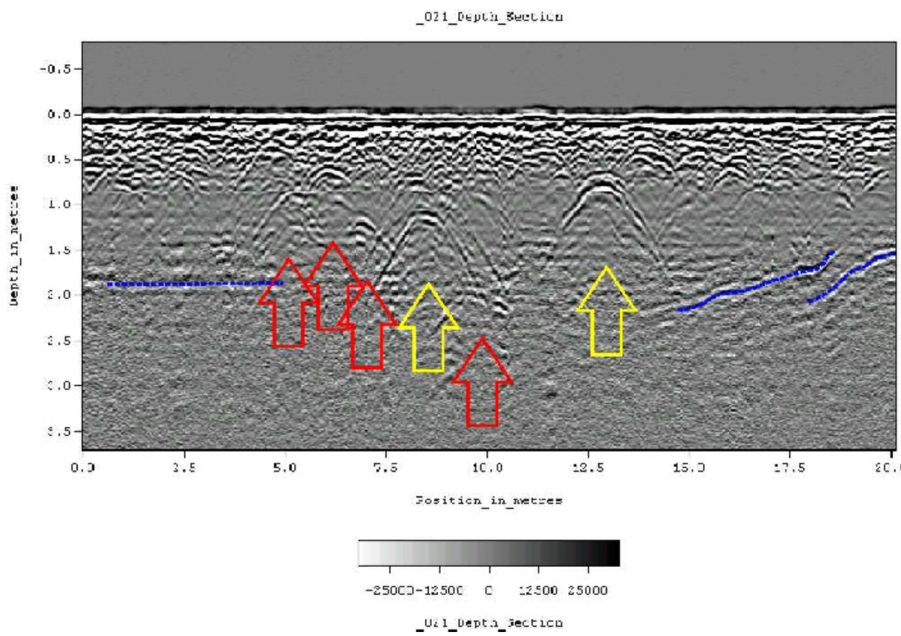


Figure 3-3 – Image Results of GPR

Source: Wikipedia (yellow arrows indicate objects as shown by the parabolic shapes)

3.2 Electrical Resistivity

Electrical resistivity is performed by measuring the electrical properties of the soils and surrounding objects. The setup for such tests includes a series of metal rods driven into the ground a specified distance apart and typically arranged in a straight line. Current is introduced at the two rods located on the ends of the array and the resulting voltage can be measured at the two inside rods. The voltage drop across the outside rods to the inside rods is used to calculate the resistivity of the underlying materials. Once the measurements are taken, the two inside rods can be moved and the process repeated at a different area. The data from each section is mapped and combined to produce an image showing the resistivity of materials. Materials that are not the same as the surrounding materials will produce an isolated area in a given plane and is analyzed to determine if it is a tank, pipe, trench, etc. (generally know what object is being located so the relative size can be an indicator when compared to the size of varying resistivity) (Yang, Wang and Liu 2008). Figure 3.4 shows the typical results from a resistivity survey, however, this is not for a utility project. The actual objects are a mapping of a coal seam and mine shafts.

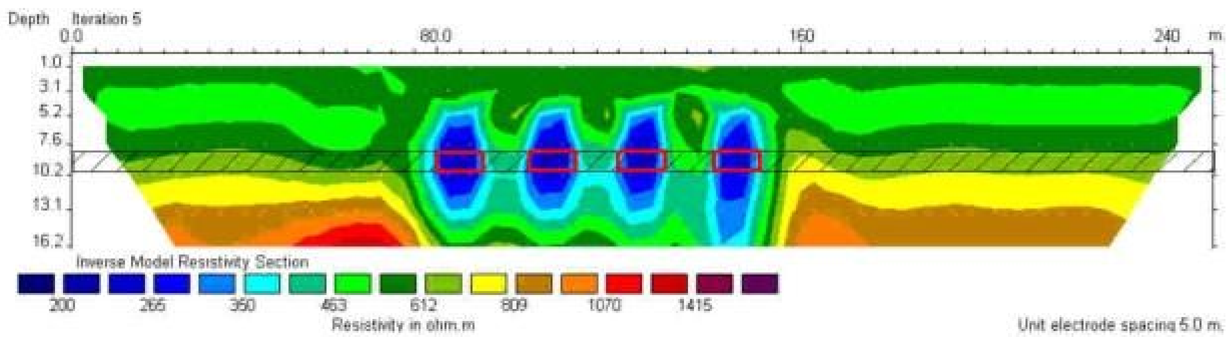


Figure 3-4 – Example Results of a Resistivity Survey
Source: William Johnson, Federal Highway Administration

3.3 Seismicity

Seismicity, or seismic surveys, rely on the propagation of seismic waves through the earth. The waves are generated through a variety of means including falling weights, the impact of sledge hammers on objects, vibrating plates, and explosives. The waves generated travel through each material at different speeds until an impenetrable material is encountered. The reflection of the wave off this material back to the surface is then measured. Geophones driven shallow depths into the surface, as shown in Figure 3.5, record the time the waves take to reach them and the corresponding seismic velocity is calculated and used to produce the depths and location of materials (Federal Lands Highway Program: Surface Geophysical Methods n.d.).

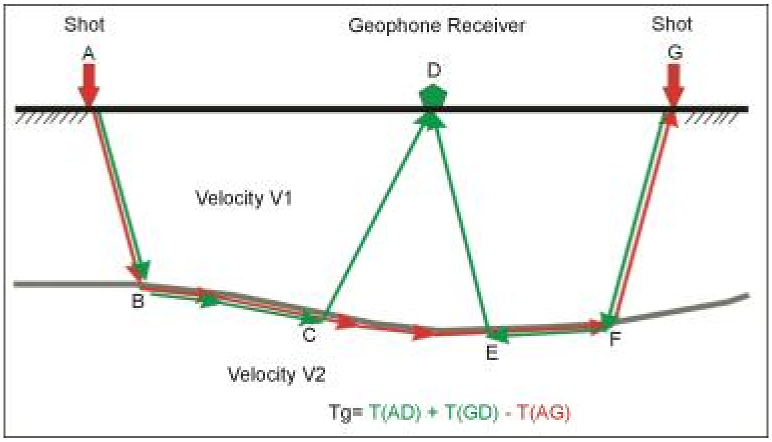


Figure 3-5 – Illustration of Seismic Survey

Source: Federal Lands Administration, FHWA

Chapter 4 – Evaluation Development & Data Collection

4.1 Background

In order to compile data on technologies used to locate buried utilities, data on the technologies was needed. Specifically, the operational characteristics, the affects of the surrounding environment, the physical limitations of the devices used, and the training required to setup and operate them in order to efficiently perform testing was needed. While textbooks and literature can give the theoretical applications, it was decided that consultants who routinely use the technologies would be a better source of data since they could correlate it to their actual experiences. The plan was to develop a questionnaire to distribute to the companies and have someone on the project engineering team complete the form. To do this, a set of standard questions would need to be developed. As a result the Performance Evaluation was devised to obtain data on the technical aspects of the technologies and the Economic Evaluation was developed to gather cost data and contributing factors. The evaluations were created in Microsoft Excel because of its' relative familiarity to a large number of people. This also allows the data to be input into a database within the final result of the research as explained in Chapter 5.

The evaluations contain a standardized set of questions consisting of multiple choice, choose one (such as yes or no, or the best fit), and short answer (such as enter a numeric value) type responses or a combination of one or more of each type. Several questions have an "Other" choice in which a response can be written or typed in. Such cases are reserved for select questions where the amount of responses could vary significantly and the answer is seen to be important. For example, Question 11 in Section C – Limitations of the Performance Evaluation reads:

> *11. Do the following structures interfere with testing (other than as a physical obstruction)? If Yes, please indicate the minimum distance these objects must be from the testing location to avoid interfering.*

Thirteen items commonly located near or in a right-of-way are listed and the evaluator must choose either 'Yes' if they cause interference or 'No' if they do not. The last response is the 'Other' in the event an object not listed can cause interference. At the end of each section is a place for comments related to that section. The location of the answer choices on the performance evaluation is also of some significance. There are in general, three distinct vertical alignments of the answer choices throughout the entire evaluation. The first column (the left most, closest to the question) is the best case response or responses for that question. The middle column contains responses that can be classified as marginal, but do not necessarily hinder or negatively impact the locating technology. They are the 'middle ground.' The third and final column of answer choices, that which is to the far right, is the worst response for that particular question. While the response may not be bad per se, it is the least ideal compared to the others. This format does not apply to short answer questions where due to space limitations the answer blank tended to have to be left justified to allow for appropriate space to enter a value or text. For Yes or No questions, the responses are either in the first or third column and vary between which response is located where depending on the question. The evaluation was set up using this format for several reasons. The first reason was to provide continuity and ensure clarity for the person completing the evaluations. The second reason was so that when the responses were converted to a numeric value during the calculation and comparison in the VT PALMS program the assigned values could correlate to the responses – a better response would therefore have a higher value assigned up to a max of three and a minimum of 0. Questions where a numeric value is asked for have that exact value copied into the cells, such as the case for minimum horizontal and vertical clearances needed to operate the locating devices. The reason for this is explained further in Section 5.5. The following sections explain each evaluation in more detail.

4.2 Performance Evaluation

This evaluation was the most significant in that it contained a set of questions to collect data regarding how the technology operates and the effects, if any, of the surrounding environment. This evaluation is broken down into four sections with varying numbers of questions as outlined below in Table 4.1. The full performance evaluation can be found in Appendix A.

Table 4.1 – Performance Evaluation Sections

Section	Description	No. of Questions
A	Setup	8
B	Operation	12
C	Limitations	12
D	Results/Data Processing	9
E	Comments, Other Information, Special Instructions or Remarks	1 (Remarks Only)
	Total:	42

4.2.1 Section A – Setup

This section encompasses the elements of a testing operation required by users before locating activities can begin in the field or in the office. Some of the items in this section include the amount of training required to set up the equipment, amount of people required, time and ease of setting up the equipment, and impact on traffic during the process. Table 4.2 below summarizes the information the questions aim to gather (Information) and the style of the response allowed on the evaluation (Response Type). Figure 4.1 illustrates a portion of this section of the performance evaluation.

Table 4.2 – Section A Questions and Response Type

Question	Information	Response Type			
		Multiple choice	Choose One	Short Answer	Comments
1	Time to Setup		X		
2	Site Preparation Required		X		
3	Ease of Setup		X		
4	Traffic Impacted		X		
5	Amount of Training		X		
6	Number of People to Setup		X		
7	Number of Setups per Test		X		
8	Permits Required		X		

A. Setup				
1	How long does equipment with this method take to setup?	☐ < 1 hour	☐ 1 - 2 hours	☐ > 2 hours
2	Are any site preparations required before setup/use?	☐ No	☐ Yes, ________	
3	Ease of setup	☐ Easy	☐ Moderate	☐ Difficult

Figure 4-1 – Portion of Section A of the Performance Evaluation

4.2.2 Section B – Operation

The second section in the performance evaluation is geared towards the operation of the equipment during locating activities. Data relating to operator notification of buried objects, number of units required to perform testing, mobility of testing operations, and clearances to operate the equipment is collection in this section of 12 questions. The section's questions are summarized in Table 4.3 and sample questions are shown in Figure 4.2 below.

Table 4.3 – Section B Questions and Response Type

Question	Information	Response Type			
		Multiple choice	Choose One	Short Answer	Comments
1	Safety Gear		X		
2	No. of People to Perform Testing		X		
3	Traffic Impacted During Testing		X		
4	Number of Units for Testing		X	X	
5	Operator Notification		X		
6	Training to Perform Testing		X		
7	Min. Horizontal Clearance			X	
8	Min. Vertical Clearance			X	
9	GPS Capabilities		X		
10	Equipment Mobility During Testing	X			
11	Terrain Influence During Testing		X		
12	Weather that Stops Testing	X		X	

B. Operation				
1	Additional safety gear (other than eye, ear, hardhat, boots, gloves) required during operation?	☐ No	☐ Yes	
2	Minimum number of people required to operate and perform testing	☐ 1 - 2	☐ 3 - 5	☐ > 5
3	Are lane closures necessary during operation?	☐ No	☐ Yes	
4	Are multiple units required for use during testing?	☐ No	☐ Yes, # ________	

Figure 4-2 – Portion of Section B of the Performance Evaluation

4.2.3 Section C – Limitations

The Limitations portion of the performance evaluation contains the most questions – 12 with 65 subparts. While it may seem like a lot at first, many of the subparts are multiple choice that are either a Yes or No response. For example, question 1 is composed of one general question that has nine different materials to evaluate, or nine subparts, each being a type of material that could reasonably be expected to be found on the surface of a testing location. The subparts for this question, which except for the last are Yes/No responses (the last having only a Yes indicator and a space to list the material) include:

- Concrete with remesh
- Concrete with rebar
- Concrete with steel fibers
- Unreinforced concrete
- Asphalt
- Wood
- Steel
- Brick/Clay tile and the
- Other category

These 12 questions and subparts collect information about the man-made and environmental surroundings and conditions that limit the performance of a locating technology during testing. The information gathered relates to types of detectable objects, incompatible soils, groundwater interference, minimum detectable sizes of objects, and ground cover and structures that cause interferences and safe working distances from these objects and more. The questions and the information is summarized in Table 4.4 below. Figures 4.3 and 4.4 illustrate two questions in this section that consist of a question that has multiple subparts and a question that involves short answer.

Table 4.4 – Section C Questions and Response Type

Question	Information	Response Type			
		Multiple choice	Choose One	Short Answer	Comments
1	Materials Technology Can Detect Objects Beneath	X		X	
2	Max. Depth An Object Can Be Located			X	
3	Detectable Metallic Objects	X		X	
4	Min. Size of Detectable Metallic Objects			X	
5	Detectable Nonmetallic Objects	X		X	
6	Min. Size of Detectable Nonmetallic Objects			X	
7	Soils Technology Can Detect Objects In	X			
8	Technology Can Work in Culverts		X		
9	Water Sources That Cause Interference	X			
10	Natural Ground Covers That Cause Interference	X		X	
11	Structures That Interfere With Testing	X		X	
12	Groundwater Interference	X		X	

C. Limitations					
1	Can this technology detect buried assets beneath:	☐ Yes	Concrete w/remesh	☐ No
		☐ Yes	Concrete w/rebar	☐ No
		☐ Yes	Concrete w/steel fibers	☐ No
		☐ Yes	Unreinforced concrete	☐ No
		☐ Yes	Asphalt	☐ No
		☐ Yes	Wood	☐ No
		☐ Yes	Steel	☐ No
		☐ Yes	Brick/Clay tile	☐ No
		☐ Yes	Other: ____________	☐ No

Figure 4-3 – Example Multiple Choice Question from Section C

4	Minimum diameter or width detectable, *metallic* objects	____________	☐ feet ☐ inches (choose one)
5		Yes	Pipes No

Figure 4-4 – Example Short Answer Question from Section C

4.2.4 Section D – Results/Data Processing

In the Performance Evaluation, this is the last section to contain standardized questions to evaluate a technology. Section D covers the portion of the locating operations that occur after the field activities have taken place. More specifically, it relates to how that data is turned into usable information that identifies the location of the buried objects, utilities in the context of this research. Topics covered in this section include the accuracy of the technology, what format the data is presented in, and the type of software and training required to view the results. These nine questions are written to determine if, once the testing has occurred, the location of the buried object is available immediately or not. In certain situations the location would need to be available immediately or in a short amount of time to allow work on a project to continue whereas during the planning stages of a project there might be some leeway in the amount of time it takes for a locating contractor to provide the locations. The questions are summarized below in Table 4.5.

Table 4.5 – Section D Questions and Response Type

Question	Information	Response Type			
		Multiple choice	Choose One	Short Answer	Comments
1	Produces Location Without Analysis		X		
2	Produces Horizontal & Vertical Position	X			
3	Horizontal & Vertical Accuracy			X	
4	Types of Information Output	X		X	
5	Further Analysis After Field Work to Find Locations		X		
6	Training Required to Interpret		X		
7	Amount of Training		X		
8	Professional Licensure Required		X		
9	Software Required to View Results	X		X	

A sample of the questions discussed in section D is shown below in Figure 4.5.

D. Results/Data Processing					
1	Is the equipment used for collecting data able to produce the location of the utility without further analysis?	☐ Yes		☐ No	
2	What information does this technology produce either during testing or after analysis/processing?	☐ Yes	Horizontal position	☐ No	
		☐ Yes	Vertical position	☐ No	
3	What is the accuracy of the position obtained from testing?	Horizontal: ______	*(please specifcy units)*	Vertical: ______	

Figure 4-5 – Portion of Section D of the Performance Evaluation

4.2.5 Section E – Comments, Other Information, Special Instructions or Remarks

This section was included as part of the evaluation in the event that the evaluator wants to include information that may not have fit into any of the previous questions or categories. Information entered here may also be available in the form of foot notes at the bottom of the database in the final product of the research. Examples of information that could have been included would be the experiences of the evaluator with the given technology, unique settings for devices that may have been found to be advantageous in locating certain types of objects, or general remarks the evaluator wished the author to know.

4.3 Economic Evaluation

The second evaluation was developed to collected data to allow a comparison economic factors relating to the technologies being evaluated. This evaluation is needed in order to more clearly define a secondary parameter to rate locating technology options in the event two scored the same on the performance evaluation. The form consisted of nine standardized questions that utilized the same formats as the performance evaluation. The data collected involves topics such as the effect of utility complexity and density on cost, types of contracts and payment forms typically used with the locating services, and a unit price for performing work using this technology. In order to compare unit prices for differing technologies, a fictional project consisting of the same utilities at the same depths, same ground coverings, surface materials, groundwater depths, clearances, and all other factors identified in the performance evaluation is used. It was found that the unit price is typically dependent on time and most companies have a minimum daily charge. It is assumed that each locating operation occurs on the same site and takes one full day to complete, regardless of the amount of hours. The number of hours depends greatly on the skill of the operator, the time of year and associated weather conditions, the number of years of experience the operator has with the make and model being used and even the health of the operator and support personnel on a particular day and time. It is very difficult to quantify an expected amount of linear feet, square feet, or otherwise dimension of length or area that testing would be able to cover in a given amount of time. Taking all this into consideration the unit prices that were found and included in the research are a unit cost to operate the technology and all associated appurtenances for one full day, regardless of location and the factors previously mentioned. If an economic evaluation were to come back with a unit cost of something other than days, such as hours, the cost would be calculated based on an 8 hour working day to get a unit cost per day. Any other answer that provides a cost per unit of length, area, and so forth would need to be clarified and converted to a unit cost per day with the person who evaluated the technology.

The questions are summarized below in Table 4.6 and examples of the evaluation's questions are shown in Figure 4.6. The full economic evaluation can be found in Appendix B.

Table 4.6 – Questions and Response Types for the Economic Evaluation

Question	Information	Response Type			
		Multiple choice	Choose One	Short Answer	Comments
1	Socioeconomic Impact		X		
2	Effect of Utility Density on Unit Cost		X		
3	Ancillary Costs Included in Unit Cost		X	X	
4	Types of Contract Payment Options Typically Used	X		X	
5	Fees for Data Analysis		X		
6	Rank of Cost of Technologies Used by Evaluator			X	
7	Effect of Utility Complexity on Unit Cost		X		
8	Additional Factors that Affect Cost			X	
9	Total Unit Cost to Use Technology			X	

9	What is the total unit cost of performing work using this technology, regardless of payment method or contract type, and including all fees? (per day, based on one full days worth of work.)	____ dollars per ____ unit (time)

Figure 4-6 – Final Question of the Economic Evaluation Asking for Unit Price

4.4 Compilation of Collected Data

The two evaluations are the primary means of evaluating technologies to include in the database located within the VT PALMS program. Once the surveys are complete the data is compared to other evaluations of the same technology before being entered into VT PALMS. This is to ensure the data entered is accurate and in-line with what is considered acceptable by the professional SUE industry. Data returned that do not closely fit similar technologies will require further evaluation. It is recommended that any technology undergo a minimum of three separate evaluations before being input into VT PALMS. Depending on the agency or firm using the program this could vary slightly. For example, an SUE provider that has x number of technologies located in house can conduct field trials and base their data on direct experiences since the program will be used in house. However, an agency such as a state department of transportation will want the same process to occur across all vendors who could potentially provide SUE services to the department. Once complete, all the evaluations can be compared to determine if discrepancies exist and steps can be taken to eliminate these discrepancies and provide high quality reliable data. As new technologies are invented or existing ones are refined, the data can easily be updated to reflect the changes. The process for each is depicted below in Figures 4.7 and 4.8. It is important to note that the VT PALMS program is intended to be an integral part of a formal SUE process and is not a stand-alone solution for utility locating.

