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ABSTRACT

Accurate locations of buried utility infrastructures are very important for utility owners, utility managers and engineers, designers, and contractors that perform new installations, repairs, and maintenances in highway projects. A lack of reliable information on underground utilities not only can result in property damages, construction delays, design changes, claims, injuries, and even deaths, but also cause traffic delays, local business disruptions, environmental problems, and utility service breakdowns. Subsurface Utility Engineering (SUE) is an engineering process to reduce the potential of underground utility conflicts in the project planning phase. SUE utilizes new and existing technologies to accurately identify, characterize, and map underground utilities with three major activities including designating utilities, locating utilities, and data management. SUE can be the most suitable method for mitigating risks associated with uncertain underground information. Although many damage prevention practices have existed, the damage prevention practice using the SUE concept has not been developed for contractors, designers, engineers, and other stakeholders associated with or impacted by underground utilities. This study focuses on an in-depth analysis of SUE projects executed by Penn DOT districts. Based on this analysis and the utility impact score which refers to utility complexity at the construction site, a decision-support tool called utility impact rating form has been developed to determine which projects should include SUE and identify the appropriate levels of SUE investigation to be
used. The computerized utility impact rating form is developed using Visual Basic software to provide a graphical interface for the purpose of enhancing the efficiency of the calculation and selection processes. A detailed benefit-cost analysis is also performed on twenty-two SUE projects and eight non-SUE projects. All of the projects show a strong relationship between SUE benefit-cost ratio and complexity level of buried utilities. The analysis clearly indicates that there is no relationship between SUE benefit-cost ratio and project cost and also no relationship between complexity level of buried utilities and project cost. The conclusion of this study is that SUE quality levels A and B should be based on the complexity of the buried utilities at the construction site to minimize associated risks and obtain maximum benefits.
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CHAPTER 1
INTRODUCTION

The first chapter presents the background and objectives of this study. Overall organization of the study is provided in the end of this chapter.

1-1. BACKGROUND

Nearly 20 million miles of underground pipelines, cables, and wires in the United States have been built since World War II and designed for lifetimes of 20-50 years (Sterling 2000). Increased population and industrial expansion have increased demands on the underground utilities, and numerous underground projects have been developed to meet the demands. In this study, underground projects mean construction projects including any excavations. However, the expansion of underground projects has resulted in underground utility conflicts that might cause increased construction costs, construction delays, utility damages, change orders, claims, fatal injuries or even deaths of workers, outages of facility service, and other social and environmental problems. In particular, damage to underground utilities has been identified as one of the most dangerous problems for the construction industry.

Doctor et al. (1995) reported that the number of U.S. utility damages in 1993 was more
than 104,000 hits, and third-party damages by gas pipeline hits exceeded $83 million of the total damage cost. Nelson and Daly (1998) stated that cable damages in U.S. The western exceeded 2,000 hits in one month and averaged over 1,000 hits per month. In March 1999, a telephone utility hit cut-off service for 12,000 customers in Colorado. In general, statistics of reported damages may be underreported, because social costs such as traffic delay cost and business impact cost and environmental costs due to utility damage are not properly quantified. Heinrich (1996) stated that an accident cost reported as $15,000 was actually closer to $313,000, almost 20 times higher than the reported cost. The American Institute of Constructors (AIC) also identified damage to underground utilities as the third most important crisis for contractors (Reid 1999). Therefore, damage prevention to underground utilities must be one of the most critical issues for owners, designers, and contractors to pursue successful underground projects.

The design of underground utility projects has traditionally relied on existing records or one-call systems. However, existing information on underground utilities is commonly incorrect, incomplete, and inadequate in as-built drawings and composite drawings, which incorporate all of the utility records for different owners. Existing records and visible feature surveys by site visit are typically 15-30% off the mark and sometimes considerably worse (Stevens and Anspach 1993). Thus, the one-call system was developed to overcome the limitations of using existing records and site visits.
The one-call system is a state-regulated program that requires utility owners to mark the locations of their utilities on the ground surface around any proposed excavation area. However, the information provided by the one-call system commonly is not enough to accurately locate underground utilities. Sterling (2000) reported that 56% of the gas pipeline damages in 1995 happened under the one-call system and 25% of hits on existing utilities were due to mislocations. He also stated that there are several inadequacies of current one-call systems in use by the industry.

As a more systemic damage prevention concept for underground utilities, subsurface utility engineering (SUE) was introduced about two decades ago. SUE is an engineering process that utilizes new and existing technologies to accurately identify, characterize, and map underground utilities early in the development of a project. The use of SUE allows not only more effective damage prevention but also more successful completion of underground projects, including roadway/highway projects, underground pipeline projects, and other projects which require any excavations. The successful use of SUE should be initiated with the appropriate selection of SUE quality levels. However, different quality levels and different application conditions pose challenges in selecting the appropriate quality levels.
1-2. OBJECTIVE, SCOPE, AND COMPOSITION OF THE STUDY

A key objective of this study is to develop a decision-support tool for appropriate selection of SUE quality level and a benefit-cost analysis of SUE for highway projects. Based on in-depth analysis of data projects and utility impact scores which refers to utility complexity at the construction site, a decision-support tool, called utility impact rating form, is developed to determine which projects should include SUE and identify the appropriate levels of SUE investigation to be used. The computerized utility impact rating form is developed using Visual Basic software to provide a graphical interface for the purpose of enhancing the efficiency of the calculation and selection processes. A detailed benefit-cost analysis is also performed on twenty-two SUE projects and eight non-SUE projects. In this study, SUE projects mean construction projects which utilize SUE and non-SUE projects mean construction projects which do not utilize SUE. The proposed decision-support tool and the benefit-cost analysis can help owners and designers to effectively select SUE quality levels and enable safer construction conditions.

All project data for this study are provided by Penn DOT. If project data from other states are used for this study, the results can be different because each state has different law/regulations to carry out projects. Thus, the application of the results of this study may be limited to projects conducted in Pennsylvania.

This study is presented in nine chapters. The first chapter presents the introduction,
including the background and the objective of this study. In the second and third chapters, comprehensive information about SUE is presented, including quality levels and geophysical techniques. The fourth chapter provides existing literature reviews about SUE. The fifth chapter explains utility impact rating. The sixth chapter shows and verifies the computerized utility impact rating form, using Visual Basic Software. The seventh chapter explains benefit-cost analysis of SUE and the eighth chapter presents research results; the last chapter summarizes the results of this study and provides recommendations for future studies.
CHAPTER 2
SUBSURFACE UTILITY ENGINEERING

This second chapter provides information needed for a better understanding of the SUE concept. First, traditional practices for locating underground utilities are reviewed to identify current problems, and then SUE is presented as a solution, including quality levels. This chapter also introduces damage prevention guidelines or best practices which have encouraged the use of SUE.

2-1. TRADITIONAL PRACTICES FOR LOCATING UNDERGROUND UTILITIES

The owners and designers traditionally rely on existing records or the one-call system for planning and designing underground projects. However, existing records of underground information are commonly incorrect, incomplete, and inadequate. Even the information provided by the one-call system is commonly incorrect. Utility damages due to inaccurate underground information can be one of the most important issues affecting the successful completion of underground projects. In most states of the United States, contractors are required to have the responsibility to identify, verify, and safely locate all utilities for an underground project. However, contractors commonly are not concerned about the locations of utilities at the planning
phase, and designers also may not make sufficient effort to accurately locate underground utilities and features at the design phase. Information on underground utilities or features may thus be left in a serious state of uncertainty and risk for contractors (Lew 1996).

Conventionally, designers must contact utility owners at the design phase, who mark their existing utility locations on the ground surface under the one-call system. In many cases, the paint marks indicating the particular location of utilities do not agree with the locations of these utilities depicted on the design plans. In addition, when some problems arise during construction, it is difficult to assign the responsibility for the location of utilities. Contractors typically ask for change orders and claims when necessary. The project owners usually are obligated to pay for these change orders and claims due to utilities being treated as a differing or unknown site condition in the standard contract documents (Lew 2000). Therefore, traditional practices for locating underground utilities have led to the assumption that unexpected problems will always arise because of uncertain underground information (Lew 1996).

The one-call system is a damage prevention program regulated by a state law. There is at least one one-call center in every state and in the District of Columbia. The one-call system is operated by funds of members consisting of public utilities and other underground facility owners/operators. The one-call system starts with a call from a contractor, a designer, or other person who is preparing a project that requires an excavation. The call usually should be made at
least 2 or 3 working days before starting the excavation. After receiving the request call, the one-call center identifies potential utility conflicts and notifies facility owners/operators around the proposed construction site. When the facility owners/operators receive the notification from the one-call center, locating crews for the facility are sent to the site to mark the location of their underground utilities on the ground surface with above-ground American Public Works Association (APWA) color-coded markings shown in Table 2-1 (Jeong et al. 2003). After all utilities are marked on the ground surface, the excavation can be started. The completion of locating work should be reported back to the one-call center.