For this research project, the above mentioned performance and economic evaluations were assembled into a packet along with instructions and a list of suggested places to find the information requested. This packet was sent to consultants and technology vendors to compile sample data on technologies for use in the model VT PALMS program. The packet is attached in Appendix C and sample results of the completed evaluations are located in Appendix D and E.

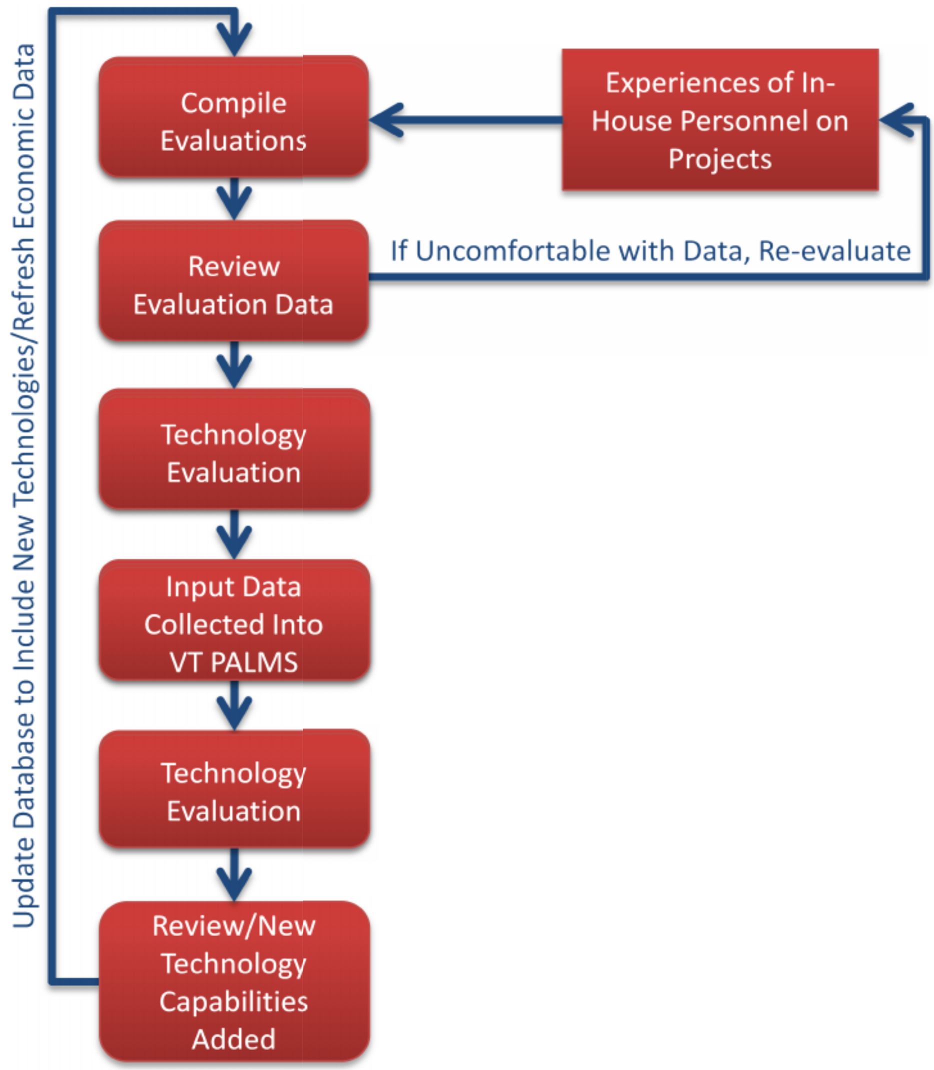


Figure 4-7 – Process to Validate Data to Use in VT PALMS for Firms with In-House Capabilities

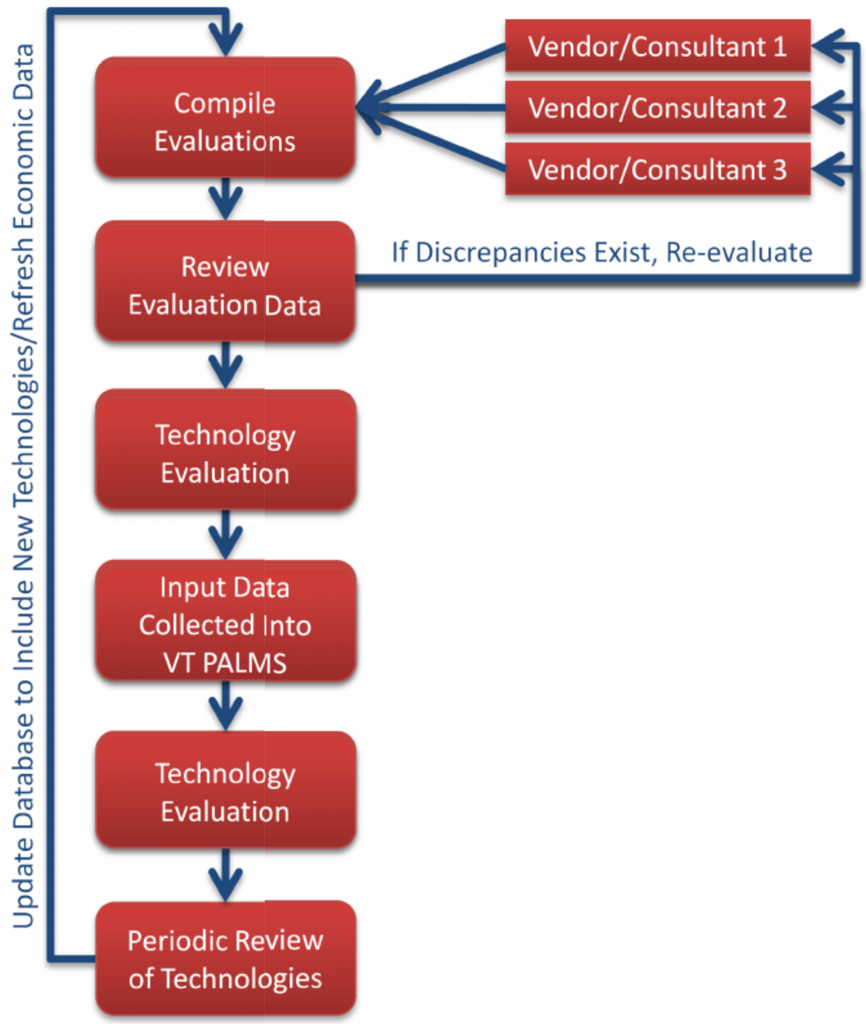


Figure 4-8 – Process for Public Agencies to Validate Data for Use in VT PALMS

Chapter 5 – Development of a Decision Support Tool – VT PALMS

5.1 Introduction

The conclusion of the research was the development of VT PALMS (Virginia Tech Program for Asset Locating Method Selection). Once the data was collected on utility locating technologies a means of comparing them was needed. Several different formats and programs were considered including a Microsoft Access-based method, a Microsoft Excel-based method, an online method, and a Microsoft Visio-based method. After review of each option the Microsoft Excel based method (from hereafter referred to simply as excel) was selected because it most closely aligned with a majority of the objectives of the research, restated here:

- Develop a simple way to compare technologies from multiple vendors.
- Centralize the data for each technology so it could be readily available to anyone.
- Ensure the tool could be used by anyone, anywhere, without the expense of completing costly and time-consuming training.
- Ensure the tool could be adapted as more technologies are developed or used as part of the SUE process.

These objectives are considered to be the most important when determining the amount of use the VT PALMS tool will receive once released to the public and therefore were given higher priority. All of the options considered met the remaining objectives of being able to compare technologies and store data within themselves, with the exception of Microsoft Visio. This option was ruled out because of a less than ideal ability to store large amounts of data for referencing throughout the program without the reliance on another Microsoft Office program, such as Access. Excel was chosen over Access because of its wider use and dissemination by the general population targeted for use of the tool. Excel was also chosen because of the ease at which new information can be input allowing for the databases to be expanded as new technologies are added. This, along with the ability to copy formulas used to compare the multiple technologies in the databases to produce the graphs as part of the results was deemed a perfect fit for developing the first model of VT PALMS. As noted earlier, VT PALMS was developed as a compliment to the SUE process and to aid those in the position to make decisions about which technology may be most appropriate for their project. In the overall life cycle of a project, as depicted in Figure 5.1, it is recommended that the tool be used in the planning stage. However, if the need were to arise and buried objects need to be located during the construction or maintenance stage of a project's life this tool is certainly applicable.

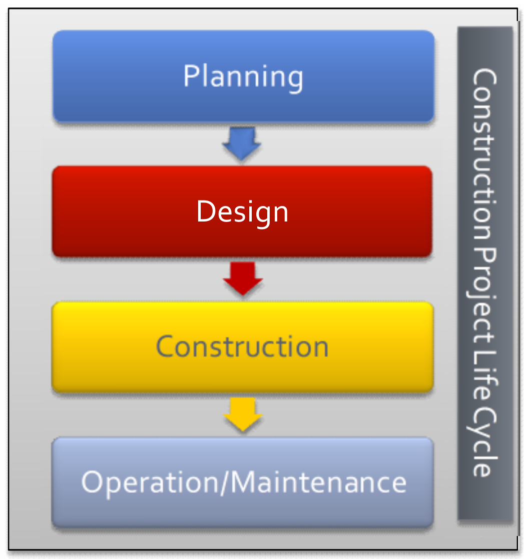


Figure 5-1 – Typical Life-Cycle of a Construction Project

5.2 Layout

The layout of the workbook consists of eight individual worksheets with the following titles and purposes:

1. **Instructions**: This worksheet provides a general overview of the entire VT PALMS program and resources for further information on the development of the workbook.

2. **Project Info Sheet**: This worksheet contains the specific project information entered by the User about the location, environment, and other parameters that can affect the overall functionality or dis-functionality of a locating technology.
3. **VT PALMS Results**: The results of the comparisons between technologies and project data are displayed on this worksheet in the forms of graphs and a matrix.
4. **Calcs & Comparison**: In order to create complete transparency for review purposes, the formulas used to determine if a given parameter satisfies the conditions necessary to operate at the project site are presented here. This worksheet is hidden and protected during normal use of VT PALMS to protect the integrity of the program.
5. **Performance Data**: The results of the Performance Evaluation are stored in this worksheet for every technology being evaluated. This worksheet is visible during normal use of VT PALMS but is restricted so that the data cannot be edited.
6. **Economic Data**: Like the Performance Data worksheet, this is the equivalent for the Economic Evaluations. It visible during normal use of VT PALMS but also cannot be edited.
7. **Chart Data**: In order to produce the speedometer charts that are part of the VT PALMS Results worksheet, several calculations are necessary as well as some static data. This worksheet serves as a place to store this information and is hidden and not editable during normal use of VT PALMS.
8. **About-Contact Info**: The final worksheet in the workbook is dedicated to providing information on the author and the reason behind the development of VT PALMS. This also serves as a place to give credit to all the individuals who helped during the

tool's development. Useful links to the Virginia Tech College of Engineering, Federal Highway SUE Programs Page, and the Virginia Tech Department of Civil Engineering websites among others.

The overall process for using VT PALMS as a part of a formal SUE program is depicted in Figure 5.2. The exact stage in which an individual agency, department, firm, etc. introduces the program is largely up to the needs of that particular entity. For example, if a program has a value engineering step then the User may wish to use VT PALMS as a means to justify an expenditure on locating utilities or use it as part of the value engineering analysis to help choose the most economical methods based on the type and quality level of data desired.

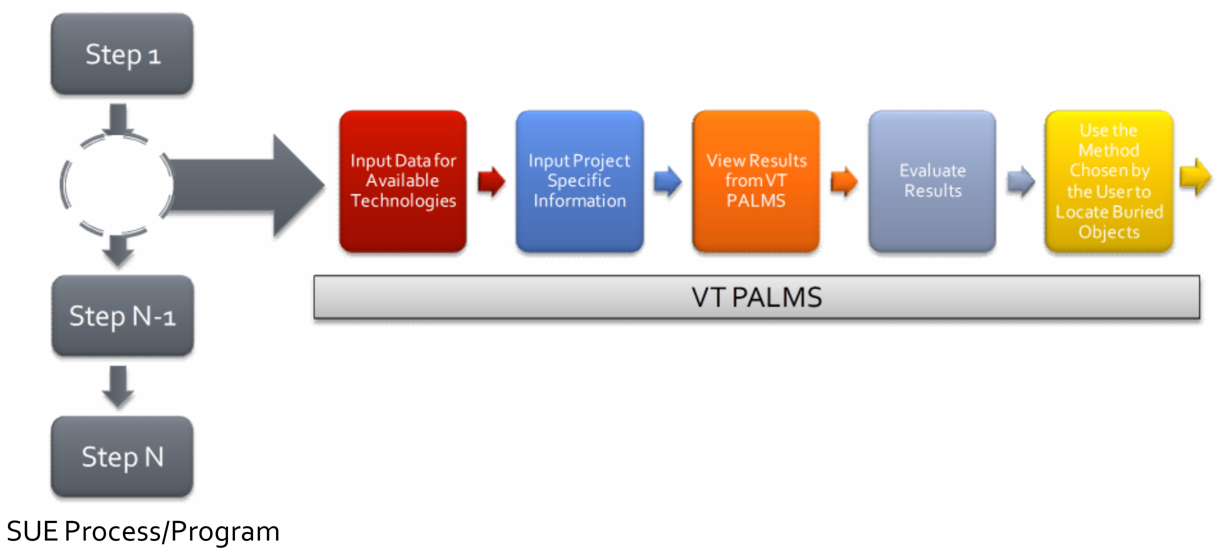


Figure 5-2 – Steps to Integrating VT PALMS Into an SUE Process

5.3 Project Information Sheet

The project information sheet is the portion of the program that the User will interface with the most. This worksheet consists of 16 questions that help to define the project area and the objects being located. The questions are similar to the type and style of those used on the evaluations. The input is once again limited and in this case to three options: an in-cell drop down list; a numerical value; or selecting a check box. The values that populate the in-cell dropdown lists are identical to the options available on some of the questions on the evaluations where a direct comparison is necessary. For example, the predominant soil type for the project is restricted to the following values in the drop down list which coincide with those in the Performance Database as shown in Table 5.1. These values are also in line with the generally accepted standard for soil classification, the Unified Soil Classification System, as described by ASTM D 2487.

Table 5.1 – Comparison of Project Information Sheet Options to Database Options

Project Info Sheet	Performance Database
Clay	Clay
Silt	Silt
Sand	Sand
Gravel	Gravel
Organics/Topsoil	Organics/Topsoil
Loam/Loess	Loam/Loess
Partially Weathered Rock	Partially Weathered Rock
Intact Rock	Intact Rock

In other instances a range for a given answer is set in the dropdown list. The reason for this is that multiple parameters in the databases may depend on the answer given and an exact value is not required. For example, question 4 deals with the size of the object to be located. Rather than indicate the exact or estimated size, several ranges are provided to choose from. The ranges available in the drop down list are: 1 inches or less; > 1 inch – 6 inches; > 6 inches – 12 inches; and > 12 inches. This question relates to minimum detectable size for metallic and nonmetallic objects (questions C.4 and C.6 in the database) and the accuracy of the technologies (questions D.4 and D.5 in the database). Because the size of the object to be located may not be known or the User may be relying on as-built documentation that is not guaranteed to be accurate, if a value is entered below the limits of the technology by accident this could produce a false negative and detract from a certain methods reliability during the VT PALMS evaluation. On the other hand, by providing a range the User has a general idea of the size of the object and the VT PALMS program can evaluate a technology's abilities with more reliability. A complete list of the questions and their allowed responses is listed below in Table 5.2.

Table 5.2 – Project Information Sheet Question Summary

Question Number	Data Question is Looking For	Allowed Responses
1	Minimum horizontal clearance of site	Any numeric value > 0
2	Minimum vertical clearance of site	Any numeric value > 0
3	Slope of the terrain at the site	< 1:1 Slope
		> 1:1 Slope
		Flat, No slope
4	Width/diameter of object being located	1 inches or less
		> 1 inch – 6 inches
		> 6 inches – 12 inches
		> 12 inches
5	Approximate depth of object being located	Any numeric value
6	Suspected objects in the locating area (checkboxes, select all that are applicable)	Pipes
		Conduits
		Cable/Wire
		Vaults/Boxes
		Valves/Components
7	Type of utilities suspected on site	Metallic
		Non-metallic
		Both
8	Metallic/Nonmetallic utilities collocated	Yes
		No

Table 5.2 continued		
Question Number	Data Question is Looking For	Allowed Responses
9	Type of equipment that can access site	ATV/Truck Mounted
		Remotely Operated Machine
		Operator & mobile equipment
		Operator & handheld/wearable equip
		Setup/Testing in a single location
10	Type of surface present	Concrete w/remesh
		Concrete w/rebar
		Concrete w/ steel fibers
		Unreinforced concrete
10		Asphalt
		Wood
		Steel
		Brick/clay tile
		Soil/natural materials
11	Location required in field, no analysis	Yes
		No
12	Distance to nearby structures	Any numeric value >= 0 for all
13	Groundwater near suspected within depth of utilities	Yes
		No
	If yes, enter value	Any numeric value >0
14	Nearby sources of water (checkboxes, select all that are applicable)	Lakes
		Ponds
		Marshlands/Swamps
		Surface water, ponding
		Surface water, flowing
		Streams, <= 10 gpm
		Streams, > 10 gpm
15	Primary soil type on site	Clay
		Silt
		Sand
		Gravel
		Organics/topsoil
		Loam/loess
		Partially weathered rock
		Intact rock
16	Natural materials present	Grasses, <= 6 inches high
		Grasses, > 6 inches high
		Shrubs/woody plants

Table 5.2 continued		
Question Number	Data Question is Looking For	Allowed Responses
16		Trees, <= 10 feet high
		Trees, > 10 feet high
		Flowers/soft stem plants
		Leaves
		Fallen sticks/branches
		Loose rock, size > gravel

Sample questions from the project information sheet are shown below in Figure 5.3 and the entire form is available in Appendix G. Once the answers are selected in the project information sheet they are transferred to the *Calculations & Comparison* worksheet automatically for comparison to the data in the databases within VT PALMS. No further work is required by the User at this point to view the results produced by the comparison and the results are available on the VT PALMS Results worksheet. A sample Project Information Sheet completed for a fictitious project is located in Appendix H.

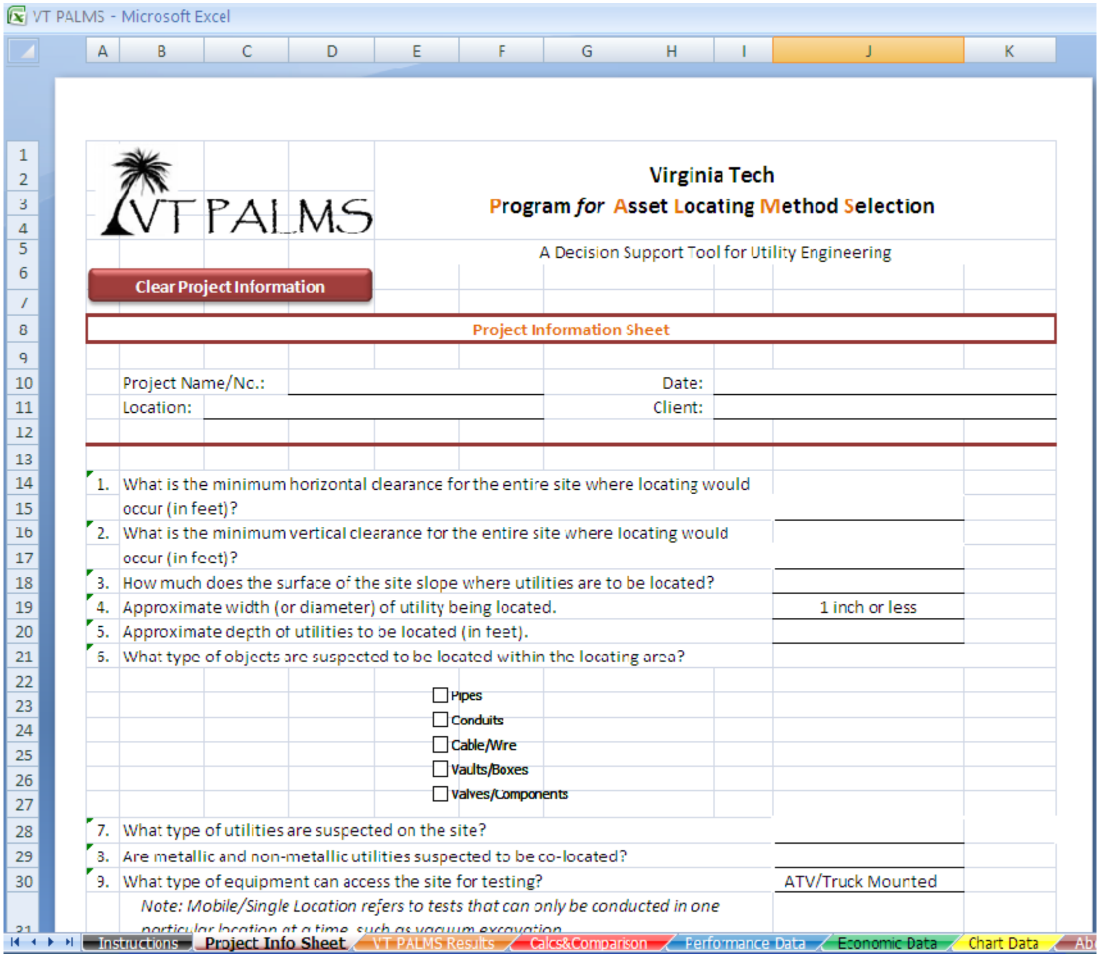


Figure 5-3 – View of the Project Information Sheet in VT PALMS

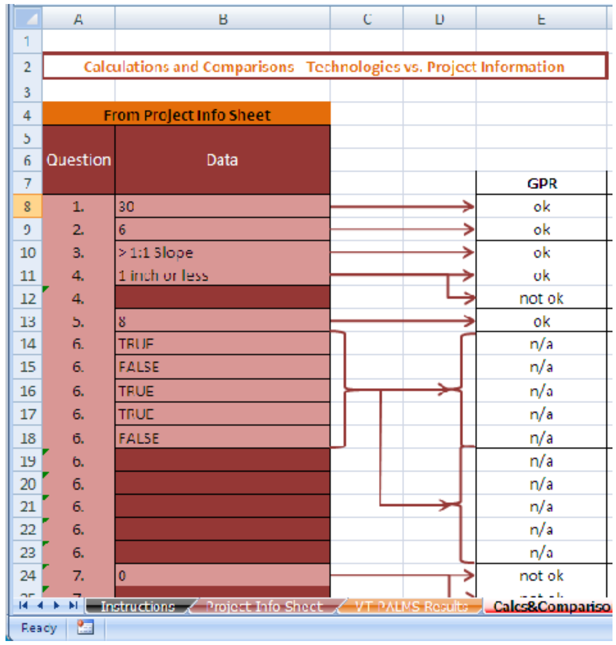
5.4 Databases Within VT PALMS

In order to compare the information obtained through the distribution of the Performance and Economic evaluations two database worksheets are included in the VT PALMS workbook. The performance evaluation data is in the Performance Data worksheet and the economic evaluation data is in the Economic Data worksheet. The two worksheets are locked for editing during the use of VT PALMS but are visible to the User in the event a question arises and they would like to view the data directly. This transparency also allows the persons who rely on a vendor or consultant to populate the information to view and check the data as well. The format for entering information into these worksheets is the same as the project information sheet using checkboxes, drop down lists, and numeric values. The appearance differs slightly from the evaluations even though the questions are identical to the evaluations. The reason is that the evaluations are designed so that they can be printed and filled in by hand, converted to a .pdf format, or emailed independently to sources for data collection. Drop down lists would not have allowed all three options to be available to collect data whereas in the VT PALMS program the data is manually entered once and remains there so these features could be utilized. The databases are formatted such that an indefinite number of technologies can be input by simply copying and pasting the existing columns into blank columns at the end of the database next to the existing technologies. Additionally, Excel has a worksheet size limit of 65, 536 rows by 256 columns per worksheet, ensuring there is ample room for a large number of technologies to be entered (Microsoft Office Online 2009). More information on copying the formulas to provide the comparison is available in Section 5.5.

5.5 Comparison of Technologies to Project Information

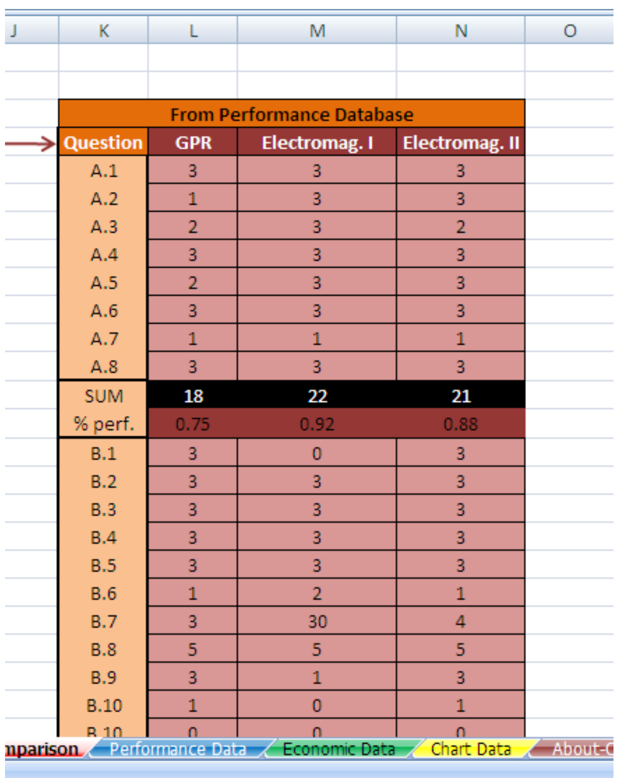
In order for the data to be useful in the database is must be converted to information. In this sense, the goal is to compare the information from the Project Information Sheet to the data in the Databases to answer the question that is driving this research: 'Will this technology work?' The *Calcs & Comparison* worksheet within VT PALMS is where the analysis of the data takes place. Once data is entered into the Project Information Sheet it is automatically copied in column B of the Calculations worksheet. The same thing is true for the data in the technology database however, this information is converted to a numeric value based on the response between 0 and 3. The numeric values for the data in the database are located in columns L though L + *n*, with *n* denoting the number of technologies being compared. Questions whose response is a numeric value, such as utility depth or minimum detectable size, are not converted and copied directly into the sheet. True and False answers use their absolute values, 0 for False and 1 for True, in the appropriate cells in the Calculations worksheet.

Having the information in one worksheet without the questions, answer choices, and other unnecessary items associated with user-friendly formatting greatly simplified the process of writing excel formulas to compare values which in turn reduced the likelihood of errors. This also allows for technology data to be entered into the database and then requires a second step consisting of copying existing cells that perform the comparison to a blank column to have the technology included in the results. This redundancy allows for data to be stored in the VT PALMS workbook while it is being evaluated and once the User is comfortable with the quality of data it can be easily integrated into the VT PALMS results. Figures 5.4 and 5.5 show the copied and converted data in the Calculations worksheet.



	A	B	C	D	E
1					
2	Calculations and Comparisons Technologies vs. Project Information				
3					
4	From Project Info Sheet				
5					
6	Question	Data			
7					GPR
8	1.	30			ok
9	2.	6			ok
10	3.	> 1:1 Slope			ok
11	4.	1 inch or less			ok
12	4.				not ok
13	5.	8			ok
14	6.	TRUE			n/a
15	6.	FALSE			n/a
16	6.	TRUE			n/a
17	6.	TRUE			n/a
18	6.	FALSE			n/a
19	6.				n/a
20	6.				n/a
21	6.				n/a
22	6.				n/a
23	6.				n/a
24	7.	0			not ok

Figure 5-4 – Column B in the Calculations & Comparison Worksheet Showing the Copied Values from the Project Information Sheet



From Performance Database			
Question	GPR	Electromag. I	Electromag. II
A.1	3	3	3
A.2	1	3	3
A.3	2	3	2
A.4	3	3	3
A.5	2	3	3
A.6	3	3	3
A.7	1	1	1
A.8	3	3	3
SUM	18	22	21
% perf.	0.75	0.92	0.88
B.1	3	0	3
B.2	3	3	3
B.3	3	3	3
B.4	3	3	3
B.5	3	3	3
B.6	1	2	1
B.7	3	30	4
B.8	5	5	5
B.9	3	1	3
B.10	1	0	1
B.10	0	0	0

Figure 5-5 – Data from the Performance Database Converted to Numeric Values in the Calculations & Comparison Worksheet

Between the cells that contain the copied values from the Project Information Sheet and the converted values from the database lie the cells that contain the formulas to evaluate and compare the technologies, as depicted in Figure 5.6. One column exists for each technology in the database being compared with the last column containing a brief description for reference, such as 'Concrete w/remesh' or 'Object Size.' Arrows were drawn in as a visual aid for when the program was being reviewed and left for continued clarity and shown below in Figure 5.7 and again in Figure 5.8.

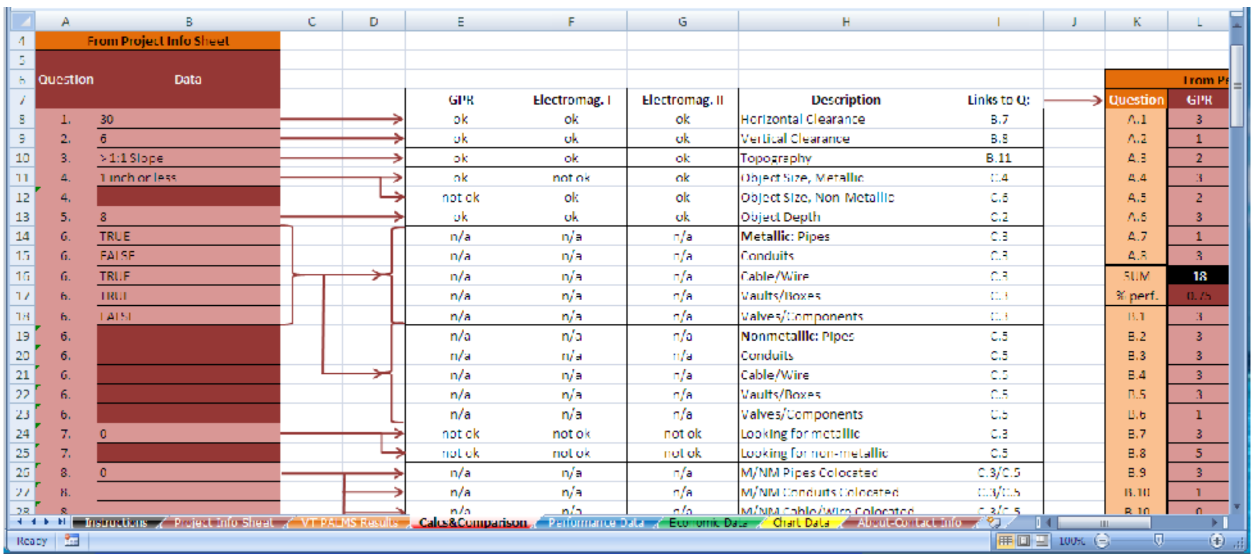


Figure 5-6 – Complete Layout of the Calculations & Comparison Worksheet

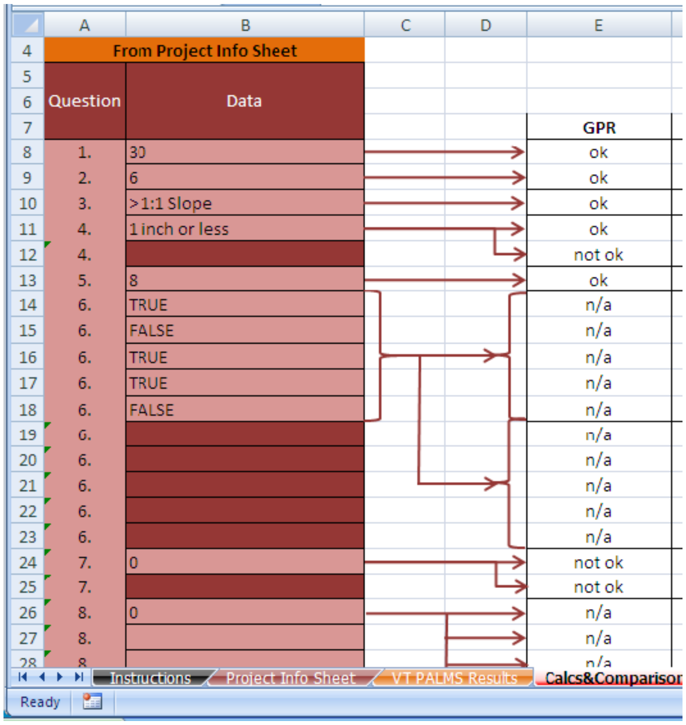


Figure 5-7 – Arrows Showing Correlation of Project Information to the Associated Calculated Result for a Technology

The formulas used to compare the data are built primarily using IF, AND, and OR excel functions. The IF statements can be nested multiple times in some instances if several variables are used to determine whether or not project conditions meet the minimum requirements for a given parameter. The same is true for AND and OR statements. A sample formula is given below in Equation 5.1 that illustrates the use of IF statements nested into one string with several AND statements embedded. The formula in Equation 5.1 is located in cell E11 in the *Calculations and Comparison* worksheet and used to determine if a metallic object is large enough to be detected by GPR. The values, their corresponding cells, and the results of the equation being evaluated are broken down in Table 5.3.

```
=IF(AND($D$11=1, L53<=1), "ok", IF(AND($D$11=2, L53>1, L53<=6), "ok", IF(AND($D$11=3, L53>6, L53<=12), "ok", IF(AND($D$11=4, L53<=12), "ok", "not ok"))))
```

Equation 5.1 – Formula Used to Evaluate the Size of Metallic Objects

A verbal translation of this formula would read as such:

> "If an object falls between the size range indicated on the project information sheet and the minimum size detectable entered in the database is less than this size, the technology cannot locate the object; but if the value is in the size range or larger than that indicated in the database the technology will be able to locate it."

Table 5.3 – Explanation of Values for Equation 5.1

A	B	C	D
Cell D11 Value	Corresponding Response	Cell L53 Value	Formula Result
1	1 inch or less	<=1	ok
2	> 1 – 6 inches	>1, <=6	ok
3	> 6 inches – 12 inches	>6, <=12	ok
4	> 12 inches	>12	ok
All other combinations			not ok

where: Column A is the converted value based on the range selected in Column B
Column B is the response from the project information sheet
Column C is the value from cell L53, equal to the minimum detectable size entered in the project database for metallic objects for GPR. In the table the upper and lower limits that correspond to the size ranges in the project information sheet are listed.
Column D is the result once the formula is evaluated

The results of the formulas have three possible outcomes: 'ok,' 'not ok,' or 'n/a.' A result of 'ok' indicates that the information entered into the project information sheet is within the limits of or equal to the minimum requirements for that technology to operate according to the data for that particular parameter in the database. A 'not ok' response indicates the opposite is true – the information entered into the project information sheet regarding a specific characteristic of the site does not meet the requirement for that technology to produce the location of a buried object with the given parameters. If the formula returns 'n/a' (not applicable) then several possibilities exist that could cause this. First, the parameter may have no affect on the performance of this particular technology and therefore there is no data to compare. Secondly, the parameter may affect the technology but the condition that would affect the technology is not located on the project within the area to be tested. This response is common for the questions that deal with water bodies and soil types.

Once the formulas have all returned a result (which is immediately after answers are selected or entered on the project information sheet) the reliability number, *R*, is calculated. This number, expressed as a percentage, is the number of parameters assessed for the project and the technology that is compatible, within the operational limits of the technology, and do not negatively affect the performance when locating buried objects on a project with the given conditions as specified on the project information sheet.

The reliability number is expressed as

$$R = \frac{\Sigma(a_{ok})}{\Sigma(a_{notok})} \times 100\%$$

where a_{ok} = number of 'ok' results in the calculations/comparison matrix
a_{notok} = number of 'not ok' results in the calculations/comparison matrix

Equation 5.2 – Determination of Reliability Number, *R*

The calculation is based on the number of 'ok' and 'not ok' responses in the calculations/comparison matrix and is simply the total number of 'ok' results divided by the total number of 'not ok' results, multiplied by 100%. The 'n/a' results are not factored into the reliability factor as they have no impact on the function of the technology for the given conditions. This R value is the number displayed beneath the chart on the results worksheet in VT PALMS.

5.6 Results of VT PALMS

The result of the comparison of project information and the information in the database is depicted in three separate ways on the VT PALMS Results worksheet. The reliability number is shown as a percentage beneath a speedometer-type chart, where the needle corresponds to the reliability number on a color-coded scale, also referred to as the Performance Indicator Chart. One chart is produced for each technology in the database and examples can be seen in Figure 5.8. On the same page and located to the right of the performance indicator charts is a vertical bar chart comparing the unit cost for locating objects using each technology. The unit cost for all the technologies are displayed on this single chart, referred to as the Economic Indicator Chart, as shown in Figure 5.9. Unit prices are taken directly from the economic database. These two indicators are the primary results display of the VT PALMS program.

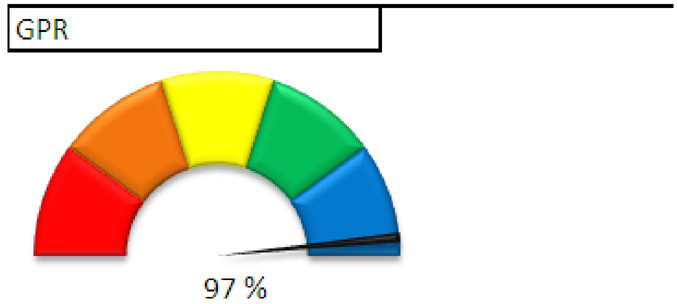


Figure 5-8 – Performance Indicator Chart

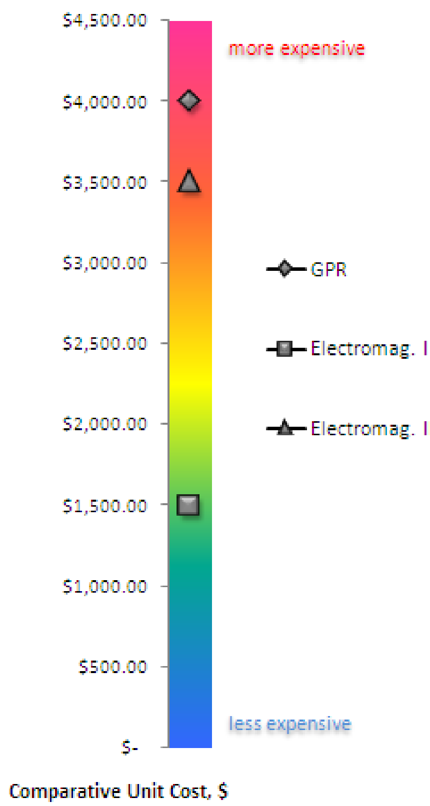


Figure 5-9 – Economic Indicator Chart

The performance and economic indicator charts are both color coded using a 5-color scale. For the performance indicator each color represents 20% and has a corresponding category rating from Not Applicable to Excellent. For the economic indicator chart the same colors are used, however, there are no clear defined limits for each color. Rather, the colors are used for consistency in the results and are intended to be used in conjunction with the ratings. The colors, % limits, and ratings for each chart are provided in Table 5.4.

Table 5.4 – Indicator Color Scales, Categories, and Limits

Performance Indicator				Economic Indicator
Color	Rating	Limits, % Lower	Limits, % Upper	Relative Expense
(blue)	Excellent	0	20	$
(green)	Good	21	40	$$
(yellow)	Fair	41	60	$$$
(orange)	Poor	61	80	$$$$
(red)	Not Applicable	81	100	$$$$$

The results of the technology comparison are also presented in a third way using a Results Matrix. This matrix consists of the questions and an individual cell for each technology and parameter/possible answer. When the above indicators are generated the matrix is automatically populated as well. Cells that contain a red 'X' indicate that the particular parameter, condition, or object is not able to be located when the given conditions in the project information sheet exist. The results matrix is considered a secondary results display used to support the primary indicators and is shown below in Figure 5.10.