The one-call system is obviously a cornerstone for damage prevention of underground utilities. However, the one-call system is not perfect. Accidents still happen. The one-call system just deals with the information on buried utilities that members of the system provide. In other words, information on existing utilities of many non-members is not available in the one-call system. Sometimes existing facility owners/operators who are notified by the one-call center incorrectly mark or even fail to mark their utility locations. In addition, old utilities that remain active may not be discovered under the one-call system. Timing of utility locations before actual construction also can be a problem, because 2 or 3 days may not be enough for utility companies to accurately locate and mark their underground utilities. Sterling (2000) stated that many contractors do not use the one-call system because of the aforementioned problems.
TABLE 2-1 APWA (American Public Works Association) Color Code

<table>
<thead>
<tr>
<th>Color</th>
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<tbody>
<tr>
<td>Red</td>
<td>Electric Power, Cable, Lighting</td>
<td>Yellow</td>
<td>Gas, Oil, Petroleum, Steam</td>
</tr>
<tr>
<td>Orange</td>
<td>Communication, Alarm, Signal</td>
<td>Blue</td>
<td>Water</td>
</tr>
<tr>
<td>Green</td>
<td>Sewer, Drain</td>
<td>Purple</td>
<td>Reclaimed Water, Irrigation</td>
</tr>
<tr>
<td>Pink</td>
<td>Temporary Survey Marking</td>
<td>White</td>
<td>Proposed Excavitation</td>
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</table>

2-2. SUBSURFACE UTILITY ENGINEERING

American Society of Civil Engineers (ASCE) defines SUE as an engineering process that utilizes new and existing technologies to accurately identify, characterize, and map underground utilities early in the development of a project. SUE was introduced in the 1970s by Henry Stutzman to accurately locate subsurface utilities and record the underground information for increasing safety and reducing economic loss in the project planning phase (http://www.sodeep.com/sue-history.htm). The concept of SUE was developed and systematically put into professional service in the 1980s (Jeong et al. 2004). The County of Fairfax, Virginia, had a contract with So-Deep, Inc. for locating underground utilities in 1982. This was the first governmental SUE contract in the United States. In 1989, the term “Subsurface Utility Engineering” was introduced to the world at the first National Highway/Utility Conference in Cleveland, Ohio. The Federal Highway Administration (FHWA) and state Departments of Transportations (DOTs) have been
promoting its use. FHWA requested proposals for educational and training materials and procurement of guidelines for SUE in 1994. ASCE established the first national standards for SUE. Today, SUE has been used for mitigating risks due to uncertain underground information for FHWA, state DOTs, and many other agencies, as well as engineering companies. SUE is still growing as a significant tool as project owners demand higher quality levels of construction.

2-2-1. SUE Practices in Department of Transportations

According to Jeong’s research in 2004, 22 states in the United States have utilized the SUE program on their highway projects (Jeong et al. 2004). Eight states reported that they considered a pilot project for the use of SUE in the past. The average annual budget for the SUE program in the eight states was about $1.5 million in 2000, $1.7 million in 2001, and $2 million in 2002. The average annual amount spent on the SUE program increased as much as 135% from 2000 to 2002 (Jeong et al. 2004). No states presented a decrease in their SUE budget during this period.

Texas spent more than $6 million annually as the most active state in encouraging the use of SUE for highway projects. Every highway project of Virginia, which has the longest history of the use of SUE, is required by state regulation to use SUE. Delaware, Maine, Maryland, North Carolina, Texas, and Pennsylvania have utilized SUE for most of their highway projects and utility projects. The other states commonly use SUE based on its usefulness. The
common criteria for applying SUE for underground projects are: (1) urban highway projects with a high potential for expected utility conflicts; (2) underground utility projects with congested utility networks and high potential for utility relocations; (3) projects with limited, narrow, and congested right-of-way; and (4) highway projects that have tight schedules (Jeong et al. 2004).

State DOTs with a SUE program have various decision-making processes to determine projects for utilizing the SUE. A project manager and a designer usually make the decision to employ SUE, or local utility agents can be involved in the decision. The central offices of the state DOTs can also make the decision directly. Qualification guidelines for selecting SUE consultants are not yet firmly established in the states. A SUE consultant typically has been selected with the considerations of past experience, availability of key personnel, ability to perform the project, and prior work experience with the DOT (Jeong et al. 2004). Based on FHWA, SUE consultants must be able to demonstrate sufficient knowledge of designating, location, surveying, and data management activities, be well trained and experienced engineers, possess adequate equipment and systems for SUE activity, and have the financial capacity to provide the required services. The ability to provide the required accuracy of SUE services and adequate insurance are also important factors for SUE consultants (FHWA 2002).
2-2-2. SUE Practices in Private Sectors

According to Jeong’s research in 2004, the majority of SUE consultants have been in business less than 10 years; 19% had greater than 10 years and less than 15 years of experience; and 14% of them had more than 15 years (Jeong et al. 2004). They are in a relatively young industry since SUE started to be applied for detecting underground utilities only in the early 1980s; 79% of SUE consultants had annual sales of less than $5 million in the 2001. These consultants can be characterized as small SUE companies. They employ less than 50 people, and their geographical domain is normally regional; 16% of SUE consultants have annual sales between $6 million and $10 million. Typically, 5% of SUE consultants, large companies which provide nationwide SUE, have annual sales more than $10 million and more than 100 employees (Jeong et al. 2004).

The annual sales per employee for SUE activities increase as the size of company increases. Small companies generate an average of $60,063 per employee in a year. In contrast, the large companies create sales of more than $100,000 per employee. The average growth rate of the SUE industry from 1997 to 2001 was 173% in sales. The main reasons for the rapid growth include the spread in awareness of the benefits of SUE such as cost saving and damage prevention, as well as the growth of underground construction in urban areas, utility rehabilitation, and replacement (Jeong et al. 2004). In SUE consultant companies, technicians for fieldwork who are in charge of designating, locating, surveying tasks and collecting data for
utility properties comprise 69% of the total employees, and project engineers, who typically manage the SUE projects in a specific region, comprise 16%. Other engineers for data management systems form 13% in SUE consultant companies. About 3% of employees are geophysicists who investigate underground information. The main purpose of SUE is to provide sufficient and accurate information related to utilities. The interpretation of different site environments, such as soil conditions, pipe material, joint type of pipe, depth of utility, and other factors, require the geophysical expertise to assess the proper use of geophysical techniques to detect underground utilities. The low number of geophysicists employed by SUE consultants is a growing concern in the industry (Jeong et al. 2004).

More than half of the projects undertaken with SUE consultants are for State DOT and Federal agency projects (55%). Approximately 16% of the clients are institutions, military, and industrial facility projects. Engineering firms form 11% and the other clients include municipalities (11%), utility companies (4%), and construction companies (3%). For SUE projects, it is common for owners to contact SUE consultants and negotiate the terms of a contract. Even though there are some projects performed under competitive bidding, it tends to be avoided in SUE industry because it allows lower service quality than the necessary levels. Strategic alliances are usually used in state DOT contracts. Under such an alliance, the owner can obtain a consistent level of underground utility information provided by a qualified SUE
consultant. These alliances typically extend over a period of 2 or 3 years (Jeong et al. 2004).

The most common type of contract used in the SUE industry is the cost-plus-fee contract (42%) while the daily rate contract comprises 14%. The wide use of cost-plus-fee contract is caused by State DOTs and Federal agencies, which form more than half of the SUE clients, who prefer the contract type since they have the resources to audit and do cost analyses. This type of contract allows SUE consultants to make reasonable profit. The major disadvantages of cost-plus-fee contracts and daily rate contracts are the difficulty in proper budgeting and fewer incentives for SUE providers to work efficiently. The alternatives of unit price contracts and lump sum contracts comprise 32% and 12%, respectively (Jeong et al. 2004).

2-2-3. Quality Levels of SUE

To understand the concept of SUE, it is necessary to define the SUE quality levels of underground information that is available to the designers, contractors, and owners (Anspach 1994). Quality levels are divided into four levels with different combinations of traditional record, site survey, geophysical technology, and vacuum excavation system. The accuracy and reliability of underground information increase from quality level D to quality level A. The costs for SUE surveys also increase from quality level D to quality level A.

Quality level D is the most basic level of information. Information is obtained from the
review of existing utility records and verbal accounts to determine the approximate location of existing underground utilities. Quality level D information has limitations of accuracy and comprehensiveness, because utility records are commonly insufficient and incorrect. Quality level C includes the information of quality level D and a site survey for surface visible features such as fire hydrants and manholes. Professional judgment is needed to prove the estimated location of underground utilities in relation to the surveyed features. Utility information of quality level B is obtained by using appropriate geophysical techniques.

Quality level B is called “Designating” and involves the information of quality level D and C. Underground utilities are identified by interpretation of received signals generated either actively or passively by geophysical techniques. The horizontal location can be determined and mapped by using quality level B. However, the depth of utilities is typically not available with quality level B. Utility information of quality level A is provided by actual exposure of underground utilities by 3-D geophysical methods. This quality level is called “Locating” and includes the information of quality level D, C, and B. Vacuum excavation systems have been used as leading methods for quality level A, because of its minimally intrusive nature. Exposing the utility at critical points provides the most accurate and reliable 3-D underground information. Visual inspection by exposing utilities can be used to verify material type of utility, depth of utility, soil conditions and other underground information, and to assess the condition of
It is important to determine which quality level must be selected for a project. If the owner wants to use lower quality information in a congested urban area, the owner must be willing to pay for the associated costs in change order, utility damage, and other unexpected problems (Lew 2000). On the contrary, the owner does not need to select expensive quality level A or B for a countryside field. Therefore, the decision and judgment for selecting the appropriate quality level for the project should be made by considerations of existing utility conditions, project site conditions, project characteristics, and other social and environmental impacts. Figure 2-1 shows quality levels.