Project Summary Sheet - Results Matrix

	Question & Description / Technology	GPR	Electromag. I	Electromag. II
1.	Horizontal Clearance	X		X
2.	Vertical Clearance	X	X	X
3.	Topography	X		X
4.	Object Size, Metallic	X	X	
	Object Size, Non-Metallic		X	X
5.	Object Depth			
6.	Metallic: Pipes			
	Conduits			
	Cable/Wire			
	Vaults/Boxes			
	Valves/Components			
	Nonmetallic: Pipes			
	Conduits			
	Cable/Wire			
	Vaults/Boxes			
	Valves/Components			
7.	Looking for metallic	X	X	X
	Looking for non-metallic	X	X	X
8.	M/NM Pipes Colocated			
	M/NM Conduits Colocated			
	M/NM Cable/Wire Colocated			
	M/NM Vaults/Boxes Colocated			
	M/NM Valves/Components Co			

Figure 5-10 – Results Matrix

In order to interpret the results, all three results displays must be used to make the most informed decision in a 3 Step Process. The interpretation of the results can best be explained using the following two triangles in Figures 5.11 and 5.12. Figure 5.11 shows the three ways results are presented overlain on a triangle. The performance indicator is at the bottom of the triangle, the base, which is the largest. The economic indicator and matrix supplement are then further up the triangle with the matrix supplement on top, the smallest section of the triangle. The three methods can be related to where they are on the triangle

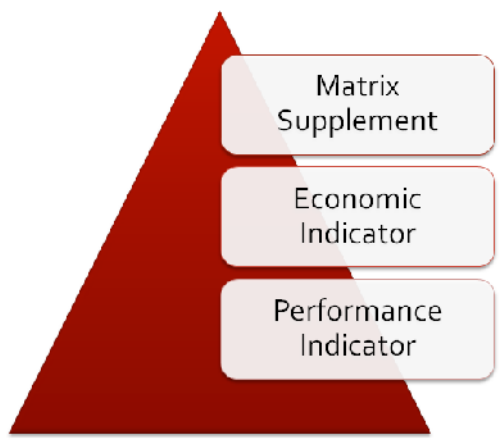


Figure 5-11 – Importance of Each Results Display

based on its' width. The first indicator to use and that has the most importance is the performance indicator (the biggest part of the triangle). Secondly, the economic indicator is in the middle of the triangle and should subsequently have less importance than the performance indicator and more than the matrix supplement. Finally, at the tip of the triangle, the smallest portion, is the third way to present the results and therefore should be used last to verify the decision made based on the two more important results. The matrix supplement is included in the results display to determine if specific project variables will completely rule out a technology – such as soil type, after a technology has been chosen. Conversely, looking at Figure 5.12 and working from the top down, the two indicators can be combined to produce a decision in the center of the triangle. At the bottom of this triangle and directly below the decision is the matrix supplement, used to verify the decision.

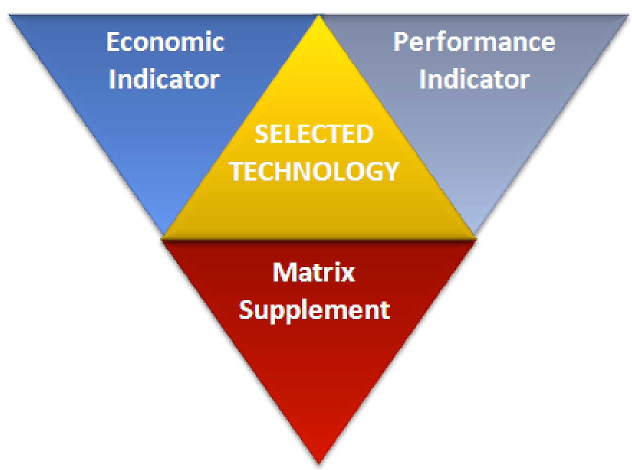


Figure 5-12 – Combining Results in VT PALMS

Step 1. View the Reliability Number on the Performance Indicator. If the R values have a significant range between them, and the highest value is in an acceptable rating category (such as Good) ,this technology is selected. Continuation to Step 2 is optional depending on the User's comfort level. However, if several of the highest values are located within the same scale or not significantly far apart, continuation to Step 2 is necessary. These results are shown below in Figure 5.13.

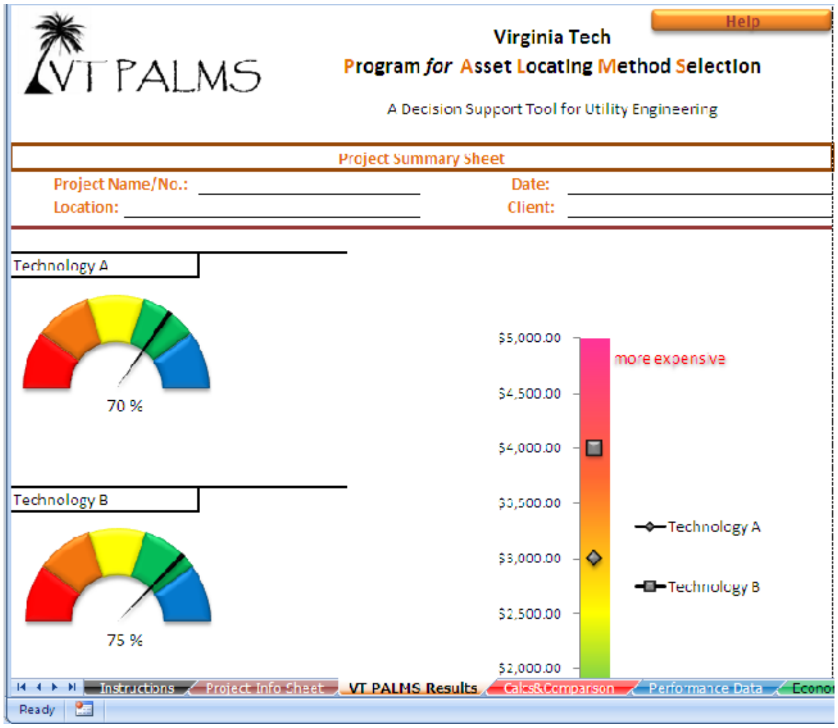


Figure 5-13 – Step 1 of Example Evaluation

Step 2. Using the Economic Indicator, find the results for each of the technologies selected in Step 1. These unit prices may or may not be near each other on the economic indicator and could present a clear choice immediately. The decision on which technology to use has now taken performance into account first and justified the decision based on cost. For example, if the top two results on the Performance Indicator returned values of 70% and 75% for technology A and B, respectively, both would fall under the Good or Green rating. A difference of 5% is small enough to necessitate use of the Economic Indicator. Upon review, technology B has a higher relative unit cost compared to technology A of about $1,000. Depending on the other technologies being compared, this difference could vary on the Economic Indicator since the scale adjusts to reflect the maximum unit price (so if a higher unit price is entered into the economic database with a new technology, the current scale would get smaller). For this example, the maximum unit price on the scale is $5,000 and the two technologies have unit prices as shown in Figure 5.14. A difference of $1,000 would be a 20% difference and be considered significant. The results would then suggest that technology A and B produce approximately the same quality of data (R values of 70 and 75) but the costs would warrant the selection of technology A, even though it's R value is 5 less because the User will get approximate the same level of results at a lower cost. Once the technology is chosen the last and final comparison is completed in Step 3.

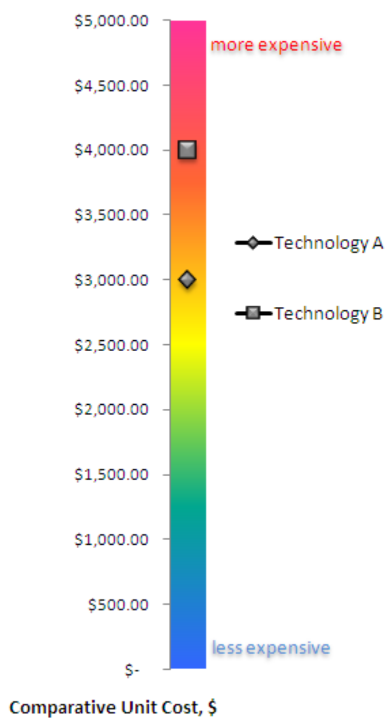


Figure 5-14 – Step 2 of Example Evaluation

Step 3. Using the results matrix provided in the results page, verify that the object(s) being located and the given conditions (such as soil), and other factors deemed most important to the User are compatible in the column for the selected technology. A red 'X' in the cell indicates a potential problem or conflict exists. If this is the case the User can choose the tab for the Performance Database to get detailed information on why this occurs. If the technology does not contain any a red 'X' for the objects, conditions, etc. then this confirms the choice of the User. If, after reviewing the matrix and the performance database, the technology is found not likely to be able to locate the object in the given conditions, repeat Step 3 for the technology with the next highest (or highest, if not used before) R value.

Continuing the example from Step 2, technology A was selected and the data in the results matrix was used to confirm the decision. After review, the soil type at the site (clay) does not support the use of technology B (technology A is located in the first column and technology B in the second column) according to the matrix while all of the other capabilities are equal (meaning the cells that contain a red 'X' value are the same for each technology). Reverting back to Step 2 technology A was the other being considered. Using technology A in Step 3 shows that the technology is compatible with the soil conditions on the site, as shown in Figure 5.15.

12.	Electric Lines	X		
	Train Rails	X	X	
	Walls/Foundations		X	
	Bridges			
	Wooden Posts/Utility Poles			
	Railroad Crossings			
	Corrosion Protection Systems			
13.	Depth Groundwater Interferes			
14.	Interference: Lakes	X	X	
	Ponds			
	Marshes/Swamps			
	Surface water, ponding			
	Surface water, flowing			
	Streams, >= 10 gpm			
	Streams, < 10 gpm			
15.	Clay		X	
	Silt			
	Sand			
	Gravel			
	Organics/Topsoil			
	Loam/Loess			
	Partially Weathered Rock			
	Intact Rock			
16.	Grasses <= 6 inches high			
	Grasses > 6 inches high			
	Shrubs/woody plants			
	Trees, <= 10 feet tall			
	Trees, > 10 feet tall			
	Flowers/soft stem plants			

Figure 5-15 – Step 3 of Example Evaluation

Example Summary. Technology A and Technology B were evaluated to determine which would be best for locating buried objects at a fictional project site. After completing the project information sheet the R values produced were 70% and 75% for technologies A and B, respectively. Technology B was selected as the initial choice after comparing unit costs on the Economic Indicator. However, after using the Results Matrix to confirm the selected technology B, it was found unable to locate buried objects in the given soil. Technology A was then evaluated using the Results Matrix and found to be sufficient.

Chapter 6 – Research Summary and Future Work

6.1 Research Summary

The research conducted had the aim of developing a tool that utility engineers, consultants, contractors, and utility providers can use when determining what locating method is a best fit for their particular projects. The VT PALMS program provides a user friendly and easily updatable place to store information about locating technologies. This Excel-based program, when integrated into a formal subsurface utility engineering program, has the potential to add value to a project by decreasing the amount of money spent on incorrect or inappropriate amounts of utility data. The performance and economic evaluation also serve to standardize the criteria used to evaluate such technologies and collect pertinent data that can be integrated into VT PALMS upon validation using the steps outlined previously. The entire process of using this tool will not increase the cost of an SUE program or associated process and can be used to evaluate an entire project or multiple parts of a single project. Immediate feedback from reviewers and industry professionals contacted has been positive. The VT PALMS program and entire process has the potential to help cut utility costs on heavy civil projects and its' implementation in pilot programs with State DOTs will further evaluate the effectiveness and contribute to quantifying cost savings from its' use.

6.2 Feedback and Evaluation

An unlocked version of the VT PALMS program was sent to several private firms that are routinely involved in subsurface utility engineering projects and the Virginia Department of Transportation. The feedback received was positive in nature and subsequent follow ups revealed a desire for future presentations and demonstrations of the VT PALMS process and program. This was as a good sign that persons in the utility engineering field had interest in learning about the program after seeing it for the first time and are likely to work with the researchers to implement the VT PALMS program as part of a formal SUE process. This will also help researchers conducting research to update and build upon the work done for this research project. The results were presented at the American Society of Civil Engineering's Pipelines 2009 Conference in San Diego, California and published in the conference proceedings in August 2009. The reviews and comments based on the discussion were integrated into the final product. A paper describing the VT PALMS process and implementation has been submitted to the ASCE Journal of Infrastructure Engineering and is pending acceptance in 2010.

6.3 Future Work

After implementation of the tool developed as part of this research, it may be necessary to modify some of the settings or features to adapt to the needs of the utility engineering profession. Future work for the project could include the following items and more depending on industry feedback and new, innovative ideas to address utility conflicts on heavy civil projects.

First, the expansion of the performance and economic databases in lieu of relying on each individual agency or firm using the program to collect its' own data would be beneficial. This would also be the start of a potential national storage space and clearing house for utility locating technology data. This data could include the data called for in VT PALMS with the addition of suppliers, resources, and technical trouble shooting to aid in producing better locating means and methods in the field. A second, complimentary item for future work that goes along with this idea is the integration of the excel-based workbook into an online workspace. Once information is entered into the database via a website it is instantly collected and transferred into the performance database (or the workbook utilizes an online database instead of an in-house database). Regardless of the data collection method, it is very likely the VT PALMS program and process will be available via an online source in the future. Work that is also likely to take place in the future would include analyzing the effectiveness of VT PALMS and the technologies used by SUE providers to determine common areas where current technologies may fall short in being able to locate buried utility assets. Case studies on the implementation of this process will result in the ability to quantify savings realized from the use of VT PALMS. This could lead to the identification of the capabilities new technologies will need to have or to the use of a multisensory array that combines several technologies to be able to locate buried utility assets in any environmental condition and eliminate the interference that can be caused due to the proximity of structures.

6.4 Dissemination

The research work is intended for use by anyone working in a role that could benefit from its' use. An accompanying website for the Virginia Tech Right of Way and Utility Management Systems (VT RUMS) Research Group was created as part of this SUE research. This, along with future SUE research at Virginia Tech, will be located here as a central place to access all research projects being done by the group, including the VT PALMS program, a Quick Start Guide to Using VT PALMS, and other supporting documents. Screen shots of the website's individual pages can be found in Appendix K and at the web address www.utilities.cee.vt.edu.

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APPENDIX A

PERFORMANCE EVALUATION

PERFORMANCE EVALUATION

Type of Technology: ______________________ Date: ______________

Manufacturer: ______________________ Evaluator: ______________

Model/Style: ______________________ Position: ______________

A. Setup

1	How long does equipment with this method take to setup?	☐ < 1 hour ☐ 1 - 2 hours ☐ > 2 hours
2	Are any site preparations required before setup/use?	☐ No ☐ Yes, ______________
3	Ease of setup	☐ Easy ☐ Moderate ☐ Difficult
4	Are lane closures necessary during setup?	☐ No ☐ Yes
5	Amount of training required for setup only	☐ 0 - 1 hour ☐ 2 - 4 hours ☐ > 4 hours
6	Minimum number of persons needed for setup.	☐ 1 - 2 ☐ 3 - 5 ☐ > 5
7	Is a setup required each time the location changes within the same project?	☐ No ☐ Yes
8	Are any permits required to be completed before setup or testing are underway?	☐ No ☐ Yes

Comments Regarding Setup:

B. Operation

1	Additional safety gear (other than eye, ear, hardhat, boots, gloves) required during operation?	☐ No ☐ Yes
2	Minimum number of people required to operate and perform testing	☐ 1 - 2 ☐ 3 - 5 ☐ > 5
3	Are lane closures necessary during operation?	☐ No ☐ Yes
4	Are multiple units required for use during testing?	☐ No ☐ Yes, # ______
5	Does the equipment notify the operator when an object is located (either visual or auditory)?	☐ Yes ☐ No
6	Amount of training required to operate equipment/perform testing	☐ 0 - 1 hour ☐ 2 - 4 hours ☐ > 4 hours
7	Minimum required horizontal distance for operation	______ feet inches (circle one)
8	Minimum required vertical distance for operation	______ feet inches (circle one)
9	Capable of tracking location using GPS during operation	☐ Yes or add-on ☐ If vehicle is equipped ☐ No
10	Mobility of equipment	☐ ATV/truck mounted ☐ Operator moves ☐ Stationary ☐ Remote controlled ☐ Wearable
11	Equipment can operate or perform testing on slopes with a grade of	☐ > 1:1 slope ☐ < 1:1 slope ☐ Flat area only
12	Do any of the following weather events cause testing to stop	☐ No ☐ Yes Rain ☐ No ☐ Yes Snow ☐ No ☐ Yes, Temperature < ____ ˚ F ☐ No ☐ Yes, Temperature > ____ ˚ F

Comments Regarding Operation:

C. Limitations

1	Can this technology detect buried assets beneath:	☐ Yes Concrete w/remesh ☐ No ☐ Yes Concrete w/rebar ☐ No ☐ Yes Concrete w/steel fibers ☐ No ☐ Yes Unreinforced concrete ☐ No ☐ Yes Asphalt ☐ No ☐ Yes Wood ☐ No ☐ Yes Steel ☐ No ☐ Yes Brick/Clay tile ☐ No ☐ Yes Other: ____________ ☐ No
2	Maximum depth an object can be located	☐ ≤ 3 feet ☐ > 3 ft. - ≤ 8 ft. ☐ > 8 feet
3	Can detect the following *metallic* objects	☐ Yes Pipes ☐ No ☐ Yes Conduits ☐ No ☐ Yes Cable/wire ☐ No ☐ Yes Vaults/boxes ☐ No ☐ Yes Valves/components ☐ No ☐ Other (specify) ____________
4	Minimum diameter or width detectable, *metallic* objects	____________ ☐ feet ☐ inches (choose one)
5	Can detect the following *non-metallic* objects	☐ Yes Pipes ☐ No ☐ Yes Conduits ☐ No ☐ Yes Cable/wire ☐ No ☐ Yes Vaults/boxes ☐ No ☐ Yes Valves/components ☐ No ☐ Yes Fiber optics ☐ No ☐ Other (specify) ____________
6	Minimum diameter or width detectable, *non-metallic* objects	____________ ☐ feet ☐ inches (choose one)
7	Which of the following subsurface materials can this technology be used in, having the primary or majority composition of each listed?	☐ Yes Clay ☐ No ☐ Yes Silt ☐ No

continued on next page

	question 7 continued	☐ Yes	Sand	☐ No
		☐ Yes	Gravel	☐ No
		☐ Yes	Organics/topsoil	☐ No
		☐ Yes	Loam/loess	☐ No
		☐ Yes	Intact rock	☐ No
8	Can the equipment operate in & testing be performed in ditches/culverts?	☐ < 4 feet deep	☐ > 4 ft. deep	☐ No
9	Do any of the following instances of water interfere with testing or nearby testing	☐ No	Lakes	☐ Yes
		☐ No	Ponds	☐ Yes
	Notes: Surface ponding and runoff can be from recent storm events, melting of snowfall/ice, from nearby activities such as washing cars or irrigation, etc. This does not include natural bodies of water such as rivers and streams.	☐ No	Marshlands/swamps	☐ Yes
		☐ No	Surface ponding	☐ Yes
		☐ No	Surface water, flowing	☐ Yes
		☐ No	Streams, ≤ 10 gpm flow	☐ Yes
		☐ No	Streams, > 10 gpm flow	☐ Yes
10	Do any of the natural ground covers, plants, or loose materials listed affect the performance of testing when located on the surface?	☐ No	Grasses ≤ 6 inches high	☐ Yes
		☐ No	Grasses > 6 inches high	☐ Yes
		☐ No	Shrubs/woody plants	☐ Yes
		☐ No	Trees, ≤ 10 ft tall	☐ Yes
		☐ No	Trees, > 10 ft tall	☐ Yes
		☐ No	Flowers/soft stem plants	☐ Yes
		☐ No	Leaves	☐ Yes
		☐ No	Fallen sticks	☐ Yes
		☐ No	Loose rock (size > gravel)	☐ Yes
		______________________ (please list above)		☐ Yes, other
11	Do the following structures interfere with testing (other than as a physical obstruction)?	Guardrail		
		☐ No	__________ ft	☐ Yes
	If Yes, please indicate the minimum distance these objects must be from the testing location to avoid interfering.	Hydrants/Pipe stems		
		☐ No	__________ ft	☐ Yes
		Sign posts (metal)		
		☐ No	__________ ft	☐ Yes

continued on next page

	question 11 continued	Traffic signal boxes ☐ No ________ ft ☐ Yes Light poles (metal) ☐ No ________ ft ☐ Yes Buried traffic sensors ☐ No ________ ft ☐ Yes Overhead electric lines ☐ No ________ ft ☐ Yes Train rails ☐ No ________ ft ☐ Yes Walls/foundations ☐ No ________ ft ☐ Yes Bridges ☐ No ________ ft ☐ Yes Wooden posts/utility poles ☐ No ________ ft ☐ Yes Railroad Crossings ☐ No ________ ft ☐ Yes Corrosion protection systems (such as for pipe) ☐ No ________ ft ☐ Yes Other: ________________ ☐ No ________ ft ☐ Yes
12	When does groundwater interfere with the use of this technology?	☐ Never ☐ Within ______ ft of the surface ☐ Always

Comments Regarding Limitations:

D. Results/Data Processing

1	Is the equipment used for collecting data able to produce the location of the utility without further analysis?	☐ Yes ☐ No
2	What information does this technology produce either during testing or after analysis/processing?	☐ Yes Horizontal position ☐ No ☐ Yes Vertical position ☐ No
3	What is the accuracy of the position obtained from testing?	Horizontal: ______ Vertical: ______ *(please specifcy units)*
4	Data gathered using this technology can produce the following:	☐ Visual of the horizontal and vertical position (any kind of map, chart, etc.) ☐ Physical or visual markings in the field ☐ Images ☐ 2D plan showing location ☐ Non-visual results (data files, coordinates) ☐ Digital model (e.g. CAD) ☐ Other, ______
5	Does data collected in the field require further analysis to determine the location of buried assets?	☐ No ☐ Yes
6	Is training required to analyze the results?	☐ No ☐ Yes
7	If you answered Yes to #6, how much?	☐ 0 - 1 hour ☐ 2 - 4 hours ☐ > 4 hours
8	Is a Professional License required to analyze the data?	☐ No ☐ Yes
9	What kind of software is required to view the data?	☐ Off-the-shelf, must be purchased ☐ Applications that can be expected at an engineering firm (such as CAD) ☐ Specialized, or developed by data collection firm ☐ Other: ______

Comments Regarding Data/Results Processing:

E. Comments, Other Information, Special Instructions or Remarks

APPENDIX B

ECONOMIC EVALUATION

ECONOMIC EVALUATION

Type of Technology: ______________________ Date: ______________

Manufacturer: ______________________ Evaluator: ______________

Model/Style: ______________________ Position: ______________

1	Based on required equipment, mobility, traffic interferences and other disruptions, what is the estimated socioeconomic impact of using this technology to locate buried utilities?	☐ Low ☐ Medium ☐ High
2	How does an increase in the density of utilities affect the unit cost of locating using this technology?	☐ Increases unit cost ☐ Decreases unit cost ☐ Has no effect OR unit cost is fixed
3	Are ancillary costs, such as per diem, equipment rental, travel, and mobilization included in the unit cost?	☐ Yes ☐ No ☐ Yes, these are: ______________ ______________ ______________ ______________
4	What types of contract do you typically use for performing work with this type of technology?	☐ Lump Sum ☐ Negotiated Price ☐ Unit Price ☐ Other, ____________
5	Are additional fees administered for data analysis?	☐ No ☐ Yes
6	In comparison to other technologies available for locating buried utilities that you use, please rank them from most expensive to least expensive.	most 1. ______________ 2. ______________ 3. ______________ 4. ______________ 5. ______________ ______________ ______________ ______________ ______________ least
7	How does the complexity of the buried utility effect the unit cost of locating using this technology?	☐ Increases unit cost with complexity ☐ Decreases unit cost with complexity ☐ Has no effect OR unit cost is fixed
8	Additional factors that would affect the unit cost of performing work using this technology	______________ ______________ ______________ ______________ ______________ ______________ ______________ ______________

9	What is the total unit cost of performing work using this technology, regardless of payment method or contract type, and including all fees? (per day, based on one full days worth of work.)	______ dollars per ______ unit (time)

Comments Regarding Testing Cost:

APPENDIX C

INFORMATION PACKET SENT TO EVALUATORS

VirginiaTech

Greetings,

I would like to thank you for taking the time to complete these two evaluations to help me complete my research on Subsurface Utility Engineering. This research is not possible without the help and cooperation of industry so that we can insure the work we're doing is practical and will be able to be transferred from an idea into a quality piece of work that others will find useful.

My research focus for this project is on the means and methods used to find buried utilities and improving the process on how to decide which method is the most appropriate for a given construction project. Traditional technologies that can be used above ground such as ground penetrating radar, seismic surveys, and vacuum excavation, among others, are the focus of this research and not methods such as RFID tags and other embedded sensors.

Enclosed you will find a packet that is aimed to help in the decision making process when owners, contractors, utility managers, consultants, and State transportation officials must choose between several options available to locate buried utilities. This packet consists of two evaluations: a Performance Evaluation (Appendix A) and an Economic Evaluation (Appendix B). The performance evaluation is designed to show the limitations of the technology in terms of setup, operation, environmental factors, and results and data processing. The economic evaluation serves as a way to compare different technologies in terms of overall cost, including implementation to final assessment of the data collected.

Please complete the enclosed evaluations for as many technologies of your choice that you routinely use (for example, ground penetrating radar) and feel comfortable evaluating.
Then, return the forms to me via email or regular postal mail, preferably within the next two weeks so that i can use the information in a report and presentation to VDOT. Feel free to also provide as much comments as you would like on the layout, clarity, comprehensiveness, contents of these evaluations, and any suggestions for improving the evaluations. The information you provide will be anonymous and will not be given to anyone other than the researchers; however, we may use the data for illustrative purposes on how to complete the evaluations. Acknowledgement will be given to you in the paper that will be published regarding the work and presented at future ASCE conferences.

If you have any questions, please contact me via the information below and thank you again.

Sincerely,

Lewis A. Hutchins

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PLEASE READ THE FOLLOWING PAGE FOR IMPORTANT INFORMATION ABOUT THIS STUDY.

1. Your information and responses will be kept confidential by the researchers at all times. Upon receipt of the responses you will be assigned an individual code that will be used instead of your name, or any other information which may personally identify you or relate you to the study. At no time will the researchers release the results of the study to anyone other than individuals working on the project without your prior, written consent.

2. Compensation is neither offered nor implied for the inputs of the research. By completing and returning the enclosures you voluntarily agree to participate in this study with the responsibilities as outlined in this document.

3. You may choose to answer/omit questions that you are not comfortable with or would otherwise not like to answer and are free to withdraw at any time, without penalty or prejudice. In either circumstance the data provided and any codes used to identify the research participants (You) and their information will be destroyed when the study is complete.

4. If I should have any questions about the protection of human research participants regarding this study, I may contact Dr. David Moore, Chair Virginia Tech Institutional Review Board for the Protection of Human Subjects, telephone: (540) 231-4991; email: moored@vt.edu; address: Office of Research Compliance, 2000 Kraft Drive, Suite 2000 (0497), Blacksburg, VA 24060.

5. It is possible that the Institutional Review Board (IRB) may view this study's collected data for auditing purposes. The IRB is responsible for the oversight of the protection of human subjects involved in research.

I have read the Consent Form (this document) and conditions of this project and have had all of my questions answered. I hereby acknowledge the above and give my voluntary consent:

____________________________________ ____________________

Signature of the Participant Date

Appendix D

Completed Performance Evaluations

PERFORMANCE EVALUATION

Type of Technology: Electromagnetics

Date: 5/7/2009

Manufacturer: Geonics

Evaluator: 1101

Model/Style: EM-61 System

Position: Geophysicist

A. Setup

1	How long does equipment with this method take to setup?	[X] < 1 hour	[ ] 1 - 2 hours	[ ] > 2 hours
2	Are any site preparations required before setup/use?	[X] No	[ ] Yes, ____	
3	Ease of setup	[ ] Easy	[X] Moderate	[ ] Difficult
4	Are lane closures necessary during setup?	[X] No	[ ] Yes	
5	Amount of training required for setup only	[X] 0 - 1 hour	[ ] 2 - 4 hours	[ ] > 4 hours
6	Minimum number of persons needed for setup.	[X] 1 - 2	[ ] 3 - 5	[ ] > 5
7	Is a setup required each time the location changes within the same project?	[ ] No	[X] Yes	
8	Are any permits required to be completed before setup or testing are underway?	[X] No	[ ] Yes	

Comments Regarding Setup:

B. Operation

1	Additional safety gear (other than eye, ear, hardhat, boots, gloves) required during operation?	[X] No	[ ] Yes	
2	Minimum number of people required to operate and perform testing	[X] 1 - 2	[ ] 3 - 5	[ ] > 5
3	Are lane closures necessary during operation?	[X] No	[ ] Yes	
4	Are multiple units required for use during testing?	[X] No	[ ] Yes, # ______	
5	Does the equipment notify the operator when an object is located (either visual or auditory)?	[X] Yes		[ ] No
6	Amount of training required to operate equipment/perform testing	[ ] 0 - 1 hour	[ ] 2 - 4 hours	[X] > 4 hours
7	Minimum required horizontal distance for operation	4	feet	(circle one)
8	Minimum required vertical distance for operation	5	feet	(circle one)
9	Capable of tracking location using GPS during operation	[X] Yes or add-on	[ ] If vehicle is equipped	[ ] No
10	Mobility of equipment	[X] ATV/truck mounted	[X] Operator moves	[ ] Stationary
		[ ] Remote controlled	[X] Wearable	
11	Equipment can operate or perform testing on slopes with a grade of	[ ] > 1:1 slope	[X] < 1:1 slope	[ ] Flat area only
12	Do any of the following weather events cause testing to stop	[ ] No	[X] Yes	Rain
		[X] No	[ ] Yes	Snow
		[X] No	[ ] Yes,	Temperature < ____ ˚ F
		[X] No	[ ] Yes,	Temperature > ____ ˚ F

Comments Regarding Operation:

C. Limitations

1	Can this technology detect buried assets beneath:	[ ] Yes Concrete w/remesh [X] No [ ] Yes Concrete w/rebar [X] No [ ] Yes Concrete w/steel fibers [X] No [X] Yes Unreinforced concrete [ ] No [X] Yes Asphalt [ ] No [X] Yes Wood [ ] No [ ] Yes Steel [X] No [X] Yes Brick/Clay tile [ ] No [X] Yes Other: Soil [ ] No
2	Maximum depth an object can be located	[ ] ≤ 3 feet [ ] > 3 ft. - ≤ 8 ft. [X] > 8 feet
3	Can detect the following *metallic* objects	[X] Yes Pipes [ ] No [X] Yes Conduits [ ] No [X] Yes Cable/wire [ ] No [X] Yes Vaults/boxes [ ] No [X] Yes Valves/components [ ] No [ ] Other (specify) ______
4	Minimum diameter or width detectable, *metallic* objects	0.5 [ ] feet [X] inches (choose one)
5	Can detect the following *non-metallic* objects	[ ] Yes Pipes [X] No [ ] Yes Conduits [X] No [ ] Yes Cable/wire [X] No [ ] Yes Vaults/boxes [X] No [ ] Yes Valves/components [X] No [ ] Yes Fiber optics [X] No [ ] Other (specify) ______
6	Minimum diameter or width detectable, *non-metallic* objects	NA [ ] feet [ ] inches (choose one)
7	Which of the following subsurface materials can this technology be used in, having the primary or majority composition of each listed?	[X] Yes Clay [ ] No [X] Yes Silt [ ] No

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	question 7 continued	[X] Yes	Sand	[ ] No
		[X] Yes	Gravel	[ ] No
		[X] Yes	Organics/topsoil	[ ] No
		[X] Yes	Loam/loess	[ ] No
		[X] Yes	Intact rock	[ ] No
8	Can the equipment operate in & testing be performed in ditches/culverts?	[ ] < 4 feet deep	[X] > 4 ft. deep	[ ] No If greater than 4 feet wide
9	Do any of the following instances of water interfere with testing or nearby testing Notes: Surface ponding and runoff can be from recent storm events, melting of snowfall/ice, from nearby activities such as washing cars or irrigation, etc. This does not include natural bodies of water such as rivers and streams.	[X] No	Lakes	[ ] Yes
		[X] No	Ponds	[ ] Yes
		[X] No	Marshlands/swamps	[ ] Yes
		[X] No	Surface ponding	[ ] Yes
		[X] No	Surface water, flowing	[ ] Yes
		[X] No	Streams, ≤ 10 gpm flow	[ ] Yes
		[X] No	Streams, > 10 gpm flow	[ ] Yes
10	Do any of the natural ground covers, plants, or loose materials listed affect the performance of testing when located on the surface?	[X] No	Grasses ≤ 6 inches high	[ ] Yes
		[ ] No	Grasses > 6 inches high	[X] Yes
		[ ] No	Shrubs/woody plants	[X] Yes
		[ ] No	Trees, ≤ 10 ft tall	[X] Yes
		[ ] No	Trees, > 10 ft tall	[X] Yes
		[X] No	Flowers/soft stem plants	[ ] Yes
		[X] No	Leaves	[ ] Yes
		[X] No	Fallen sticks	[ ] Yes
		[ ] No	Loose rock (size > gravel)	[X] Yes
			____ (please list above)	[ ] Yes, other
11	Do the following structures interfere with testing (other than as a physical obstruction)? If Yes, please indicate the minimum distance these objects must be from the testing location to avoid interfering.	Guardrail		
		[ ] No	10 ft	[X] Yes
		Hydrants/Pipe stems		
		[ ] No	10 ft	[X] Yes
		Sign posts (metal)		
		[ ] No	10 ft	[X] Yes

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	question 11 continued	Traffic signal boxes ☐ No 10 ft ☒ Yes Light poles (metal) ☐ No 10 ft ☒ Yes Buried traffic sensors ☐ No 10 ft ☒ Yes Overhead electric lines ☐ No 20 ft ☒ Yes Train rails ☐ No 10 ft ☒ Yes Walls/foundations ☐ No 10 ft ☒ Yes if reinforced Bridges ☐ No 10 ft ☒ Yes Wooden posts/utility poles ☒ No ____ ft ☐ Yes Railroad Crossings ☐ No 10 ft ☒ Yes Corrosion protection systems (such as for pipe) ☐ No 10 ft ☒ Yes if metal Other: ____________ ☐ No ____ ft ☐ Yes
12	When does groundwater interfere with the use of this technology?	☒ Never ☐ Within _______ ft of the surface ☐ Always

Comments Regarding Limitations:

#4 increases with depth

D. Results/Data Processing

1	Is the equipment used for collecting data able to produce the location of the utility without further analysis?	[X] Yes but generally no ☐ No
2	What information does this technology produce either during testing or after analysis/processing?	[X] Yes Horizontal position ☐ No [X] Yes Vertical position ☐ No
3	What is the accuracy of the position obtained from testing?	Horizontal: 3 feet Vertical: 6 feet *(please specifcy units)*
4	Data gathered using this technology can produce the following:	[X] Visual of the horizontal and vertical position (any kind of map, chart, etc.) [X] Physical or visual markings in the field [X] Images [X] 2D plan showing location [X] Non-visual results (data files, coordinates) [X] Digital model (e.g. CAD) ☐ Other, ________
5	Does data collected in the field require further analysis to determine the location of buried assets?	[X] No but generally yes ☐ Yes
6	Is training required to analyze the results?	☐ No [X] Yes
7	If you answered Yes to #6, how much?	☐ 0 - 1 hour ☐ 2 - 4 hours [X] > 4 hours
8	Is a Professional License required to analyze the data?	[X] No ☐ Yes
9	What kind of software is required to view the data?	☐ Off-the-shelf, must be purchased ☐ Applications that can be expected at an engineering firm (such as CAD) [X] Specialized, or developed by data collection firm ☐ Other: ________

Comments Regarding Data/Results Processing:

E. Comments, Other Information, Special Instructions or Remarks

PERFORMANCE EVALUATION

Type of Technology: Electromagnetics

Date: 5/7/2009

Manufacturer: Fisher

Evaluator: 1101

Model/Style: Gemini-3

Position: Geophysicist

A. Setup

1	How long does equipment with this method take to setup?	[X] < 1 hour	[ ] 1 - 2 hours	[ ] > 2 hours
2	Are any site preparations required before setup/use?	[X] No	[ ] Yes, ______	
3	Ease of setup	[X] Easy	[ ] Moderate	[ ] Difficult
4	Are lane closures necessary during setup?	[X] No	[ ] Yes	
5	Amount of training required for setup only	[X] 0 - 1 hour	[ ] 2 - 4 hours	[ ] > 4 hours
6	Minimum number of persons needed for setup.	[X] 1 - 2	[ ] 3 - 5	[ ] > 5
7	Is a setup required each time the location changes within the same project?	[ ] No	[X] Yes	
8	Are any permits required to be completed before setup or testing are underway?	[X] No	[ ] Yes	

Comments Regarding Setup:

B. Operation

1	Additional safety gear (other than eye, ear, hardhat, boots, gloves) required during operation?	[X] No [ ] Yes
2	Minimum number of people required to operate and perform testing	[X] 1 - 2 [ ] 3 - 5 [ ] > 5
3	Are lane closures necessary during operation?	[X] No [ ] Yes
4	Are multiple units required for use during testing?	[X] No [ ] Yes, # ______
5	Does the equipment notify the operator when an object is located (either visual or auditory)?	[X] Yes [ ] No
6	Amount of training required to operate equipment/perform testing	[ ] 0 - 1 hour [X] 2 - 4 hours [ ] > 4 hours
7	Minimum required horizontal distance for operation	30 feet (circle one)
8	Minimum required vertical distance for operation	5 feet (circle one)
9	Capable of tracking location using GPS during operation	[ ] Yes or add-on [ ] If vehicle is equipped [X] No
10	Mobility of equipment	[ ] ATV/truck mounted [X] Operator moves [ ] Stationary [ ] Remote controlled [ ] Wearable
11	Equipment can operate or perform testing on slopes with a grade of	[X] > 1:1 slope [ ] < 1:1 slope [ ] Flat area only
12	Do any of the following weather events cause testing to stop	[ ] No [X] Yes Rain [X] No [ ] Yes Snow [X] No [ ] Yes, Temperature < ____ ° F [X] No [ ] Yes, Temperature > ____ ° F

Comments Regarding Operation:

C. Limitations

1	Can this technology detect buried assets beneath:	[X] Yes Concrete w/remesh [ ] No [X] Yes Concrete w/rebar [ ] No [X] Yes Concrete w/steel fibers [ ] No [X] Yes Unreinforced concrete [ ] No [X] Yes Asphalt [ ] No [X] Yes Wood [ ] No [X] Yes Steel [ ] No [X] Yes Brick/Clay tile [ ] No [ ] Yes Other: ________ [ ] No
2	Maximum depth an object can be located	[ ] ≤ 3 feet [ ] > 3 ft. - ≤ 8 ft. [X] > 8 feet
3	Can detect the following *metallic* objects	[X] Yes Pipes [ ] No [X] Yes Conduits [ ] No [ ] Yes Cable/wire [X] No [X] Yes Vaults/boxes [ ] No [X] Yes Valves/components [ ] No [ ] Other (specify) ________
4	Minimum diameter or width detectable, *metallic* objects	NA [ ] feet [ ] inches (choose one)
5	Can detect the following *non-metallic* objects	[ ] Yes Pipes [X] No [ ] Yes Conduits [X] No [ ] Yes Cable/wire [X] No [ ] Yes Vaults/boxes [X] No [ ] Yes Valves/components [X] No [ ] Yes Fiber optics [X] No [ ] Other (specify) ________
6	Minimum diameter or width detectable, *non-metallic* objects	NA [ ] feet [ ] inches (choose one)
7	Which of the following subsurface materials can this technology be used in, having the primary or majority composition of each listed?	[X] Yes Clay [ ] No [X] Yes Silt [ ] No

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	question 7 continued	[X] Yes — Sand — [ ] No [X] Yes — Gravel — [ ] No [X] Yes — Organics/topsoil — [ ] No [X] Yes — Loam/loess — [ ] No [X] Yes — Intact rock — [ ] No
8	Can the equipment operate in & testing be performed in ditches/culverts?	[ ] < 4 feet deep [X] > 4 ft. deep [ ] No
9	Do any of the following instances of water interfere with testing or nearby testing Notes: Surface ponding and runoff can be from recent storm events, melting of snowfall/ice, from nearby activities such as washing cars or irrigation, etc. This does not include natural bodies of water such as rivers and streams.	[ ] No — Lakes — [X] Yes [X] No — Ponds — [ ] Yes [X] No — Marshlands/swamps — [ ] Yes [X] No — Surface ponding — [ ] Yes [X] No — Surface water, flowing — [ ] Yes [X] No — Streams, ≤ 10 gpm flow — [ ] Yes [X] No — Streams, > 10 gpm flow — [ ] Yes
10	Do any of the natural ground covers, plants, or loose materials listed affect the performance of testing when located on the surface?	[X] No — Grasses ≤ 6 inches high — [ ] Yes [X] No — Grasses > 6 inches high — [ ] Yes [X] No — Shrubs/woody plants — [ ] Yes [X] No — Trees, ≤ 10 ft tall — [ ] Yes [X] No — Trees, > 10 ft tall — [ ] Yes [X] No — Flowers/soft stem plants — [ ] Yes [X] No — Leaves — [ ] Yes [X] No — Fallen sticks — [ ] Yes [X] No — Loose rock (size > gravel) — [ ] Yes ______ (please list above) [ ] Yes, other
11	Do the following structures interfere with testing (other than as a physical obstruction)? If Yes, please indicate the minimum distance these objects must be from the testing location to avoid interfering.	Guardrail [X] No ______ ft [ ] Yes Hydrants/Pipe stems [X] No ______ ft [ ] Yes Sign posts (metal) [X] No ______ ft [ ] Yes

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	question 11 continued	Traffic signal boxes [X] No ________ ft [ ] Yes Light poles (metal) [X] No ________ ft [ ] Yes Buried traffic sensors [X] No ________ ft [ ] Yes Overhead electric lines [X] No ________ ft [ ] Yes Train rails [X] No ________ ft [ ] Yes Walls/foundations [X] No ________ ft [ ] Yes Bridges [X] No ________ ft [ ] Yes Wooden posts/utility poles [X] No ________ ft [ ] Yes Railroad Crossings [X] No ________ ft [ ] Yes Corrosion protection systems (such as for pipe) [X] No ________ ft [ ] Yes Other: ____________ [ ] No ________ ft [ ] Yes
12	When does groundwater interfere with the use of this technology?	[X] Never [ ] Within ______ ft of the surface [ ] Always

Comments Regarding Limitations:

All limitations depend on which mode the instrument is being used in. The most reliable mode (conductive search) was chosen to answer most of the above questions.