![FIGURE 2-1 Quality Levels of SUE](image-url)
2-3. American Society of Civil Engineers

The American Society of Civil Engineers (ASCE) published the first SUE national standard in 2002 titled “Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data”, called CI/ASCE 38-02. ASCE defines SUE as a branch of engineering practice that involves managing certain risks associated with utility mapping at appropriate quality levels, utility coordination, utility relocation design, utility condition assessment, communication of utility data to concerned parties, utility relocation cost estimates, implementation of utility accommodation polices, and utility design.

This guideline was developed as the basis of a scope of work for utility mapping, planning, design, and construction. The guideline presents a system to classify four quality levels of SUE with typical tasks for engineers. The quality levels range from quality level D to quality level A. In particular, this guideline describes how subsurface information of SUE quality levels is collected and shows how the information is depicted on design plans, with three examples. This guideline is organized into eight sections and appendices. The sections include an introduction, scope, definitions, engineer and owner collection and depiction tasks, utility quality attributes, deliverables formatting, relative costs and benefits of quality levels, and information sources. The appendices identify geophysical techniques that are used to designate underground utilities in quality level A or B and describe how each geophysical technique works.
2-4. American Association of State and Highway Transportation Officials

Guidelines and Best Practices prepared by the Highway Subcommittee on Right of Way and Utilities of The American Association of State and Highway Transportation Officials (AASHTO) includes a Chapter 7 titled “Utilities” to recommend that SUE should be incorporated into project planning, design, and construction. The first guideline of Chapter 7 is for using currently available technology to the greatest extent possible. The guideline states that utilities should be depicted at appropriate quality levels on all highway plans and that the SUE information of utilities should be collected early in the development of all highway projects. It also encourages the FHWA to continue its support of SUE. The FHWA’s efforts, such as documenting cost savings of SUE, demonstrating benefits of SUE, allowing Federal funds to be used for SUE, and encouraging the use of SUE, have proved helpful to state DOTs that are trying to establish and maintain SUE programs. AASHTO recommends that state DOTs keep good records of cost and time savings, because this information is commonly beneficial for justifying the use of SUE. For instance, the FHWA study titled “Cost Savings on Highway Projects Utilizing Subsurface Utility Engineering (2000)” is widely used to introduce and propagate the SUE in evaluating cost savings. AASHTO also supports the efforts of ASCE in developing a standard guideline to present a system to classifying four quality levels of SUE. AASHTO states that all state DOTs should comply with the requirements in ASCE standard guideline for projects.
2-5. Federal Highway Administration

The Federal Highway Administration (FHWA) expanded on AASHTO’s guidelines in a 2002 FHWA report titled “Avoiding Utility Relocations.” The intent of the report is to encourage highway designers to avoid unnecessary utility relocations in the design stage. This report describes the value of avoiding relocations on highway projects and the technologies that can be used to avoid relocations. It also describes the successful processes being used in the planning, design, and construction phases that support coordination and reduce conflicts among owners.

In this report, SUE is one of the key conclusions and recommendations for avoiding relocations, because SUE can identify the presence, exact location of underground utilities, and other data that can be provided by exposing utilities. The report states cost and time savings of SUE by referencing other research. It also describes the importance of early communication and cooperation among utilities and state DOTs, because they allow highway designers to explore highway alignment alternatives prior to project design to avoid utility relocations. Even though the relocation cannot be completely avoided, efficient relocation work can be conducted to reduce unnecessary delays through early and frequent coordination, cooperation, and communication (CCC).

The strategies for CCC were explored in the new video available from the FHWA, “CCC: Making the Effort Works?”. The video shows the efforts of such states as Georgia,
Maryland, and Wisconsin to improve CCC between state DOTs and utility companies. The CCC also outlines ways that state DOTs can reduce unexpected utility conflict, minimize cost, and increase construction productivity. The FHWA states that enhanced coordination, cooperation, and communication (CCC) between state DOTs and utility companies, and utilization of accurate comprehensive information provided by using SUE make it possible for designers to make relatively minor relocations and design around many utilities that traditionally would have been relocated.

2-6. General Accounting Office

The General Accounting Office (GAO) developed a report in 1999 titled “Transportation Infrastructure: Impacts of Utility Relocations on Highway and Bridge Projects.” This report assesses the impacts that delays caused by utility relocations are having on the delivery and cost of highway and bridge projects. It examines the following; (1) the extent to which states are experiencing delays and the causes and impacts of the delays; (2) the number of states that are compensating construction contractors for the increased costs incurred by untimely relocations by utility companies; (3) the available technologies, such as SUE, that are being used for project design to reduce the number or impact of delay caused by utility relocations; (4) the mitigation methods that states are using, such as incentives, penalties, and litigations, to encourage or force
cooperation of utility companies.

GAO states that although the FHWA recommends SUE as a means of using new and existing technologies to accurately identify, characterize, and map underground utilities, many states do not use yet the engineering process on half or more of their projects. The report emphasizes that having SUE information early in the design process offers project designers the ability to redesign the project or avoid conflicts with existing utilities.
CHAPTER 3

GEOPHYSICAL TECHNIQUES AND VACUUM EXCAVATION SYSTEM

This chapter describes various geophysical techniques and vacuum excavation systems for locating underground utilities. The chapter also presents many factors affecting the use of geophysical techniques which are used in SUE.

3-1. GEOPHYSICAL TECHNIQUES

Geophysical techniques are non-invasive technologies used to image subsurface conditions in the earth through measuring, analyzing, and interpreting physical properties. Every geophysical technique depends upon the ability to identify contrasts in subsurface materials that include various physical properties (Fenning and Hansan 1993). These techniques have been applied to locate underground utilities in civil engineering. In typical applications of geophysical techniques, a form of energy is input into the earth, and the energy reflected from underground utilities or objects is observed, analyzed, and interpreted to identify the location of the utility (Jeong and Abraham 2004). However, no single geophysical technique can work well for all of the different site conditions and for all of the various properties of underground utilities or objects. The use of multiple techniques may yield the best possible target information.
3-2. APPLICABLE GEOPHYSICAL TECHNIQUES

There are various geophysical techniques available to acquire data needed for two-dimensional location of underground utilities for SUE quality level B, “Designation”. It is important for consultants, designers, or contractors to be familiar with various geophysical techniques for the successful designation of underground utilities.

3-2-1. Pipe and Cable Locator

The pipe and cable locator system utilizes transmission coils that release electromagnetic energy at selected frequencies. The electromagnetic energy generates magnetic fields around the electrically conductive material, and the receiver coil on the surface detects the induced magnetic field, which is used to produce a visual or audible indication of the horizontal location of the utility (Jeong and Abraham 2004). The pipe and cable locator is the most widely used method for quality level B of SUE. In particular, it is good for tracing underground utilities. At least 70% of utility-designating data have been created from pipe and cable locators, with other methods used to verify the information for situations where pipe and cable locator provides poor information (Noone 2004).

Frequencies from 50 to 480 kHz are usually used for successful utility searches. As the frequency becomes higher, the detection distance range for utility designation decreases, but
relatively smaller objects can be found with high frequencies within an effective distance range. High frequency tends to create an electromagnetic coupling effect due to its propensity to transfer electromagnetic fields to near-conductive materials. This can cause false identification of utility location as the peak signal is captured at an inaccurate horizontal position. Some transmitters have adjustable power outputs. Higher output can increase the signal strength. This also can increase the potential of an electromagnetic coupling effect and impact the ability to isolate an individual utility. The pipe and cable locator works well for metallic utilities, utilities that have tracing materials installed above the utility, and utilities that have spaces for metallic conductors or transmitters inserted into the utility. The major shortcoming is that non-metallic utilities without the aforementioned conditions cannot be detected with this method. In general, pipe and cable locators are relatively inexpensive and useful up to a 15-foot burial depth (ASCE 2002). A crew size of 1 or 2 people can locate underground utilities with the pipe and cable locator method. Figure 3-1 shows electromagnetic coupling effect and survey.

FIGURE 3-1 Electromagnetic Coupling Effect and Survey (Source: Jeong and Abraham 2004)
3-2-2. Ground Penetrating Radar

Ground Penetrating Radar (GPR) is an electromagnetic method that detects interfaces between subsurface materials with differing dielectric constants (Anderson et al. 2003). Microwave pulses are transmitted into the ground from an antenna, and any reflections that are returned are detected by the receiver and passed on to a computer to depict a continuous graphic profile of the strata. Reflecting surfaces appear as bands on the cross-section profile of distance and reflection delay time. The result of the GPR survey depends on the microwave frequency (10 to 1,000 MHz), dielectric constants, and conductivity of the soil (ASCE 2002).

The maximum depth of the GPR survey is highly site specific and is limited by signal attenuation, which is dependent on the electrical conductivity of the subsurface materials and the frequency of the signal. Signal attenuation is greatest in soils with high electrical conductivity such as clays, saturated sands, and tidal areas where salt is prevalent, because the high conductivity transforms the electromagnetic energy into heat. Conversely, the signal attenuation is lowest in soils with relatively low electrical conductivity, such as unsaturated sand or rock. In general, the maximum penetration depth of a GPR signal is less than 3 feet in clay, but 15 feet in dry soil. The maximum survey depth is also dependent on antenna frequency. The depth increases with decreasing frequency. While the higher frequency cannot penetrate as deep into the earth as the lower frequency, the higher frequency can detect utilities with smaller diameters.
and provide high spatial resolution and target definition. The main benefit of GPR is its ability to image both metallic and non-metallic utilities, since the signal is reflected from any changes in all three electromagnetic characteristics of dielectric constant, conductivity, and magnetic permeability. GPR also provides subsurface information efficiently by rapidly surveying large areas with minimum interference due to local traffic. The major shortcoming of GPR is its highly limited usability. Restricted applicable soil conditions and low penetration depth restrict the use of GPR. Even in ideal conditions such as dry sand, GPR is not effective to detect underground utilities at depths greater than 15 feet (ASCE 2002). Figure 3-2 shows GPR survey and diagram.