D. Results/Data Processing

1	Is the equipment used for collecting data able to produce the location of the utility without further analysis?	[X] Yes; [ ] No
2	What information does this technology produce either during testing or after analysis/processing?	Horizontal position: [X] Yes [ ] No Vertical position: [ ] Yes [X] No
3	What is the accuracy of the position obtained from testing?	Horizontal: 1 foot; Vertical: NA *(please specifcy units)*
4	Data gathered using this technology can produce the following:	[ ] Visual of the horizontal and vertical position (any kind of map, chart, etc.) [X] Physical or visual markings in the field [ ] Images [ ] 2D plan showing location [ ] Non-visual results (data files, coordinates) [ ] Digital model (e.g. CAD) [ ] Other, ______
5	Does data collected in the field require further analysis to determine the location of buried assets?	[X] No; [ ] Yes
6	Is training required to analyze the results?	[X] No; [ ] Yes
7	If you answered Yes to #6, how much?	[ ] 0 - 1 hour; [ ] 2 - 4 hours; [ ] > 4 hours
8	Is a Professional License required to analyze the data?	[X] No; [ ] Yes
9	What kind of software is required to view the data?	[ ] Off-the-shelf, must be purchased [ ] Specialized, or developed by data collection firm [ ] Applications that can be expected at an engineering firm (such as CAD) [ ] Other: ______

Comments Regarding Data/Results Processing:

E. Comments, Other Information, Special Instructions or Remarks

PERFORMANCE EVALUATION

Type of Technology: Ground Penetrating Radar

Date: 5/7/2009

Manufacturer: Geophysical Survey Systems (GSSI)

Evaluator: 1101

Model/Style: SIR-3000 System

Position: Geophysicist

A. Setup

1	How long does equipment with this method take to setup?	[X] < 1 hour	[ ] 1 - 2 hours	[ ] > 2 hours
2	Are any site preparations required before setup/use?	[ ] No	[X] Yes, survey grid is usually neede	
3	Ease of setup	[ ] Easy	[X] Moderate	[ ] Difficult
4	Are lane closures necessary during setup?	[X] No	[ ] Yes	
5	Amount of training required for setup only	[ ] 0 - 1 hour	[X] 2 - 4 hours	[ ] > 4 hours
6	Minimum number of persons needed for setup.	[X] 1 - 2	[ ] 3 - 5	[ ] > 5
7	Is a setup required each time the location changes within the same project?	[ ] No	[X] Yes	
8	Are any permits required to be completed before setup or testing are underway?	[X] No	[ ] Yes	

Comments Regarding Setup:

Performance Evaluation

B. Operation

1	Additional safety gear (other than eye, ear, hardhat, boots, gloves) required during operation?	[X] No ☐ Yes
2	Minimum number of people required to operate and perform testing	[X] 1 - 2 ☐ 3 - 5 ☐ > 5
3	Are lane closures necessary during operation?	[X] No ☐ Yes
4	Are multiple units required for use during testing?	[X] No ☐ Yes, # ______
5	Does the equipment notify the operator when an object is located (either visual or auditory)?	[X] Yes ☐ No
6	Amount of training required to operate equipment/perform testing	☐ 0 - 1 hour ☐ 2 - 4 hours [X] > 4 hours
7	Minimum required horizontal distance for operation	3 feet (circle one)
8	Minimum required vertical distance for operation	5 feet (circle one)
9	Capable of tracking location using GPS during operation	[X] Yes or add-on ☐ If vehicle is equipped ☐ No
10	Mobility of equipment	[X] ATV/truck mounted [X] Operator moves ☐ Stationary ☐ Remote controlled ☐ Wearable
11	Equipment can operate or perform testing on slopes with a grade of	☐ > 1:1 slope [X] < 1:1 slope ☐ Flat area only
12	Do any of the following weather events cause testing to stop	☐ No [X] Yes Rain [X] No ☐ Yes Snow [X] No ☐ Yes, Temperature < ____ ˚ F [X] No ☐ Yes, Temperature > ____ ˚ F

Comments Regarding Operation:

C. Limitations

1	Can this technology detect buried assets beneath:	[X] Yes Concrete w/remesh [ ] No [X] Yes Concrete w/rebar [ ] No [?] Yes Concrete w/steel fibers [ ] No [X] Yes Unreinforced concrete [ ] No [X] Yes Asphalt [ ] No [X] Yes Wood [ ] No [ ] Yes Steel [X] No [X] Yes Brick/Clay tile [ ] No [X] Yes Other: Soil [ ] No
2	Maximum depth an object can be located	[ ] ≤ 3 feet [ ] > 3 ft. - ≤ 8 ft. [X] > 8 feet
3	Can detect the following *metallic* objects	[X] Yes Pipes [ ] No [X] Yes Conduits [ ] No [X] Yes Cable/wire [ ] No [X] Yes Vaults/boxes [ ] No [X] Yes Valves/components [ ] No [ ] Other (specify) ______
4	Minimum diameter or width detectable, *metallic* objects	1 [ ] feet [X] inches (choose one)
5	Can detect the following *non-metallic* objects	[X] Yes Pipes [ ] No [X] Yes Conduits [ ] No [X] Yes Cable/wire [ ] No [X] Yes Vaults/boxes [ ] No [X] Yes Valves/components [ ] No [X] Yes Fiber optics [ ] No [ ] Other (specify) ______
6	Minimum diameter or width detectable, *non-metallic* objects	2 [ ] feet [X] inches (choose one)
7	Which of the following subsurface materials can this technology be used in, having the primary or majority composition of each listed?	[X] Yes Clay [ ] No [X] Yes Silt [ ] No

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	question 7 continued	[X] Yes — Sand — [ ] No [X] Yes — Gravel — [ ] No [X] Yes — Organics/topsoil — [ ] No [X] Yes — Loam/loess — [ ] No [X] Yes — Intact rock — [ ] No
8	Can the equipment operate in & testing be performed in ditches/culverts?	[ ] < 4 feet deep [X] > 4 ft. deep [ ] No If greater than 2 feet wide
9	Do any of the following instances of water interfere with testing or nearby testing Notes: Surface ponding and runoff can be from recent storm events, melting of snowfall/ice, from nearby activities such as washing cars or irrigation, etc. This does not include natural bodies of water such as rivers and streams.	[X] No — Lakes — [ ] Yes [X] No — Ponds — [ ] Yes [X] No — Marshlands/swamps — [ ] Yes [X] No — Surface ponding — [ ] Yes [X] No — Surface water, flowing — [ ] Yes [X] No — Streams, ≤ 10 gpm flow — [ ] Yes [X] No — Streams, > 10 gpm flow — [ ] Yes
10	Do any of the natural ground covers, plants, or loose materials listed affect the performance of testing when located on the surface?	[X] No — Grasses ≤ 6 inches high — [ ] Yes [ ] No — Grasses > 6 inches high — [X] Yes [ ] No — Shrubs/woody plants — [X] Yes [ ] No — Trees, ≤ 10 ft tall — [X] Yes [ ] No — Trees, > 10 ft tall — [X] Yes [X] No — Flowers/soft stem plants — [ ] Yes [X] No — Leaves — [ ] Yes [X] No — Fallen sticks — [ ] Yes [ ] No — Loose rock (size > gravel) — [X] Yes ______ (please list above) [ ] Yes, other
11	Do the following structures interfere with testing (other than as a physical obstruction)? If Yes, please indicate the minimum distance these objects must be from the testing location to avoid interfering.	Guardrail [X] No ______ ft [ ] Yes Hydrants/Pipe stems [X] No ______ ft [ ] Yes Sign posts (metal) [X] No ______ ft [ ] Yes

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	question 11 continued	Traffic signal boxes [X] No ______ ft [ ] Yes Light poles (metal) [X] No ______ ft [ ] Yes Buried traffic sensors [X] No ______ ft [ ] Yes Overhead electric lines [X] No ______ ft [ ] Yes Train rails [X] No ______ ft [ ] Yes Walls/foundations [X] No ______ ft [ ] Yes Bridges [X] No ______ ft [ ] Yes Wooden posts/utility poles [X] No ______ ft [ ] Yes Railroad Crossings [X] No ______ ft [ ] Yes Corrosion protection systems (such as for pipe) [X] No ______ ft [ ] Yes Other: ______ [ ] No ______ ft [ ] Yes
12	When does groundwater interfere with the use of this technology?	[ ] Never [X] If target is several feet below the WT, depending on [ ] Always

Comments Regarding Limitations:

D. Results/Data Processing

1	Is the equipment used for collecting data able to produce the location of the utility without further analysis?	[X] Yes [ ] No
2	What information does this technology produce either during testing or after analysis/processing?	[X] Yes Horizontal position [ ] No [X] Yes Vertical position [ ] No
3	What is the accuracy of the position obtained from testing?	Horizontal: .5 toot Vertical: .5 toot *(please specifcy units)*
4	Data gathered using this technology can produce the following:	[X] Visual of the horizontal and vertical position (any kind of map, chart, etc.) [X] Physical or visual markings in the field [X] Images [X] Non-visual results (data files, coordinates) [X] 2D plan showing location [X] Digital model (e.g. CAD) [ ] Other, ______
5	Does data collected in the field require further analysis to determine the location of buried assets?	[X] No [ ] Yes
6	Is training required to analyze the results?	[ ] No [X] Yes
7	If you answered Yes to #6, how much?	[ ] 0 - 1 hour [ ] 2 - 4 hours [X] > 4 hours
8	Is a Professional License required to analyze the data?	[X] No [ ] Yes
9	What kind of software is required to view the data?	[ ] Off-the-shelf, must be purchased [X] Specialized, or developed by data collection firm [ ] Applications that can be expected at an engineering firm (such as CAD) [ ] Other: ______

Comments Regarding Data/Results Processing:

#3 depends on what antenna is being used. Values stated are for 400 MHz antenna, typically used for utility surveys.

E. Comments, Other Information, Special Instructions or Remarks

Appendix E

Completed Economic Evaluations

ECONOMIC EVALUATION

Type of Technology: Electromagnetics

Date: 5/7/09

Manufacturer: Geonics

Evaluator: 1101

Model/Style: EM61-mk2 System

Position: Geophysicist

1	Based on required equipment, mobility, traffic interferences and other disruptions, what is the estimated socioeconomic impact of using this technology to locate buried utilities?	[X] Low [ ] Medium [ ] High
2	How does an increase in the density of utilities affect the unit cost of locating using this technology?	[ ] Increases unit cost [ ] Decreases unit cost [X] Has no effect OR unit cost is fixed
3	Are ancillary costs, such as per diem, equipment rental, travel, and mobilization included in the unit cost?	[ ] Yes [X] No [ ] Yes, these are: equipment fees are included
5	What types of contract do you typically use for performing work with this type of technology?	[X] Lump Sum [ ] Negotiated Price [ ] Unit Price [ ] Other, ______
6	Are additional fees administered for data analysis?	[X] No [ ] Yes
7	In comparison to other technologies available for locating buried utilities that you use, please rank them from most expensive to least expensive.	most 1. SIR-3000 2. EM61 3. Gemini-3 4. 5. least
8	How does the complexity of the buried utility effect the unit cost of locating using this technology?	[ ] Increases unit cost with complexity [ ] Decreases unit cost with complexity [X] Has no effect OR unit cost is fixed
9	Additional factors that would affect the unit cost of performing work using this technology	rain/lightning can slow down the data acquisition see below

10	What is the total unit cost of performing work using this technology, regardless of payment method or contract type, and including all fees? (for example, for a lump sum contract the toal $ divided by number of units tested = unit cost; direct unit cost charged; etc.)	$3,500 dollars per day unit time

Comments Regarding Testing Cost:

Cost is really a factor of time, not distance. Some sites you can collect 10 miles of data in a day, some you can only collect 1 mile of data in a day. How much data is collected is also highly dependent on the proficiency of the operator. I have changed the cost above to reflect a unit time, instead of a unit dist. The cost above also does not include travel, per diem, or mobilization costs, since one day of work in the same town as we're located would not have travel or per diem costs, but a 13 day job in Afghanistan would have significant travel costs.

ECONOMIC EVALUATION

Type of Technology: Electromagnetics

Date: 5/7/09

Manufacturer: Fisher

Evaluator 1101

Model/Style: Fisher Gemini-3

Position: Geophysicist

1	Based on required equipment, mobility, traffic interferences and other disruptions, what is the estimated socioeconomic impact of using this technology to locate buried utilities?	[X] Low [ ] Medium [ ] High
2	How does an increase in the density of utilities affect the unit cost of locating using this technology?	[X] Increases unit cost [ ] Decreases unit cost [ ] Has no effect OR unit cost is fixed
3	Are ancillary costs, such as per diem, equipment rental, travel, and mobilization included in the unit cost?	[ ] Yes [X] No [ ] Yes, these are: equipment fees are included
5	What types of contract do you typically use for performing work with this type of technology?	[X] Lump Sum [ ] Negotiated Price [ ] Unit Price [ ] Other, ______
6	Are additional fees administered for data analysis?	[X] No [ ] Yes Not applicable
7	In comparison to other technologies available for locating buried utilities that you use, please rank them from most expensive to least expensive.	most → least 1. SIR-3000 2. EM61 3. Gemini-3 4. 5.
8	How does the complexity of the buried utility effect the unit cost of locating using this technology?	[X] Increases unit cost with complexity [ ] Decreases unit cost with complexity [ ] Has no effect OR unit cost is fixed
9	Additional factors that would affect the unit cost of performing work using this technology	see below

10	What is the total unit cost of performing work using this technology, regardless of payment method or contract type, and including all fees? (for example, for a lump sum contract the toal $ divided by number of units tested = unit cost; direct unit cost charged; etc.)	$1,500 dollars per day unit time

Comments Regarding Testing Cost:

ECONOMIC EVALUATION

Type of Technology: Ground Penetrating Radar

Date: 5/7/09

Manufacturer: Geophysical Survey Systems (GSSI)

Evaluator: 1101

Model/Style: SIR-3000 System

Position: Geophysicist

1	Based on required equipment, mobility, traffic interferences and other disruptions, what is the estimated socioeconomic impact of using this technology to locate buried utilities?	[X] Low ☐ Medium ☐ High
2	How does an increase in the density of utilities affect the unit cost of locating using this technology?	[X] Increases unit cost ☐ Decreases unit cost ☐ Has no effect OR unit cost is fixed
3	Are ancillary costs, such as per diem, equipment rental, travel, and mobilization included in the unit cost?	☐ Yes [X] No ☐ Yes, these are: equipment fees are included
5	What types of contract do you typically use for performing work with this type of technology?	[X] Lump Sum ☐ Negotiated Price ☐ Unit Price ☐ Other, ______________
6	Are additional fees administered for data analysis?	[X] No ☐ Yes
7	In comparison to other technologies available for locating buried utilities that you use, please rank them from most expensive to least expensive.	most → least 1. SIR-3000 2. EM61 3. Gemini-3 4. 5.
8	How does the complexity of the buried utility effect the unit cost of locating using this technology?	[X] Increases unit cost with complexity ☐ Decreases unit cost with complexity ☐ Has no effect OR unit cost is fixed
9	Additional factors that would affect the unit cost of performing work using this technology	rain/lightning slows down data collection see below

10	What is the total unit cost of performing work using this technology, regardless of payment method or contract type, and including all fees? (for example, for a lump sum contract the toal $ divided by number of units tested = unit cost; direct unit cost charged; etc.)	$4,000 dollars per day unit time

Comments Regarding Testing Cost:

Cost is really a factor of time, not distance. Some sites you can collect 10 miles of data in a day, some you can only collect 1 mile of data in a day. How much data is collected is also highly dependent on the proficiency of the operator. I have changed the cost above to reflect a unit time, instead of a unit distance. The cost above also does not include travel, per diem, or mobilization costs, since one day of work in the same town as we're located would not have travel or per diem costs, but a 13 day job in Afghanistan would have significant travel costs.

APPENDIX F

VT PALMS INTRODUCTION SHEET

Virginia Tech

Program *for* Asset Locating Method Selection

A Decision Support Tool for Utility Engineering

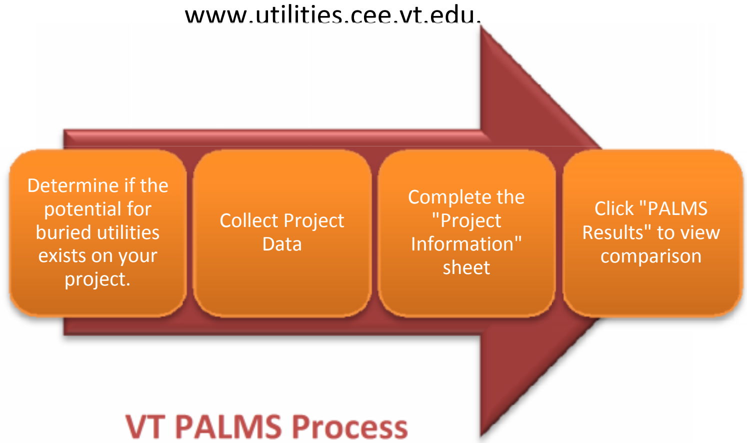
Instructions

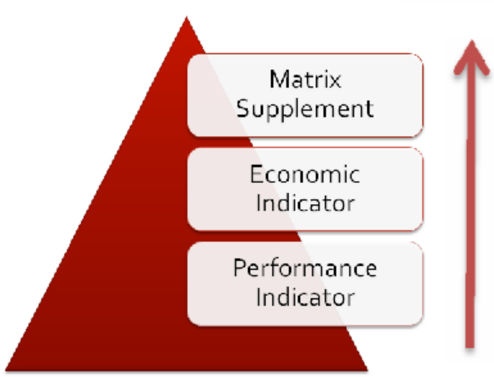
Welcome to the VT PALMS Program for evaluating subsurface utitlity engineering locating technology. This program is an Excel 2007 Macro Enabled-based workbook and may not work to the full capacity with previous versions. To begin, click on the maroon "Project Info Sheet" tab below. The standardized questions help to define your project and compare the existing conditions to the capabilities of the technologies within the database . Once you've answered all the questions, click on the orange "PALMS Results" tab to see the results displayed in a graphical form and a detailed matrix view.

Each time the answer to a question on the Project Info Sheet is changed the results are updated automatically, if they change at all. You must click "Save A Copy" in order to save the PALMS Results and Project Info Sheet . The workbook does not store more than the current data entered into the Project Info Sheet and the associated Results.

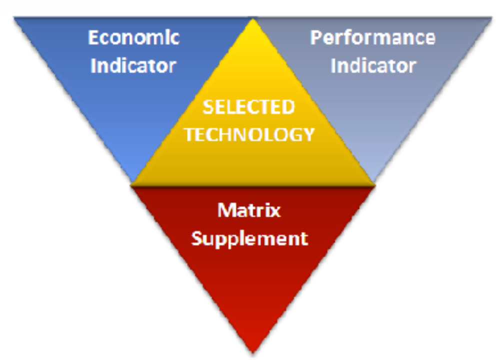
IMPORTANT: YOU MUST ANSWER ALL QUESTIONS ON THE PROJECT INFO SHEET TO HAVE THE MOST ACCURATE RESULTS.

Detailed information on the program, theory behind development, evaluations of technologies, explanation of questions and answers, and other research projects relating to subsurface utility engineering can be found online at www.utilities.cee.vt.edu.





Depiction of the relative importance of each results display.



Use the Performance and Economic Indicators first to select a technology and then verify with the Matrix Supplement.

Appendix G

VT PALMS Project Information Sheet

Virginia Tech

Program *for* Asset Locating Method Selection

A Decision Support Tool for Utility Engineering

Project Information Sheet

Project Name/No.: ______________ Date: ______________

Location: ______________ Client: ______________

1. What is the minimum horizontal clearance for the entire site where locating would occur (in feet)? ______________
2. What is the minimum vertical clearance for the entire site where locating would occur (in feet)? ______________
3. How much does the surface of the site slope where utilities are to be located? ______________
4. Approximate width (or diameter) of utility being located. ______________
5. Approximate depth of utilities to be located (in feet). ______________
6. What type of objects are suspected to be located within the locating area?