![GPR Survey and Diagram](source: Krause 2006)

3-2-3. **Terrain Conductivity Survey**

A terrain conductivity survey uses the difference of conductivity between buried underground utilities and the surrounding soil. The transmitter in a terrain conductivity system introduces an eddy current into the ground, and the eddy current is reflected once it meets a different
conductivity. The receiver measures and analyzes the reflected currents to detect underground utilities. In general, buried metallic utilities have lower conductivity than the surrounding soil (Jeong and Abraham 2004). This method is not useful in utility-congested areas because there is too much noise to isolate and interpret the signal. Discrete metallic utilities, storage tanks, wells, and vault covers are usually detectable with this method. Under some ideal conditions, terrain conductivity surveys can detect large non-metallic pipelines. This method works well in conductive areas and has an effective maximum depth of 15 feet (ASCE 2002). Figure 3-3 shows image and survey of terrain conductivity.

![Image and Survey of Terrain Conductivity](http://www.geovision.com)

**FIGURE 3-3 Image and Survey of Terrain Conductivity (Source: http://www.geovision.com)**

### 3-2-4. Resistivity Survey

The resistivity survey works by introducing DC current into the ground through two or more electrodes and measuring the resulting voltage difference between another pair of electrodes. The
electrode pairs are moved along a surveyed line and the electrical measurements result in a horizontal profile of apparent resistivity. The subsurface resistivity is calculated by knowing the electrode separation and geometry of the electrode position, applied current, and measured voltage. Different electrode spacings change the effective depth of measurement. The length of electrodes spacings is about 10 times the depth of measurement. Resistivity methods may be useful for a utility search, but not a utility trace (ASCE 2002). This method works well in resistive areas. In general, most soils are electrical insulators (highly resistive) but they become less resistive as moisture or water content in soils increases. Figure 3-4 shows resistivity survey and image.

![Resistivity Survey and Image](http://www.geovision.com)

**FIGURE 3-4 Resistivity Survey and Image (Source: http://www.geovision.com)**

3-2-5. Metal Detector

A metal detector starts by transmitting an AC magnetic field, which induces eddy currents in nearby metallic utilities within instrument range. These eddy currents produce a secondary field
in the metallic utilities, which interacts with the primary field. The search coil in the receiver captures the difference in these magnetic fields. The most important factors influencing the result of the metal detector include properties of the target, properties of soil, target size, and depth. Most metal detectors are limited to depths near the ground surface. In general, the effective depth is only 2 feet for utility designation (Jeong and Abraham 2004). However, some metal detectors are better than pipe and cable locators for detecting small-diameter metallic utilities within the effective depth. Metal detectors sensitively respond to both ferrous and non-ferrous metal objects, so that noise can be caused by nearby fences, vehicles, buildings, concrete reinforcement, metallic debris, etc. In addition, metal detectors may react to high concentrations of natural iron-bearing minerals, salt water, acids, and other highly conductive fluids. These may result in ground noise and a false signal reading by the metal detector. Figure 3-5 shows metal detector and image.

FIGURE 3-5 Metal Detector and Image (Source: http://www.geomodel.com)
3-2-6. Magnetic Survey

Magnetometers can be used to detect buried ferrous metallic objects such as pipelines and tanks with contrasting magnetite content. By detecting anomalies in the earth’s magnetic field caused by ferrous metallic utilities, the magnetometer provides underground information for utility designation. The response is proportional to the mass of the buried ferrous metallic utilities. In general, the effective maximum depth is 10 feet. The intensity of the magnetic field can change on a daily basis in response to solar magnetic storms and ionosphere conditions.

Two basic types of magnetometers are commonly used: a proton magnetometer for total field measurement and a fluxgate magnetometer for gradiometric measurement. In the proton magnetometer, an excitation voltage is applied to a coil around a container filled with a proton-rich fluid such as kerosene. The field reorients the protons in the fluid, allowing for measurement of a nuclear precession frequency, which is proportional to the strength of the field. The proton magnetometer measures the earth’s total field intensity, which reveals the existence of ferrous metallic utilities. It can be useful for utility designation in wide areas, but power lines, railroads, vehicles, etc. can interfere with the total field measurement. In the fluxgate magnetometer, the different intensities of magnetic field are captured by two sensors separated by a known distance. The sensors consist of an iron core that undergoes changes in magnetic saturation in response to variations in the earth’s magnetic field. The fluxgate magnetometer is easier to use and more
useful for utility designation than the proton magnetometer. It is typically effective to detect isolated shallow ferrous metallic utilities, underground storage tanks, wells, and vault covers. Magnetized non-metallic fiber optic cables and cast iron pipes also can be detected with this magnetometer (Jeong and Abraham 2004). Figure 3-6 shows magnetometer and image.

![Magnetometer and Image](http://www.geophysics.co.uk)

**FIGURE 3-6 Magnetometer and Image (Source: http://www.geophysics.co.uk)**

### 3-2-7. Acoustic Survey

The acoustic survey generally works through findings of utility noises. The noises are strongest directly over the utilities because the noise travel distance is the shortest. However, utility noises are commonly interfered with by other noises such as aircraft, vehicles, trains, electrical transformers, and so forth. In addition, the type of ground surface, soil compaction, moisture, and utility material affect the noise propagation.

Typically there are three types of acoustic emissions: active sonics, passive sonics, and resonant sonics. In the active sonics method, a transducer, which is connected to the surface
appurtenance of the underground utility, introduces sound waves (typically 132 to 210 Hz) into the utility (Jeong and Abraham 2004). The sound waves travel along the utility and reach the ground surface above before they are attenuated. The receivers, such as geophones or accelerometers, detect the sound waves and the underground utility can be traced by measuring and marking the strongest signal points. The need for prior knowledge about the surface appurtenance of the target utility limits this method only to utility tracing. The passive sonics method relies on the utility’s product. For instance, water at a hydrant or service petcock makes some vibrations that travel along the utility and are captured by the surface receiver. The sources of noise in this method are affected by product pressure, shape and size of orifice, and type of utility material. The resonant sonics rely on the utility’s product, typically a non-compressible fluid. The vibration is created by interfacing the fluid surface and generating a pressure wave in the fluid, which generates a ground motion that is detected by the receiver (ASCE 2002). Figure 3-7 shows active sonic method of acoustic survey.

FIGURE 3-7 Active Sonic Method of Acoustic Survey (Source: Jeong and Abraham 2004)
These acoustic surveys are typically useful for plastic water pipelines (6.5 feet of effective depth) and gas pipelines (8 feet of effective depth) (Jeong and Abraham 2004).

3-2-8. Thermal Survey (Infrared Method)

In a thermal survey, anomalies of the temperature field are used to identify underground utilities that disturb the normal ground temperature field due to the function of utilities such as steam pipelines or utilities that have different thermal characteristics than the surrounding ground (Sterling 2000). In general, this method detects and measures the heat flux emitted from some utilities such as steam systems, high-voltage power lines, and sanitary sewers. This method is useful for insulated steam systems or other high heat flux systems. Changes in solar radiation input to the ground surface or air temperature variations may cause sufficient changes in the thermal field for shallow buried utilities (Hoover et al. 1996). Figure 3-8 shows image and LV system of thermal survey.

FIGURE 3-8 Image and LV System of Thermal Survey (Source: http://www.thermal.co.uk)
3-2-9. Gravity Survey

Gravity surveys can be used to detect underground utilities or objects that exhibit density differences from surrounding materials. Since the changes in gravitational field are very small, a microgravity method should be utilized for utility designation (Anspach 1994). Gravity is the attraction between masses. The strength of gravitational force is a result of the mass and distance separating the objects. Gravity anomalies are captured by differences in density due to the presence of underground utilities or objects. For instance, if an empty utility is buried at the target point, a lower gravitational force is measured at the surface than at surrounding areas that are filled with soils. This method is relatively expensive and slow. Figure 3-9 shows gravity anomaly and survey.

FIGURE 3-9 Gravity Anomaly and Survey (Source: http://www.geovision.com)
3-2-10. Seismic Survey

A seismic survey can be used to detect underground utilities. Seismic waves are introduced into the ground using hammers or small explosive sources. Once the seismic waves meet discontinuities such as utilities, the reflected and refracted waves are returned back and detected by the receivers, such as geophones, which are emplaced at the ground surface at various distances from the seismic source. Seismic waves travel at different velocities in different materials. In general, solid, denser, and water-saturated materials tend to have higher velocities. So, the time-distance relationships measured in this survey may indicate the presence and 3-D location of underground utilities or other objects. This method is useful where field conditions are extremely limited due to signal/noise ratio problems for other methods, but it is relatively expensive and difficult to interpret the results (Anspach 1994). Figure 3-10 shows seismic data and time-distance table.

FIGURE 3-10 Seismic Data and Time-Distance Table (Source: http://www.geophysics.co.uk)
3-3. FACTORS AFFECTING ACCURACY OF SUE

Every geophysical technique has its own limitations. In general, there is no single geophysical technique that can be used for different utilities in different soil and site conditions. Many factors, including characteristics of expected underground utilities, geological conditions at the site, and other social and environmental factors should be considered as criteria for the appropriate selection of geophysical techniques. Information about the factors can be obtained from existing documents, as-built drawings, utility companies, site visits, and other sources.

3-3-1. Type of Utility

There are many types of utilities that provide various services: gas line, sewer line, water main, electric cable, communication cable, etc. However, certain techniques are not available or very useful for the detection of specific types of utilities. In general, the passive sonics method and the resonant method of acoustic surveys are used only for water and gas pipelines because they create vibrations that can be captured by a surface receiver. The thermal survey is also useful only for warm utilities such as sanitary sewers and high-voltage power lines, which generate detectable anomalies in the surface temperature field.
3-3-2. Material of Utility

Various materials have been used for underground utilities: iron, steel, PVC, concrete, clay, etc. However, some techniques are limited or more effective for specific materials. For instance, the magnetic survey is not applicable to non-ferrous metallic materials such as copper, plastic materials, and concrete materials, but is applicable for ferrous metallic materials, including steel, cast iron, and ductile iron. However, some electromagnetic methods such as GPR or terrain-conductive survey have a great benefit, because they can image both metallic and non-metallic materials.

3-3-3. Depth of Utility

The depths of underground utilities are highly variable. In general, while a sanitary sewer is buried at a depth of 7 ft, a communication cable is buried at a depth of 18 inches. Hence, the penetration limitation of the signal that each technique uses is an important factor for the selection of techniques. For instance, some metal detectors are more effective than a pipe and cable locator to detect metallic utilities. However, the applicable depth of metal detectors is less than 2 ft, while that of pipe and cable locators is up to 15 ft. The applicable depth of passive and resonant acoustic surveys varies in relation to target utilities. The typical depth is 6.5 ft for water pipelines but 8 ft for gas pipelines (Jeong and Abraham 2004).
3-3-4. Type of Soil

The input signal penetrations of some geophysical techniques depend on the properties of the soil. For example, the higher the water contents in the soil, the higher the electrical conductivity of the soil, which reduces electromagnetic signal penetrations. High conductivity in clays or highly saturated sand causes rapid dissipation of GPR signals, so that the penetration of GPR signals is reduced to less than 3 ft. The loss of GPR penetration depth is significant in comparison with 6 ft in low-conductivity soil. A terrain conductive method is more effective in highly conductive soils, while a resistivity method works well in highly resistive soils.

3-3-5. Ground Surface Condition

Ground surface condition means a cover condition on the ground affecting the input signal of geophysical techniques. Many underground utilities are buried under surface pavements with asphalt or reinforced concrete. These ground conditions can cause disturbances to specific techniques. For instance, reinforced concrete pavement may impede the introduction of electromagnetic signals into the ground because of the metallic rebar in the pavement. Acoustic surveys and thermal surveys also may have some difficulty capturing vibration and heat flux, respectively, emitted from utilities located under such a pavement.
3-3-6. Access Point of Utility

Access point of utility means the presence of a surface access point connected to the underground utility in the site vicinity. The access point also is an important factor for selecting appropriate geophysical techniques. For instance, in the active sonics method of the acoustic survey, prior knowledge about the surface appurtenance of the target utility is necessary, because the transducer introduces sound waves into the utilities through the surface appurtenance. A fire hydrant is a good example of an access point of utility.

3-3-7. Internal Condition of Utility

The internal condition of utilities refers to the filled level in empty utilities with fluid/gas/other materials. Some techniques work better depending on the internal condition of utilities. For instance, the acoustic survey is better applicable when the pipeline is filled with fluid/gas because the method is based on the fluid/gas pressure to propagate the sound wave. The internal condition of utilities also affects the density anomalies of the gravity survey. The gravity survey detects different densities due to the presence of underground pipelines distinct from surrounding materials. For the gravity survey, an empty water pipeline is more detectable than a filled water pipeline because of the density difference between air and water.
3-3-8. Density of Utility

Density of utility ultimately means how many utilities or buried objects are present around the target utility. In general, congested utilities and nearby buried objects may interfere with and confuse the interpretation of survey results. Thus, surveys for a site with high utility density are required to use more reliable and sophisticated techniques to avoid such interference and confusion. In addition, high utility density increases the possibility of accidents due to hitting one of the utilities, and the results from such accidents can be serious. In general, urban areas and commercial areas have more congested underground utilities.

3-3-9. Special Materials for Detecting Non-Metallic Utilities

In general, the detection of non-metallic utilities is more difficult than that of metallic utilities due to their own characteristics compared to surrounding soil conditions; only a few geophysical techniques are available for non-metallic utilities. However, the installation of special materials on or above the utilities during construction can help to detect non-metallic utilities. The presence of such materials allows geophysical techniques to work better and more geophysical techniques can be applied for non-metallic materials. Special materials include metallic marking tapes, tracing wires, and electronic markers.
3-3-10. Qualified SUE Consultants

Qualified SUE consultants who are familiar with all geophysical techniques are necessary to select the appropriate geophysical methods to use, survey underground utilities, and interpret the results of the surveys. Unqualified SUE consultants can cause the need for additional surveys and create serious problems for projects.

3-3-11. Other Factors

Rebar and wire mesh can make false identification in using electromagnetic methods such as utility and cable locators and GPR. Guard rail post, asbestos, wooden water pipeline, and other factors also can disturb the effective use of geophysical techniques.

3-4. VACUM EXCAVATION SYSTEMS

Vacuum excavation systems provide the highest accuracy of underground information. The use of vacuum excavation systems eliminates damage to underground utilities by pinpointing exactly where the utilities are positioned in three dimensions. In addition, information such as the properties of utilities, pavements, and soils can be obtained through vacuum excavation systems to assist the designers in making important decisions for underground projects. The air-vacuum excavation system is the predominant leader of vacuum excavation systems. The process starts
with digging an approximately 1-ft-by-1-ft hole at the horizontal location provided during the
designating stage by geophysical techniques. This system proceeds with the simultaneous action
of compressed air jets to loosen soil and vacuum extraction of the resulting debris (Sterling
2000). The process continues until the utility is exposed. The utility type, material, size, depth,
three-dimensional location, condition, soil type, water table, contamination, and other properties
of soils are provided with this system.

Until recently, air has been the primary source of digging power, but high-pressure water
systems are now beginning to be used for excavation because of their lower price compare to air
systems. A water system also is more effective than an air system in wet soils, heavy clays and
caliches. However, the use of water excavation is limited to the supply of water in the holding
tank, and wet debris is more difficult to handle than the dry material produced by an air system.
In addition, improper operation of a water system has the potential of damaging the utilities. The
appropriate selection of the vacuum excavation system should be made for the successful utility
location considering target soil and utility properties.

FIGURE 3-11 Vacuum Excavation System Diagram and Survey (Source: Noone 2004)
CHAPTER 4

PAST EXPERIENCE IN APPLICATION OF SUE

Research on subsurface utility engineering has been conducted from the mid 1990s, but most of it has been concerned about what SUE is. Only few studies have been carried out dealing with advanced issues such as benefit-cost analysis of SUE or geophysical techniques. In this chapter, the following issues are reviewed in depth: General SUE, Benefit-Cost Analysis of SUE, and Geophysical Technique of SUE.

4-1. GENERAL SUE

As mentioned above, most of SUE studies have tried to introduce and popularize SUE to many engineers, designers, and contractors. A few representative studies are reviewed to understand emerging SUE for underground damage prevention in this study.

Steven (1993) introduced the SUE as a damage prevention program. He stated that contractors have obtained benefits from professional SUE services with the accuracy and accountability of underground utility location. He also mentioned that So-Deep, a SUE consultant, provided many attributes that can be important to effective completion of the construction process. The attributes included such information as locations, size, type, condition,
and material of utility as well as type of soil and thickness and material of any covering paving.

He concluded that the application of SUE can make a quantum leap in the ability to reduce risk and save time and money on construction projects.

Anspach (1994) compared the most prevalent damage prevention program (one-call system) and SUE on the following issues: responsibility party, unknown utilities, abandoned utilities, available time to analyze underground information, data management, and other issues. He also explained the engineers’, utility owners’, and constructors’ typical position on the use of SUE. These comparisons and explanations showed that SUE is the more competitive damage prevention strategy for everyone.

Lew (1996) argued that information of quality level C and D, which can be identified with traditional methods, have a 15 to 30 percent error and omission rate. His paper recommended instituting a program to update underground information on public facilities with SUE quality level of at least “B”, and developing regulatory standards for the depiction of utility information on construction documents. He also would require the use of SUE on all projects that are publicly funded where underground features may be encountered.

Statement of Need (SON) published by Sterling (2000) addressed an issue of significant national importance - the current and increasing potential for damage to underground utility systems caused by utility installation/repair activities and other excavations. It stated that the
current one call system has several inadequacies which may be serious for the successful locating of underground utilities. The results of SON showed the successful use of the vacuum excavation system and geophysical technology of SUE.

Jeong et al (2004) recommended the systemic use of SUE to improve the safety of existing utilities in underground construction projects, through evaluating and comparing available systems for ensuring utility safety during construction. This study also used a survey to identify current SUE practice in DOTs and in private sectors. The survey indicated that 22 states have utilized SUE and the average growth rate of SUE business was 173% in sales from 1997 to 2001. They mentioned that SUE marketplace has just entered a robust adolescence period, but has yet to achieve the status of a mature industry.