- ☐ Pipes
- ☐ Conduits
- ☐ Cable/Wire
- ☐ Vaults/Boxes
- ☐ Valves/Components

7. What type of utilities are suspected on the site? ______________
8. Are metallic and non-metallic utilities suspected to be co-located? ______________
9. What type of equipment can access the site for testing? ______________
   Note: Mobile/Single Location refers to tests that can only be conducted in one particular location at a time, such as vacuum excavation
10. What type of surface is present above the utilities? ______________
11. Do you require the locating to provide the results of the locating of the utility in the field, without further analysis in the office, lab, etc.? ______________
12. What is the approximate distance from the structures to the locating area?
    Leaving blank also indicates there are none of that particular structure nearby where the locating is to occur. Enter "0" if the testing will cross the particular object.

________	Guardrail	________	Train Rails
________	Hydrants/Pipe Stems	________	Walls/Foundations
________	Sign Posts (metal)	________	Bridges
________	Traffic Signal Boxes	________	Wooden Posts/Utility Poles
________	Light Poles (metal)	________	Railroad Crossings
________	Buried Traffic Sensors	________	Corrosion Protection Systems
________	Overhead Electric Lines		

13. Are groundwater levels close to the surface (within the depth of buried utilities)? ________________
    If so, at what depth (in feet, with 0 being the gound surface)? ________

14. Are any of the following bodies of water located directly in or in close proximity to the locating area?

- ☐ Lakes
- ☐ Ponds
- ☐ Marshlands/Swamps
- ☐ Surface Water, Ponding
- ☐ Surface Water, Flowing
- ☐ Streams, <= 10 gpm flow
- ☐ Streams, > 10 gpm flow

15. What is the primary soil type located on the site? ________________
16. Are any of these natural materials present in the area where testing will occur? ________________

APPENDIX H

SAMPLE VT PALMS PROJECT INFORMATION SHEET

VT PALMS

Virginia Tech
Program *for* Asset Locating Method Selection

A Decision Support Tool for Utility Engineering

Project Information Sheet

Project Name/No.: ______________________ Date: ______________________

Location: ______________________ Client: ______________________

1. What is the minimum horizontal clearance for the entire site where locating would occur (in feet)? **30**
2. What is the minimum vertical clearance for the entire site where locating would occur (in feet)? **6**
3. How much does the surface of the site slope where utilities are to be located? **> 1:1 Slope**
4. Approximate width (or diameter) of utility being located. **1 inch or less**
5. Approximate depth of utilities to be located (in feet). **8**
6. What type of objects are suspected to be located within the locating area?

- [x] Pipes
- [ ] Conduits
- [x] Cable/Wire
- [x] Vaults/Boxes
- [ ] Valves/Components

7. What type of utilities are suspected on the site? **Both**
8. Are metallic and non-metallic utilities suspected to be co-located? **Yes**
9. What type of equipment can access the site for testing? **ATV/Truck Mounted**
   Note: Mobile/Single Location refers to tests that can only be conducted in one particular location at a time, such as vacuum excavation
10. What type of surface is present above the utilities? **Asphalt**
11. Do you require the locating to provide the results of the locating of the utility in the field, without further analysis in the office, lab, etc.? **Yes**
12. What is the approximate distance from the structures to the locating area?
    Leaving blank also indicates there are none of that particular structure nearby where the locating is to occur. Enter "0" if the testing will cross the particular object.

1	Guardrail	8	Train Rails
2	Hydrants/Pipe Stems	9	Walls/Foundations
3	Sign Posts (metal)	0	Bridges
4	Traffic Signal Boxes	11	Wooden Posts/Utility Poles
5	Light Poles (metal)	22	Railroad Crossings
6	Buried Traffic Sensors	33	Corrosion Protection Systems
7	Overhead Electric Lines		

13. Are groundwater levels close to the surface (within the depth of buried utilities)? Yes

    If so, at what depth (in feet, with 0 being the gound surface)? **Enter Value-->** 25

14. Are any of the following bodies of water located directly in or in close proximity to the locating area?

    - [x] Lakes
    - [x] Ponds
    - [x] Marshlands/Swamps
    - [x] Surface Water, Ponding
    - [x] Surface Water, Flowing
    - [x] Streams, <= 10 gpm flow
    - [x] Streams, > 10 gpm flow

15. What is the primary soil type located on the site? Silt
16. Are any of these natural materials present in the area where testing will occur? Grasses, <= 6 inches high

APPENDIX I

VT PALMS RESULTS SUMMARY SHEET

Virginia Tech
Program *for* **A**sset **L**ocating **M**ethod **S**election

A Decision Support Tool for Utility Engineering

Project Summary Sheet

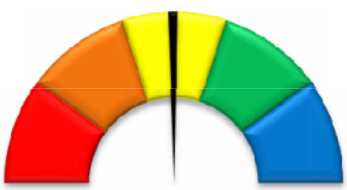
Project Name/No.: ________________ **Date:** ________________

Location: ________________ **Client:** ________________

GPR

50 %

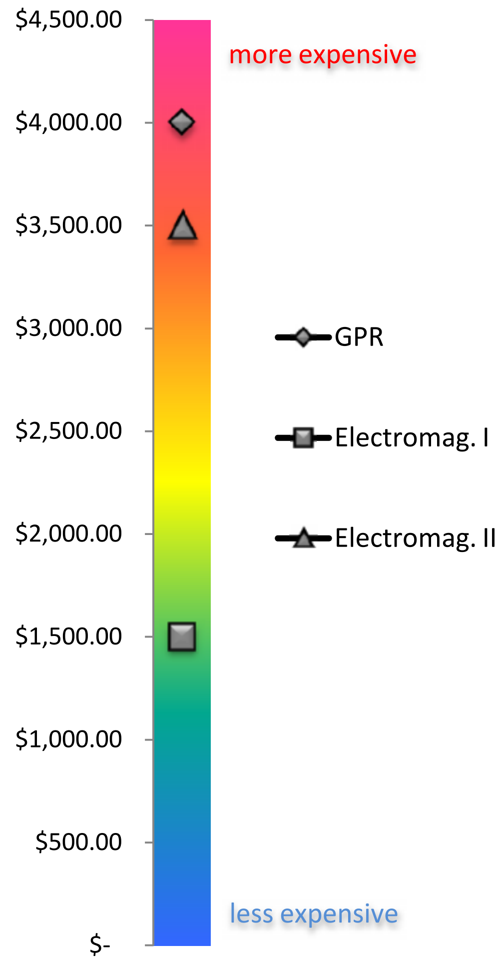
Electromag. I



50 %

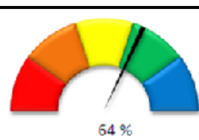
Electromag. II

50 %



Comparative Unit Cost, $

Scales and Indicator Key



Performance Indicator

Economic Indicator

Not Applicable	Poor	Fair	Good	Excellent

Project Summary Sheet - Detail View

Question & Description / Technology		GPR	Electromag. I	Electromag. II
1.	Horizontal Clearance	X	X	X
2.	Vertical Clearance	X	X	X
3.	Topography	X	X	X
4.	Object Size, Metallic	X	X	X
	Object Size, Non-Metallic	X	X	X
5.	Object Depth			
6.	Metallic: Pipes			
	Conduits			
	Cable/Wire			
	Vaults/Boxes			
	Valves/Components			
	Nonmetallic: Pipes			
	Conduits			
	Cable/Wire			
	Vaults/Boxes			
	Valves/Components			
7.	Looking for metallic	X	X	X
	Looking for non-metallic	X	X	X
8.	M/NM Pipes Colocated			
	M/NM Conduits Colocated			
	M/NM Cable/Wire Colocated			
	M/NM Vaults/Boxes Colocated			
	M/NM Valves/Components Coloca			
9.	ATV/Truck			
	Remotely Operated Machine			
	Operator & Mobile Equipment			
	Equipment Operator Holds/Wears			
	Setup/Testing in a Single Location			
10.	Concrete w/remesh			
	Concrete w/rebar			
	Concrete w/steel fibers			
	Unreinforced concrete			
	Asphalt			
	Wood			
	Steel			
	Bick/Clay Tile			
	Soil/Natural Materials			
11.	Produce location in field	X	X	X
12.	Proximity Of: Guardrail			
	Hydrants/Pipe stems			
	Sign Posts (metal)			
	Traffic Signal Boxes			
	Light Poles (metal)			
	Buried Traffic Sensors			

Project Summary Sheet - Detail View

12.	Electric Lines			
	Train Rails			
	Walls/Foundations			
	Bridges			
	Wooden Posts/Utility Poles			
	Railroad Crossings			
	Corrosion Protection Systems			
13.	Depth Groundwater Interferes			
14.	Interference: Lakes			
	Ponds			
	Marshes/Swamps			
	Surface water, ponding			
	Surface water, flowing			
	Streams, >= 10 gpm			
	Streams, < 10 gpm			
15.	Clay			
	Silt			
	Sand			
	Gravel			
	Organics/Topsoil			
	Loam/Loess			
	Partially Weathered Rock			
	Intact Rock			
16.	Grasses <= 6 inches high			
	Grasses > 6 inches high			
	Shrubs/woody plants			
	Trees, <= 10 feet tall			
	Trees, > 10 feet tall			
	Flowers/soft stem plants			
	Leaves			
	Fallen sticks/branches			
	Loose rock (size > gravel)			

X Indicates Potential Source of Interference with Testing or Option is Not Available (such as the use of remote controlled equipment).

NOTES:

CAUTION: Several factors are seen to be a potential cause of disruption or the desireable options are not available when using GPR to locate buried utilities on this project. Further evaluation should be conducted to ensure problems do not exist in the field with the parameters indicated above.

CAUTION: Several factors are seen to be a potential cause of disruption or the desireable options are not available when using Electromag. I to locate buried utilities on this project. Further evaluation should be conducted to ensure problems do not exist in the field with the parameters indicated above.

CAUTION: Several factors are seen to be a potential cause of disruption or the desireable options are not available when using Electromag. II to locate buried utilities on this project. Further evaluation should be conducted to ensure problems do not exist in the field with the parameters indicated above.

APPENDIX J

SAMPLE VT PALMS RESULTS SUMMARY

Virginia Tech

Program *for* Asset Locating Method Selection

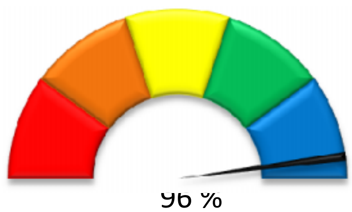
A Decision Support Tool for Utility Engineering

Project Summary Sheet

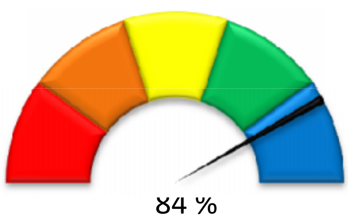
Project Name/No.: Road Widening | **Date:** October 12, 20XX

Location: Alexandria, Virginia | **Client:** State DOT

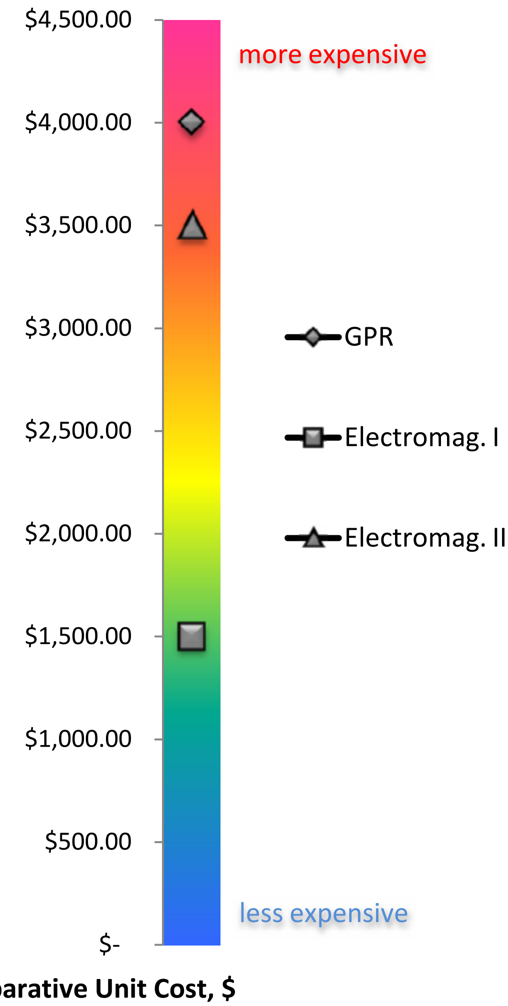
GPR



Electromag. I



Electromag. II



Scales and Indicator Key

Performance Indicator

Economic Indicator

Not Applicable	Poor	Fair	Good	Excellent

Project Summary Sheet - Detail View

	Question & Description / Technology	GPR	Electromag. I	Electromag. II
1.	Horizontal Clearance		X	
2.	Vertical Clearance			
3.	Topography			
4.	Object Size, Metallic		X	
	Object Size, Non-Metallic	X		
5.	Object Depth			
6.	Metallic: Pipes			
	Conduits			
	Cable/Wire		X	
	Vaults/Boxes			
	Valves/Components			
	Nonmetallic: Pipes			
	Conduits			
	Cable/Wire			
	Vaults/Boxes			
	Valves/Components			
7.	Looking for metallic			
	Looking for non-metallic		X	X
8.	M/NM Pipes Colocated			
	M/NM Conduits Colocated			
	M/NM Cable/Wire Colocated			
	M/NM Vaults/Boxes Colocated			
	M/NM Valves/Components Coloca			
9.	ATV/Truck			
	Remotely Operated Machine			
	Operator & Mobile Equipment			
	Equipment Operator Holds/Wears			
	Setup/Testing in a Single Location			
10.	Concrete w/remesh			
	Concrete w/rebar			
	Concrete w/steel fibers			
	Unreinforced concrete			
	Asphalt			
	Wood			
	Steel			
	Bick/Clay Tile			
	Soil/Natural Materials			
11.	Produce location in field			X
12.	Proximity Of: Guardrail			X
	Hydrants/Pipe stems			
	Sign Posts (metal)			
	Traffic Signal Boxes			
	Light Poles (metal)			
	Buried Traffic Sensors			

Project Summary Sheet - Detail View

12.	Electric Lines			
	Train Rails			
	Walls/Foundations			
	Bridges			
	Wooden Posts/Utility Poles			
	Railroad Crossings			
	Corrosion Protection Systems			
13.	Depth Groundwater Interferes			
14.	Interference: Lakes			
	Ponds			
	Marshes/Swamps			
	Surface water, ponding			
	Surface water, flowing			
	Streams, >= 10 gpm			
	Streams, < 10 gpm			
15.	Clay			
	Silt			
	Sand			
	Gravel			
	Organics/Topsoil			
	Loam/Loess			
	Partially Weathered Rock			
	Intact Rock			
16.	Grasses <= 6 inches high			
	Grasses > 6 inches high			
	Shrubs/woody plants			
	Trees, <= 10 feet tall			
	Trees, > 10 feet tall			
	Flowers/soft stem plants			
	Leaves			
	Fallen sticks/branches			
	Loose rock (size > gravel)			

X Indicates Potential Source of Interference with Testing or Option is Not Available (such as the use of remote controlled equipment).

NOTES:

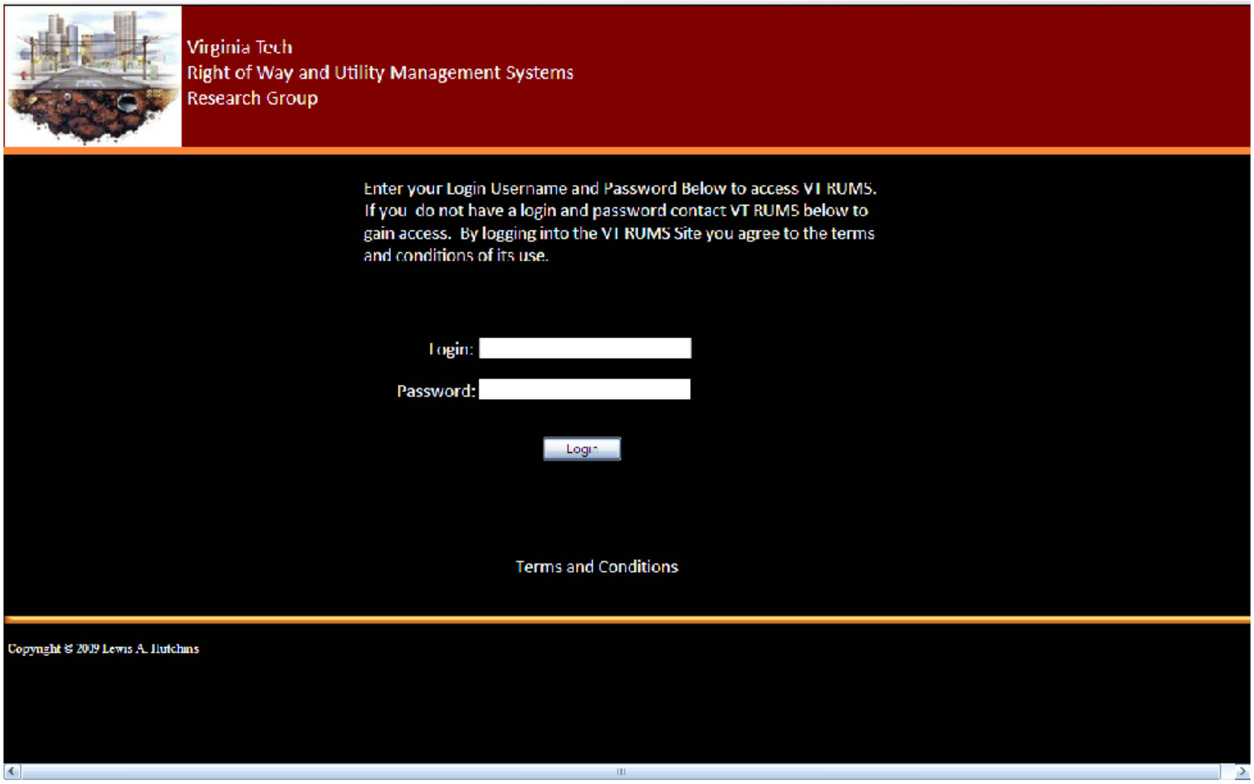
CAUTION: Several factors are seen to be a potential cause of disruption or the desireable options are not available when using GPR to locate buried utilities on this project. Further evaluation should be conducted to ensure problems do not exist in the field with the parameters indicated above.

CAUTION: Several factors are seen to be a potential cause of disruption or the desireable options are not available when using Electromag. I to locate buried utilities on this project. Further evaluation should be conducted to ensure problems do not exist in the field with the parameters indicated above.

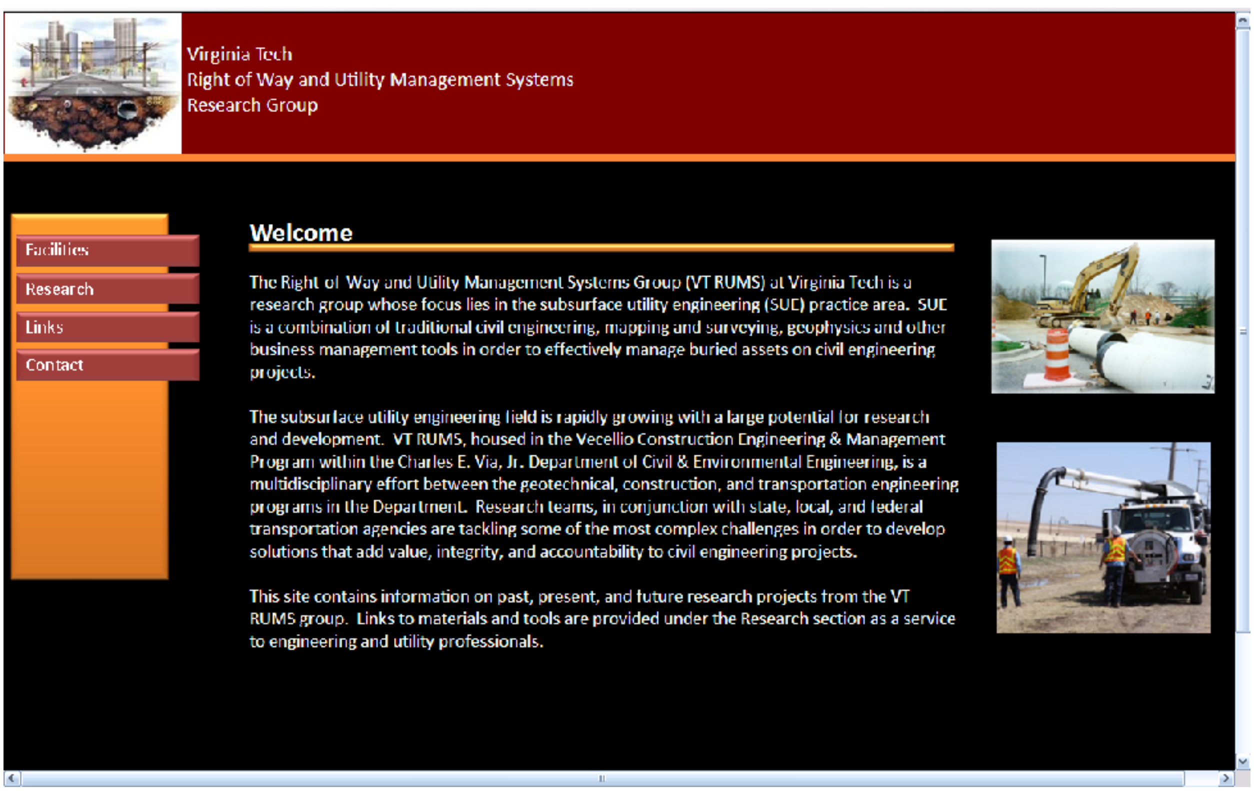
CAUTION: Several factors are seen to be a potential cause of disruption or the desireable options are not available when using Electromag. II to locate buried utilities on this project. Further evaluation should be conducted to ensure problems do not exist in the field with the parameters indicated above.