Jackson (2004) presented SUE on municipal utility projects from an engineering firm’s perspective. A case study of his paper showed that the SUE process confirmed that the existing water line was not located in the area indicated by the as-built drawing but was off by approximately 7 feet. He stated that quality levels of SUE allow the projects owner, engineer, designer, and constructor to develop strategies to reduce risk by increasing the reliability of information on existing underground utilities in a well-defined manner.
4-2. BENEFIT-COST ANALYSIS OF SUE

Designers and engineers for public and private projects expect numerous benefits on their own projects with SUE. These benefits are important to the DOTs, utility owners, designers, contractors and engineers. In general, SUE reduces unnecessary utility relocations, unexpected utilities, utility damages, and social and environmental damages, and improves design and construction by using accurate underground information. The benefits are combined with subsequent savings in time and cost for utility relocations, change orders and claims, redesigns, damage restorations, insurances for workers’ injuries or death, legal and litigation processes, social problems such as traffic delay, business interruption, and facility service loss, and environmental problems. Ultimately, these benefits result in reduction in time and cost for whole projects. Figure 4-1 shows significant benefits which can be derived from using SUE.

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**FIGURE 4-1 Significant Benefits of SUE**

- Reduced Unnecessary Relocations
- Reduced Unexpected Utilities
- Reduced Utility Damages
- Reduced Social & Environmental Problems
- Efficient Design & Construction

Accurate Underground Information by SUE

Reduction in Time and Cost for Projects
Stevens (1993) presented cost savings in various forms for the taxpayer, the ratepayer, and the owner on projects utilizing SUE as shown in Table 4-1. In his research, administrative cost savings is 2% of overall project costs, because projects were completed up to 10% faster. Costs for insurance, bonding, and change orders also may be less. Engineering cost savings yield 0.5% because SUE techniques may save time by using digital transfer of survey data into CADD. Construction costs realize savings of 2.25% because construction bids may be lowered by fewer utility conflicts with accurate underground information. Liability for identification of utilities is also transferred from contractors to the SUE companies. Overrun costs realize savings of 5%. The overrun savings may be derived from reduced delay claims, reduced engineering rework, and reduced utility damages. Utility relocation cost savings yield 5% of overall project costs.

TABLE 4-1 Cost Saving Rate on Projects utilizing SUE (Stevens 1993)

<table>
<thead>
<tr>
<th>Cost</th>
<th>Expenditure on Typical Projects</th>
<th>Saving Rates</th>
<th>Savings on Overall Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administrative</td>
<td>20%</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>Engineering</td>
<td>10%</td>
<td>5%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Construction</td>
<td>45%</td>
<td>5%</td>
<td>2.25%</td>
</tr>
<tr>
<td>Overrun</td>
<td>15%</td>
<td>33%</td>
<td>5%</td>
</tr>
<tr>
<td>Utility Relocation</td>
<td>10%</td>
<td>50%</td>
<td>5%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>-</td>
<td>14.75%</td>
</tr>
</tbody>
</table>
Designers using accurate underground information may eliminate much underground utility relocations before construction. The results of this research showed that, in comparison with projects not utilizing SUE, the total cost saving of SUE projects may range from 10% to 15% on a typical project.

Anspach (1994) summarized SUE savings which were derived by various parties. In his research, FHWA reported that applying SUE nationwide would result in cost savings exceeding $100 million per year for highway work alone. A state utility engineer of Virginia DOT stated that $700,000 worth of utility conflicts was eliminated with less than $100,000 for SUE in a project in Richmond. He also dealt with other SUE savings related to relocation costs, construction delay claims, project completion time, construction bids, and other issues.

A study titled “Cost Savings on Highway Projects utilizing Subsurface Utility Engineering” which the FHWA commissioned Purdue University to estimate the cost savings of SUE on highway projects was presented in 2000 (Lew 2000). Lew developed 21 categories to quantify the savings in terms of time, cost, and risk management aspects after interviewing and surveying with the DOTs, utility owners, SUE consultants, and contractors. Table 4-2 shows the categories of SUE cost savings. Four states, including Virginia, North Carolina, Ohio, and Texas, were selected to provide their SUE projects.
TABLE 4-2 Categories of SUE Cost Savings of Purdue Study (Lew 2000)

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reduction in unforeseen utility conflicts and relocations</td>
</tr>
<tr>
<td>2</td>
<td>Reduction in project delays due to utility relocates</td>
</tr>
<tr>
<td>3</td>
<td>Reduction in claims and change orders</td>
</tr>
<tr>
<td>4</td>
<td>Reduction in delays due to utility cuts</td>
</tr>
<tr>
<td>5</td>
<td>Reduction in project contingency fees</td>
</tr>
<tr>
<td>6</td>
<td>Lower project bids</td>
</tr>
<tr>
<td>7</td>
<td>Reduction in costs caused by conflict redesign</td>
</tr>
<tr>
<td>8</td>
<td>Reduction in the cost of project design</td>
</tr>
<tr>
<td>9</td>
<td>Reduction in travel delays during construction to the motoring public</td>
</tr>
<tr>
<td>10</td>
<td>Improvement in contractor productivity and quality</td>
</tr>
<tr>
<td>11</td>
<td>Reduction in utility companies’ cost to repair damaged facilities</td>
</tr>
<tr>
<td>12</td>
<td>Minimization of utility customers’ loss of service</td>
</tr>
<tr>
<td>13</td>
<td>Minimization of damage to existing pavements</td>
</tr>
<tr>
<td>14</td>
<td>Minimization of traffic disruption, increasing DOT public credibility</td>
</tr>
<tr>
<td>15</td>
<td>Improvement in working relationship between DOT and utilities</td>
</tr>
<tr>
<td>16</td>
<td>Increased efficiency of activities by elimination duplicate surveys</td>
</tr>
<tr>
<td>17</td>
<td>Facilitation of electronic mapping accuracy</td>
</tr>
<tr>
<td>18</td>
<td>Minimization of the chance of environmental damage</td>
</tr>
<tr>
<td>19</td>
<td>Inducement of savings in risk management and insurance</td>
</tr>
<tr>
<td>20</td>
<td>Introduction of the concept of a comprehensive SUE process</td>
</tr>
<tr>
<td>21</td>
<td>Reduction in Right-of-Way acquisition costs</td>
</tr>
</tbody>
</table>
This study analyzed 71 SUE projects through studying projects in detail, interviewing the personnel involved in the project, and applying historical cost data. True qualitative costs, which may be significant for real cost savings, were not included in the estimation. The results of this study showed a total of $4.62 in savings for every $1.00 spent on SUE. It ranged from $0.34 to $206.67. The $4.62 saving has been widely cited whenever the benefits of SUE are discussed. The study concluded that that SUE is a viable technology that reduces project costs related to the risks caused by inaccurate underground information. It also described that, when used in a systemic manner, SUE should result in significant quantifiable and qualitative benefits and a minimum national savings of approximately $1 billion per year.

Brown and Mckim (2002) stated many benefit-cost ratios to describe the cost savings attributed to the use of SUE. In their research, a study by Virginia DOT indicated a cost savings of $7.00 for every $1.00 spent on SUE. The Society of American Value Engineers (SAVE) showed a 10:1 return rate, and Maryland DOT showed an 18:1 savings. However, these saving ratios were commonly underestimated because they did not consider social and environmental impacts and they used a limited number of projects to produce results.

Jeong et al. (2004) modified the results of the Purdue Study by Lew (2000) after reanalyzing the same data, including 71 projects. In their research, the ratio of the cost of SUE to the total construction cost ranged from 0.02 to 10.76%, and the average ratio was 1.39%. The
average $12.23 in savings for every $1.00 spent on SUE was quantified in SUE projects. They also carried out cost savings analysis for each individual category. Reduced number of utility relocations was analyzed as the most outstanding cost saving with 37.1% in SUE cost savings. Reduced claims and change order (19.3%), reduced accidents and injuries (11.6%), and reduced project delay (9.6%) were ranked as significant contributors to cost savings in order. Other cost savings that consist of 22.3% included reduced right-of-way acquisition costs (3.5%), induced savings in risk management and insurance (3.3%), and other categories (15.5%).

In 2005, the University of Toronto presented a study commissioned by the Ontario Sewer & Watermain Contractors Association. Osman and El-Diraby (2005) investigated 9 infrastructure projects, which used SUE in Ontario, through interviews with project owners and contractors and project case studies with drawings. It used 11 cost saving items which were reduced from the 21 cost savings items identified by Purdue Study. Table 4-3 shows the 11 cost saving items. The study included detailed documentation of the qualitative or quantitative costs and benefits of using SUE in nine projects. In particular, this study highlighted the important saving characteristics of case studies that could make the SUE investigation a worthwhile investment and encourage better understanding of SUE benefits. The results of the study showed that the average Return-On-Investment (ROI) for SUE is approximately $3.41 for each $1 spent. The ROI varied considerably across the projects and ranges from 1.98 to 6.59. This study
indicated that with careful scoping of SUE services, the project risks can be appropriately reduced at reasonable cost. It concluded with possible improvements to the SUE process and recommendations indicated by various SUE project participants in Ontario. It also presented an industry survey to identify how inaccurate utility information impact project outcomes.