APPENDIX K

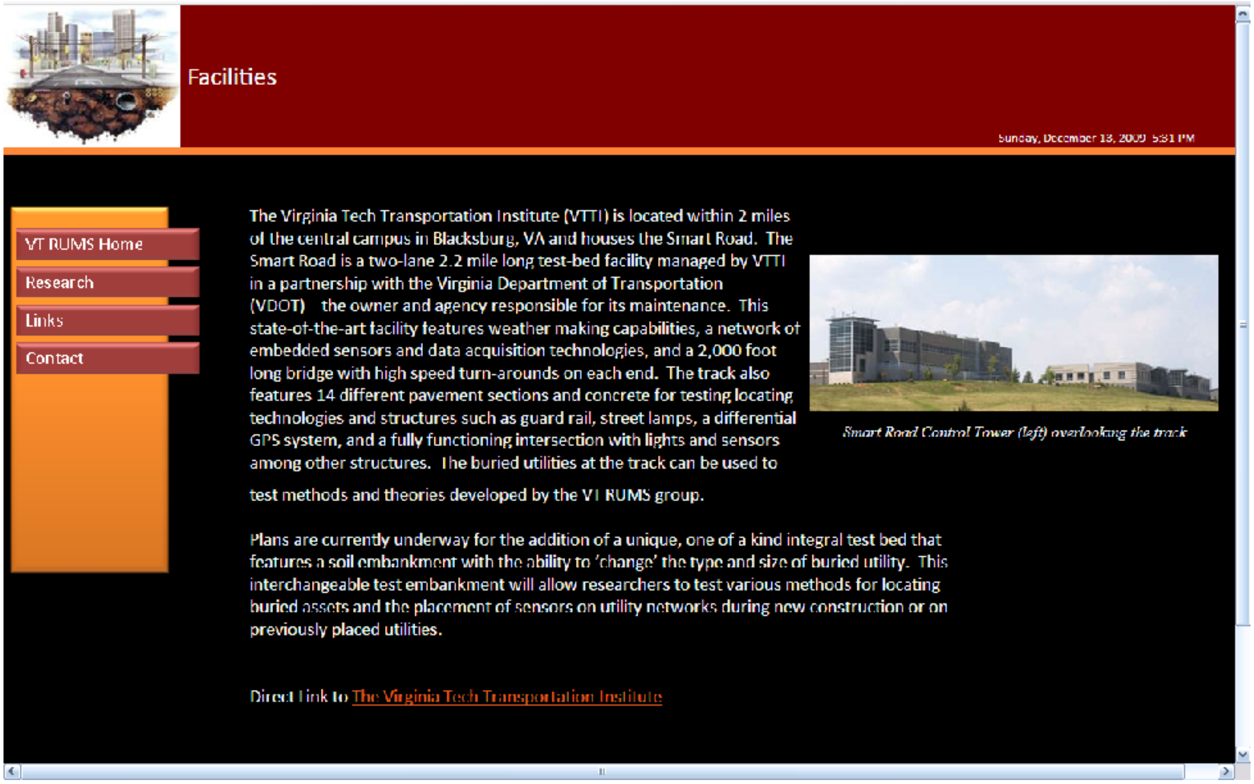
SCREENSHOT OF VT RUMS WEBSITE



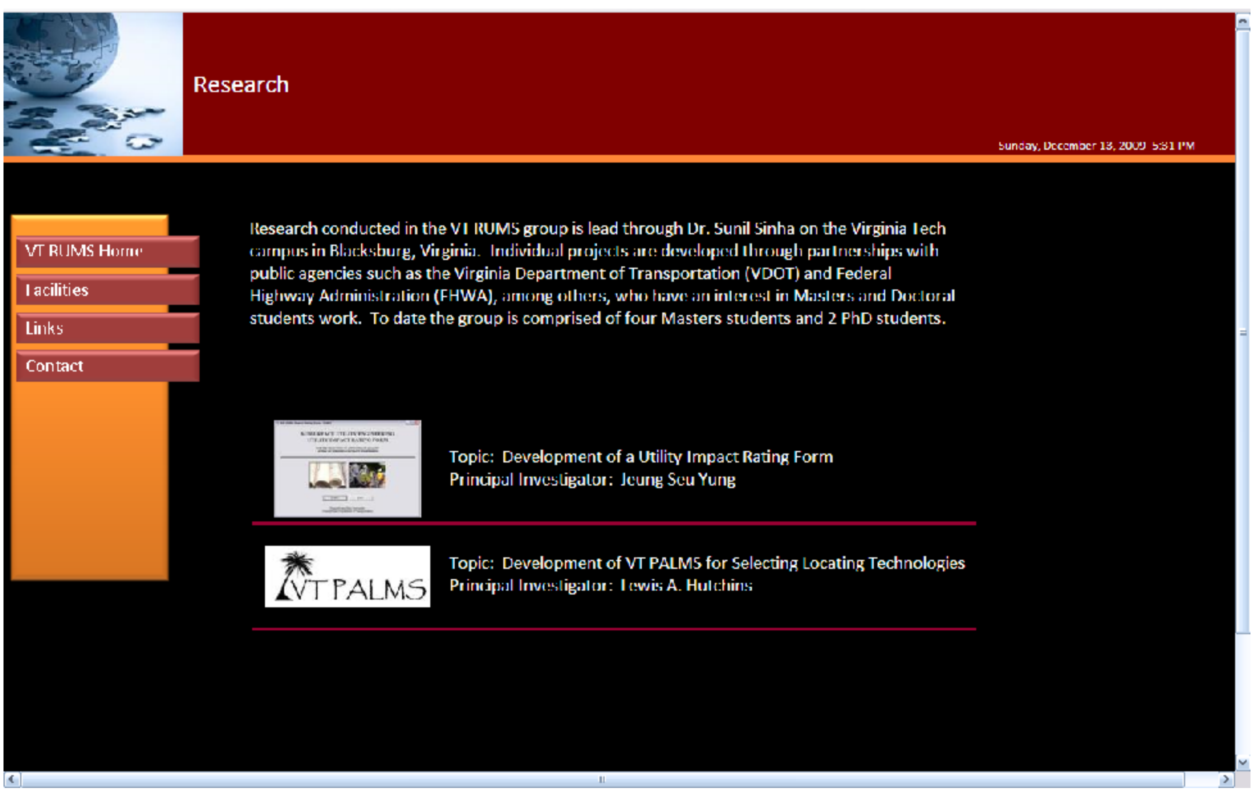
Login Screen



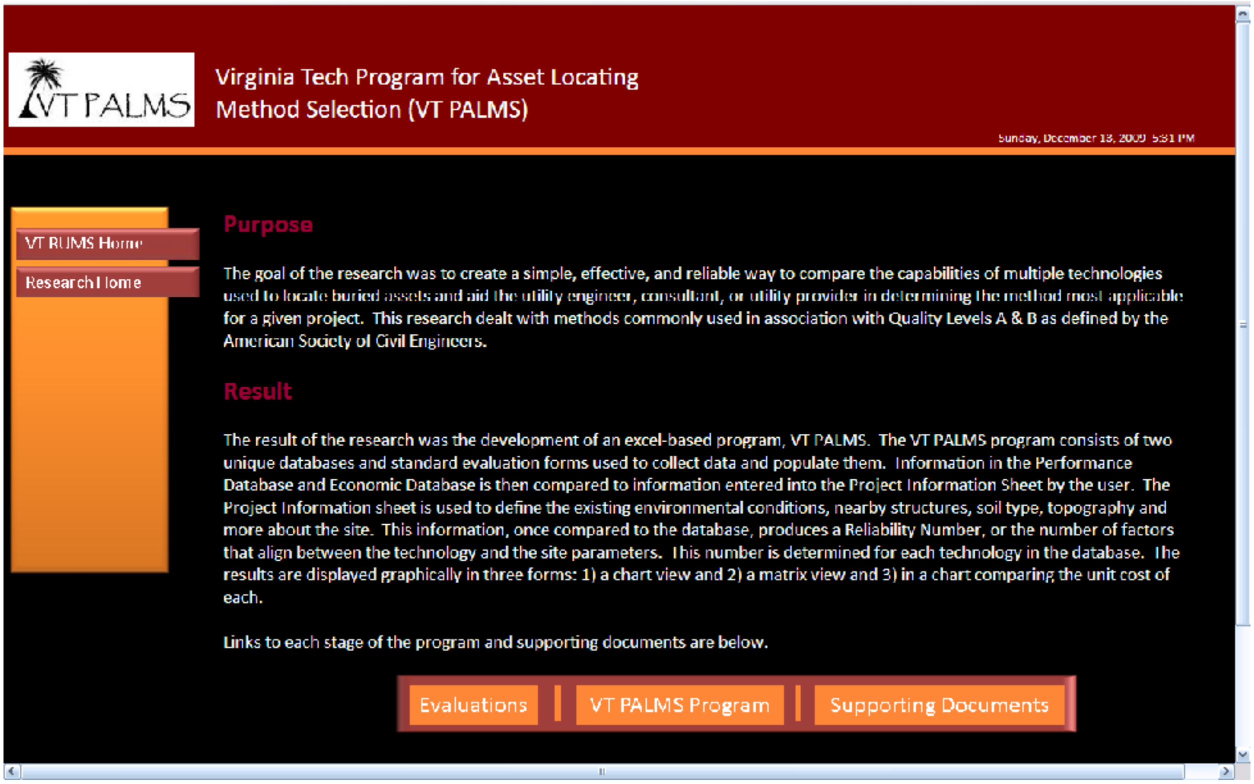
VT RUMS Home



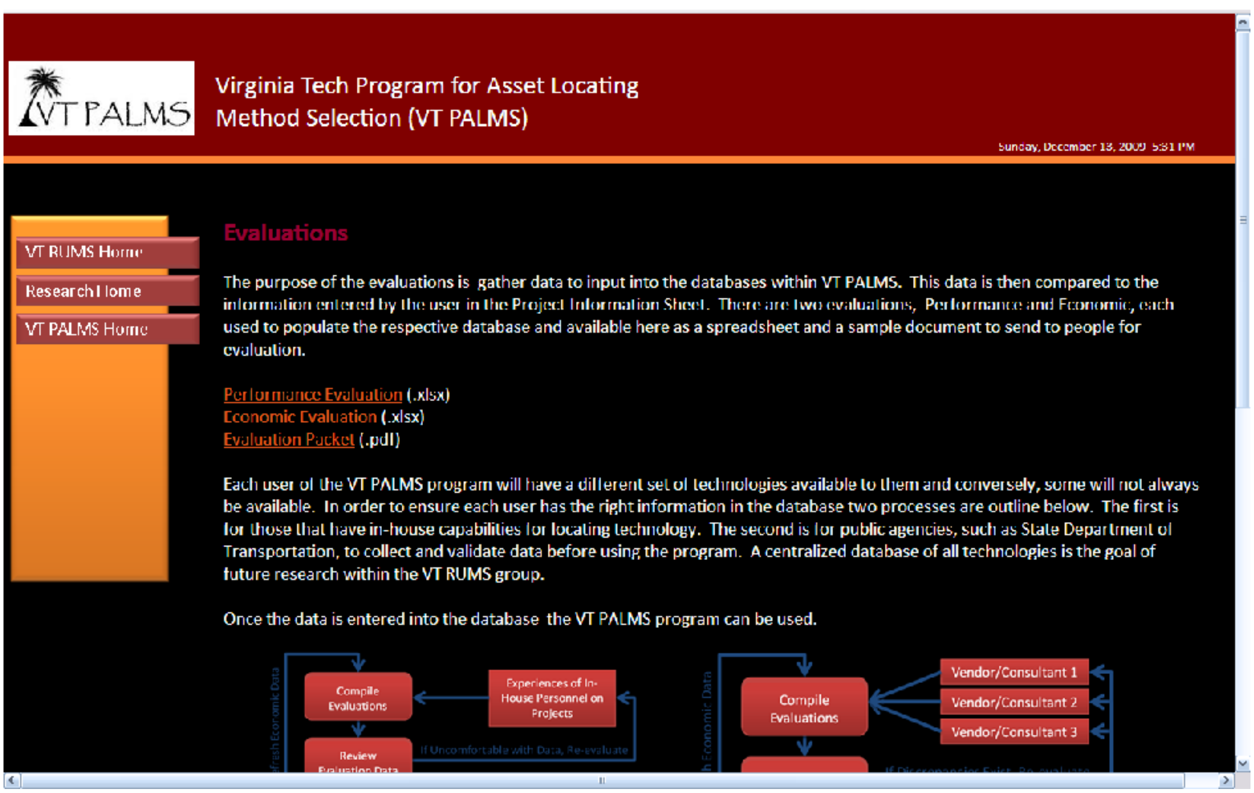
Facilities Page



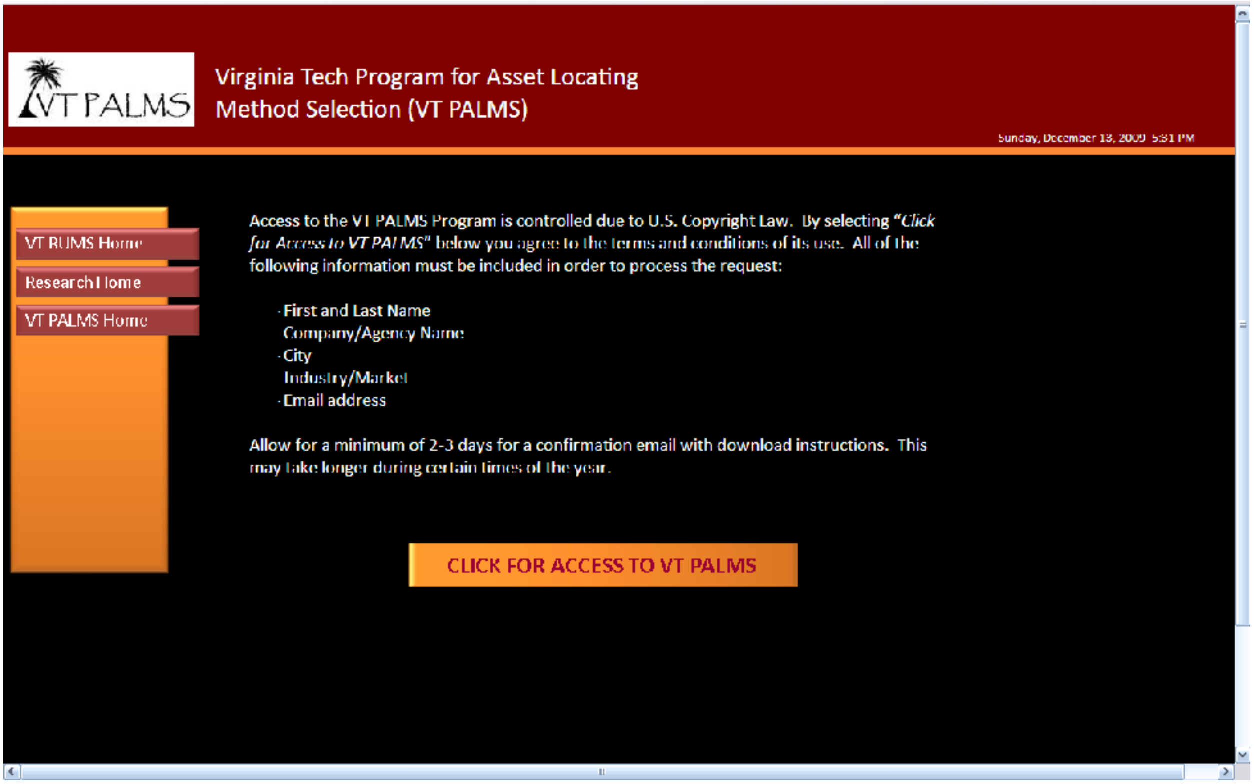
VT RUMS Research Home



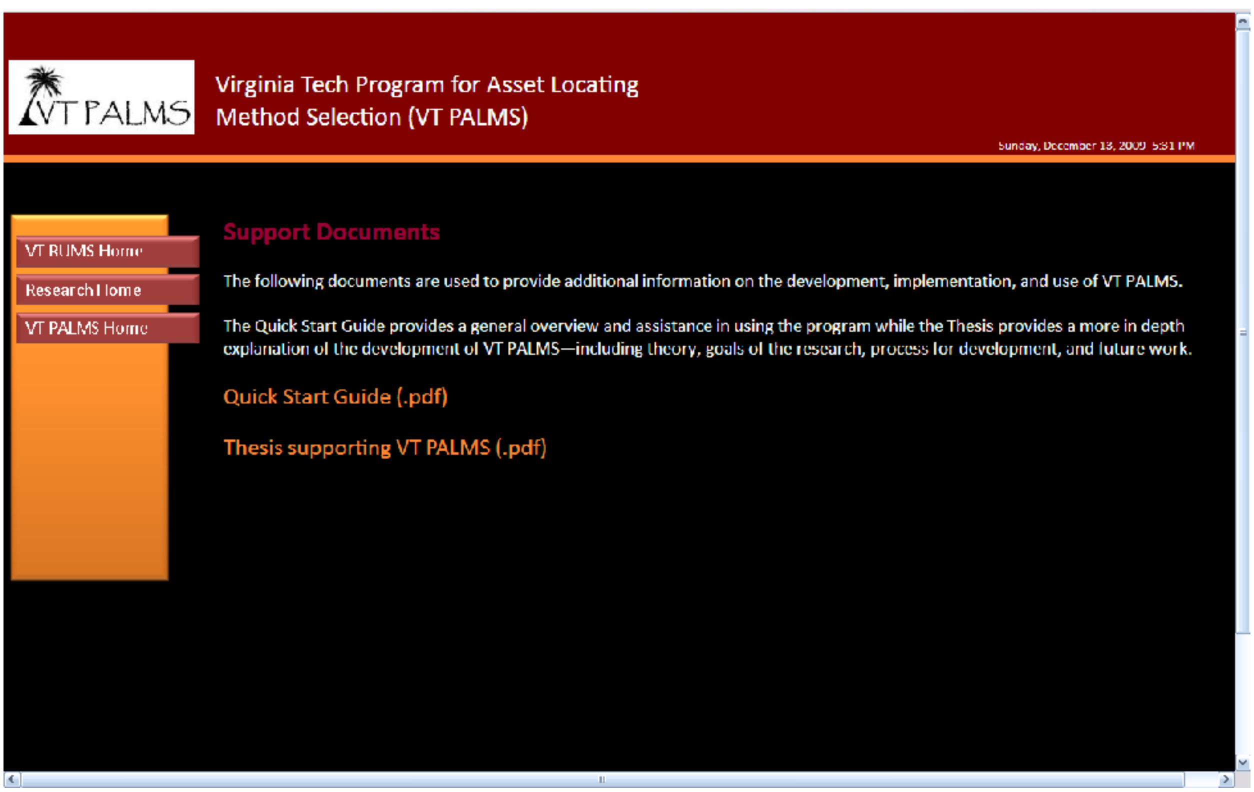
VT PALMS Home



Portion of Evaluations Page



VT PALMS Access Page (generates email to verify credentials before allowing the user to download).



Supporting Documents (such as thesis and Quick Start Guide)