**TABLE 4-3 Categories of SUE Cost Savings of Toronto Study (Osman and El-Diraby 2005)**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Design Cost</td>
</tr>
<tr>
<td>2</td>
<td>Utility Relocation Cost</td>
</tr>
<tr>
<td>3</td>
<td>Savings to Overall Construction Cost</td>
</tr>
<tr>
<td>4</td>
<td>Contractors Contingency Cost</td>
</tr>
<tr>
<td>5</td>
<td>Contractor Claims &amp; Change Order Cost</td>
</tr>
<tr>
<td>6</td>
<td>Construction Personnel Injury Cost</td>
</tr>
<tr>
<td>7</td>
<td>Public Injury Cost</td>
</tr>
<tr>
<td>8</td>
<td>Utility Damage Cost</td>
</tr>
<tr>
<td>9</td>
<td>Travel Delay Cost</td>
</tr>
<tr>
<td>10</td>
<td>Business Impact Cost</td>
</tr>
<tr>
<td>11</td>
<td>Service Interruption Cost</td>
</tr>
</tbody>
</table>

**4-3. GEOPHYSICAL TECHNIQUES OF SUE**

Most of studies related to geophysical techniques of SUE have tried only to encourage the use of
existing techniques for locating underground utilities, because the techniques have originally been utilized successfully in geophysics or related geosciences fields. They have described the strength and the weakness of each technique for using in civil engineering field. Only one study was carried out to select appropriate techniques based on conditions of proposed sites and target utilities.

Anspach (1994) briefly explained the characteristics of geophysical techniques such as magnetic survey, seismic survey, gravity survey, and other techniques. He also mentioned that the techniques are usually sufficient to accomplish preliminary engineering goals, but the engineers may need more reliable data which cannot be obtained from simply applying the geophysical techniques. He introduced the air vacuum excavation system to obtain more information such as soil type, pipe conditions, and other attributes. Anspach also recommended that cost effective analysis should be conducted for selecting geophysical techniques.

Noone (1996) addressed electronic utility location techniques which include electromagnetic line locator, radio frequency line locator, magnetic locator, ground probing radar, and acoustic location method. These techniques were placed in order of usefulness for exactly identifying particular utility lines. He also presented the air vacuum excavation system of SUE quality level A. The conclusion of his paper stated that electronic utility location techniques provide approximate horizontal location and air vacuum excavation techniques provide exact
horizontal and vertical location.

As an aid to the highway engineer, Anderson and Cardimona (2000) constructed tabularized information about commonly employed geophysical techniques, and presented a generalized approach for evaluating underground utilities. The information included the physical properties, resolution, cost-effective ranking, measured parameter, available site conditions, and potential application in engineering of each technique.

Sterling (2000) studied the location alternatives, including destructive methods, vacuum excavation system, and geophysical techniques. His research analyzed seven technology constraints, and presented possible improvements for mitigating the damage hazards experienced today. He also analyzed the cost range for current practices for utility locating as the following: $0 to $50 for one-call systems, $0.2 to $2 per foot for geophysical techniques, and $150 to $500 per pit for vacuum excavation systems. He concluded that the future geophysical technique should be a single multi-sensor system which accurately locates all underground utilities under the variety of site conditions in urban areas.

Jeong et al. (2004) used a survey with 21 SUE companies to determine the types of geophysical techniques used and to evaluate the use of various geophysical techniques on highway projects. In the results of the study, pipe and cable locators, ground penetrating radar (GPR), and metal detectors were found to be the main geophysical techniques used for SUE
projects, as most of the responding companies are equipped with these field equipments. Acoustic pipe tracers, magnetometers, terrain conductivity meters, and electronic marker systems were also available for locating underground utilities; Eighty-two percent of highway projects were conducted by using pipe and cable locators, and acoustic pipe traces (6%) were ranked as the second most common method. As the third most common method, GPR (5%) was utilized for locating different types of buried materials. The other geophysical techniques, which were utilized in less than 3% of SUE projects, included metal detector, magnetometer, and other techniques.

Jeong and Abraham (2004) proposed a decision tool that was developed to help in selecting appropriate geophysical techniques based on site conditions and target utility properties. The proposed decision tool, called IMAGTECH, utilized the deterministic parallel selection technique (DPST) as a decision framework. When input values were provided, the DPST evaluated the input data to determine the applicability to each geophysical technique based on an established knowledge base. The first step was the conversion of values of linguistic applicability to numeric values. Second, a computation process using the obtained numeric values discarded inappropriate methods, and ranked the appropriate geophysical techniques. They concluded that there is strong need in industry for a new and robust imaging technology which can overcome the drawbacks of existing geophysical techniques.
4-4. LIMITATIONS OF EXISTING STUDIES

The preceding reviews show that SUE is an effective alternative method which overcomes current problems of traditional damage prevention system. SUE provides not only accurate underground information but also achieves cost savings in different forms for owners. Ultimately, the application of SUE leads to more successful underground projects. To effectively utilize SUE, however, the appropriate quality levels must be selected as the first step. Quality level A is the best choice for preventing damage anywhere, but not all projects need to use quality level A, which requires the highest cost. Thus, there is a need to determine which SUE quality levels should be selected for the effective project process. Unfortunately, all existing studies just describe what the definition of each quality level is or what information each quality level includes. When quality levels A and B are selected, another important factor in utilizing SUE is the selection of appropriate geophysical techniques based on different site and target utility conditions. Jeong and Abraham (2004) studied how to assist in selecting appropriate techniques, but used a knowledge base that was not validated with field engineers. Besides, the study did not reflect the relative importance of criteria to determine numeric values of geophysical techniques. In conclusion, previous studies have found what is needed for damage prevention, but have not determined how to effectively use what they found. Thus, this study develops a decision making tool and conducts benefit-cost analyses to effectively use SUE.
CHAPTER 5

UTILITY IMPACT RATING

This chapter introduces and explains utility impact rating, which refers to the utility complexity for a given project, section or location. Although SUE quality level A provides the most reliable underground information, not all projects need to use quality level A, which requires the highest cost. The utility impact rating form is designed to recommend appropriate quality levels of SUE based on the utility impact score.

The Georgia Department of Transportation (Georgia DOT) and Washington State Department of Transportation (Washington State DOT) have developed some kinds of utility impact form. The Georgia DOT form seeks to know how many impacts related to utility issues exist on an underground project through 10 questions, and the Washington State DOT applies six criteria to identify whether a DOT project qualifies as a SUE project. However, both of these are too limited to provide meaningful utility impacts on an underground project, and neither addresses appropriate quality levels of SUE, which is helpful for project owners, designers, and contractors.

The utility impact form developed in this study consists of three steps. Step 1 and Step 2 are screening processes for possible SUE projects, and Step 3 is a utility impact evaluation on
underground projects passing Step 1 and Step 2 to select appropriate quality levels of SUE.

Figure 5-1 shows the decision-making framework for the appropriate selection of SUE quality levels. All questions, complexity factors, and designs of steps in the form have been determined through literature reviews and interviews with utility managers and engineers of the Pennsylvania Department of Transportation (Penn DOT).

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**FIGURE 5-1 Decision-Making Framework for the selection of SUE quality levels**
5-1. STEP 1

Information such as project title, project cost, project description (general summary), and project scope (actual work scope) should be filled out before beginning Step 1. If the scope of the project is changed, the utility impact rating analysis should be conducted again. Step 1 determines whether or not SUE (Quality levels A & B) should be utilized for a project. Figure 5-2 shows two questions involved in Step 1.

<table>
<thead>
<tr>
<th>No.</th>
<th>QUESTIONS</th>
<th>Column 1</th>
<th>Column 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Is there evidence of underground utilities in the project area? (based on information from quality levels D&amp;C)</td>
<td>NO</td>
<td>YES or Unknown</td>
</tr>
<tr>
<td>2</td>
<td>Does the project require any excavation “regardless of depth”? Note: This includes any TCE or other easements.</td>
<td>NO</td>
<td>YES or Unknown</td>
</tr>
</tbody>
</table>

FIGURE 5-2 Step 1 of Utility Impact Rating Form

The questions can be answered with traditional utility information (Quality levels C & D) provided by a one-call system, utility companies, site visits, etc. If there are no boxes checked in Column 2, then it is generally not practical to perform SUE quality level A or B investigations. If any boxes in Column 2 are checked, the utility impact rating analysis proceeds to Step 2 to conduct further analysis for possible SUE project classification.
5-2. STEP 2

Step 2 further analyzes and determines whether or not SUE (Quality levels A & B) should be utilized for a project. Figure 5-3 shows five questions involved in Step 2. The questions can be answered with traditional utility information (Quality levels C & D) provided by a one-call system, utility companies, site visits, etc. If there are no boxes checked in Column 2, then it is generally not practical to perform SUE Quality level A or B investigations. If any boxes in Column 2 are checked, the utility impact rating analysis proceeds to Step 3 to calculate a utility impact score and determine the appropriate SUE quality levels.

<table>
<thead>
<tr>
<th>No.</th>
<th>QUESTIONS</th>
<th>Column 1</th>
<th>Column 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Depth of project excavation.</td>
<td>≤ 18”</td>
<td>&gt; 18”</td>
</tr>
<tr>
<td>2</td>
<td>Do you feel that the utility owners in the project area will be able to accommodate the project’s schedule in regards to showing the location of their utility facilities?</td>
<td>Confident</td>
<td>Doubtful</td>
</tr>
<tr>
<td>3</td>
<td>What is the likelihood that project will have an impact on the existing utilities?</td>
<td>No Impact</td>
<td>Impact</td>
</tr>
<tr>
<td>4</td>
<td>How often have the utility owners in the project area provided accurate utility information?</td>
<td>Always</td>
<td>Seldom</td>
</tr>
<tr>
<td>5</td>
<td>Reliability of designer providing accurate design-construction related information.</td>
<td>Good</td>
<td>Poor</td>
</tr>
</tbody>
</table>

FIGURE 5-3 Step 2 of Utility Impact Rating Form
5-3. STEP 3

Step 3 determines which SUE quality levels should be selected for a project/section/location. Title, cost, description (general summary), and scope (actual work scope) should be filled out before answering the questions. The Step 3 questions are answered for a project, a section, or a location, while all questions of Step 1 and Step 2 are for a project. One project can have several sections or locations that have different utility impacts. Step 3 can be conducted for each section or location so that appropriate SUE quality levels should be selected for each section or location.

Figure 5-4 shows 17 complexity factors involved in Step 3. The utility impact rating to the right that best fits the analyst’s opinion of the issue is checked based on traditional utility information (Quality levels C & D) provided by one-call system, utility companies, site visits, etc. Column 1, Column 2, and Column 3 mean low impact, medium impact, and high impact, respectively. If the answer for the complexity factor is unknown, Column 3, high impact, always should be checked. If the number of checked boxes for each column is known after checking for all complexity factors, the utility impact score is calculated with following equation.

\[
UIS = \frac{(1 \times \Sigma \text{Column 1}) + (2 \times \Sigma \text{Column 2}) + (3 \times \Sigma \text{Column 3})}{n} \quad \text{Equation 5-1}
\]

Where, \( UIS \) = Utility Impact Score

\( n \) = Number of the complexity factors considered/checked
<table>
<thead>
<tr>
<th>No.</th>
<th>Complexity Factors</th>
<th>Column 1 (Low)</th>
<th>Column 2 (Medium)</th>
<th>Column 3 (High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density of Utilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Type of Utilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Pattern of Utilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Material of Utilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Access to Utilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Age of Utilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Estimated Utility Relocation Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Estimated Project Traffic Volume (ADT per lane)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Project Time Sensitivity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Project Area Description</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Type of Project/Section/Location</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Quality of Utility Record</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Excavation Depth within Highway Right-of-Way, including Easement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Estimated Business Impact</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Estimated Environmental Impact</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Estimated Safety Impact</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Other Impact Factors (Specify):</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FIGURE 5-4 Step 3 of Utility Impact Rating Form
Equation 5-1 utilizes 1, 2, and 3 to differentiate weights for three Columns. This equation provides utility impact scores ranged from 1 to 3. 1 means the lowest impact, while 3 means the highest impact. Based on this utility impact score, the utility impact rating form recommends and describes the appropriate SUE quality level and shows risk levels for a project/section/location.

Table 5-1 shows the project complexity levels, recommended SUE quality levels to be used, relative cost levels of using SUE quality level, and project risk levels based on the utility impact score. Utility impact scores are divided into five grades and the ranges are determined evenly to provide equal range for each grade. Relative cost of using SUE is calculated based on the typical unit price of the different quality level costs. The cost of using SUE quality level A is almost four times the cost of using SUE level B investigation and sixty-six times the cost of using SUE level C and D investigations.

<table>
<thead>
<tr>
<th>Utility Impact Score</th>
<th>1.0 ≤, &lt;1.4</th>
<th>1.4 ≤, &lt;1.8</th>
<th>1.8 ≤, &lt;2.2</th>
<th>2.2 ≤, &lt;2.6</th>
<th>2.6 ≤, ≤ 3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity Levels</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>SUE Quality Levels</td>
<td>D&amp;C</td>
<td>C/B</td>
<td>B</td>
<td>B/A</td>
<td>A</td>
</tr>
<tr>
<td>Relative Costs</td>
<td>1</td>
<td>6.67</td>
<td>16.67</td>
<td>33.33</td>
<td>66.67</td>
</tr>
<tr>
<td>Project Risk Levels</td>
<td>Low (L)</td>
<td>Fair (F)</td>
<td>Medium (M)</td>
<td>High (H)</td>
<td>Very High (V)</td>
</tr>
</tbody>
</table>
Although this utility impact rating form recommends appropriate SUE quality levels, in some cases, the project owner or designer must use his/her discretion for selecting appropriate SUE quality levels. This form also presents project risk levels for the SUE quality levels that the project owner or designer selects. Table 5-2 shows SUE quality levels and project risk levels.

**TABLE 5-2 Quality Levels and Project Risk Levels**

<table>
<thead>
<tr>
<th>Recommended Quality Level</th>
<th>D&amp;C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selected Quality Level</td>
<td>D&amp;C</td>
</tr>
<tr>
<td>Project Risk Level</td>
<td>L</td>
</tr>
<tr>
<td>Recommended Quality Level</td>
<td>C/B</td>
</tr>
<tr>
<td>Selected Quality Level</td>
<td>D&amp;C</td>
</tr>
<tr>
<td>Project Risk Levels</td>
<td>F</td>
</tr>
<tr>
<td>Recommended Quality Level</td>
<td>B</td>
</tr>
<tr>
<td>Selected Quality Level</td>
<td>D&amp;C</td>
</tr>
<tr>
<td>Project Risk Levels</td>
<td>M</td>
</tr>
<tr>
<td>Recommended Quality Level</td>
<td>B/A</td>
</tr>
<tr>
<td>Selected Quality Level</td>
<td>D&amp;C</td>
</tr>
<tr>
<td>Project Risk Levels</td>
<td>H</td>
</tr>
<tr>
<td>Recommended Quality Level</td>
<td>A</td>
</tr>
<tr>
<td>Selected Quality Level</td>
<td>D&amp;C</td>
</tr>
<tr>
<td>Project Risk Levels</td>
<td>V</td>
</tr>
</tbody>
</table>

L: Low, F: Fair, M: Medium, H: High, V: Very High
For instance, the recommended quality level is supposed to be B. If a project owner selects C, the project risk becomes high, but if project owner selects A, the project risk becomes low. This means that if the project owner wants to use lower quality levels than the recommended quality levels, the owner must be willing to take more risks on the project and potentially pay for the associated cost in unnecessary utility relocation, change orders, utility damages, and other unexpected problems caused by increased risks.

5-4. COMPLEXITY FACTORS

In order to properly evaluate the utility impact rating in Step 3, this section presents a detailed description of each complexity factor.

5-4-1. Density of Utilities (DOU)

Density of utilities refers to the number of buried utilities per roadway cross-section that can be expected to be encountered on the project. If there are many utilities expected to be buried at the project site, more reliable data/information will be required to successfully locate those utilities. A higher density of utilities means more utility complexity, which requires getting better information related to underground utilities on the project. Densities are clarified as follows:

Low : One pipe / roadway cross section
Medium : Two or three pipes / roadway cross sections

High : More than three pipes / roadway cross sections

5-4-2. Type of Utilities (TOU)

Type of utilities refers to the various service types of buried utilities that can be expected to be encountered on the project. Utilities can be broadly divided into three different categories: (1) municipal, (2) energy, and (3) communication. Fiber-optic lines classified as a critical utility are more shallowly buried than other types of utilities, so the possibility of accidentally hitting these lines is high. In addition, hitting gas or high-voltage lines can have serious impacts. Therefore, critical utilities generally require a greater level of data/information than other underground utilities on the project. The clarification of various types of utilities is as follows:

Less-Critical : Water, forced sewer main, storm water

Sub-Critical : Telephone, electric, television cable, gravity sewer

Critical : Fiber-optic cable, gas, oil, petroleum, high-voltage line

5-4-3. Pattern of Utilities (POU)

Pattern of utilities refers to the configuration of buried utilities that can be expected to be encountered on the project. Some areas may have a simple pattern that consists of a few parallel
or crossing utilities, while other areas may have a complex pattern that consists of numerous parallel and crossing utilities. For instance, an intersection in a downtown location may have a more complex pattern of utilities than other areas. A more complex pattern of utilities requires more reliable underground information. These patterns are defined as follows:

**Simple**: One parallel and/or one crossing utility

**Medium**: Two parallel and/or two crossing utilities

**Complex**: More than two parallel and/or crossing utilities

### 5-4-4. Material of Utilities (MOU)

Material of utilities refers to the material types of buried utilities that can be expected to be encountered on the project. This factor is characterized into three different categories: (1) rigid, (2) flexible, and (3) brittle. Brittle material requires more reliable underground information because those materials are more susceptible to damage than other materials. The material factors are clarified as follows:

**Rigid**: Concrete, cast iron, ductile iron

**Flexible**: PVC, HDPE

**Brittle**: Clay
5-4-5. Access to Utilities (ATU)

Access to utilities refers to the difficulty or ease of access to buried utilities that may be encountered on the project. If access to buried utilities is restricted, it will be more difficult to get accurate information on these buried utilities than in areas where access to utilities is easy. It is recommended that more reliable underground information be used when access to utilities is more restricted. Access to utilities is clarified as follows:

**Easy** : Open land

**Medium** : Few light structures, pavements, medians

**Restricted** : Bridge pier, other large structures

5-4-6. Age of Utilities (AOU)

Age of utilities may reveal the type of utility material and the physical condition of the utility. Older pipelines may have deteriorated extensively and become more easily damaged by accidental hit during construction activity. In addition, existing records on older utilities may be less reliable. Age clarification of utilities is as follows:

**New** : ≤ 10 years

**Medium** : > 10 and ≤ 25 years

**Old** : > 25 years
5-4-7. **Estimated Total Utility Relocation Costs (ERC)**

When higher utility relocation costs (including Penn DOT and utilities costs) are expected for the project, more accurate underground information is required to reduce risks of increased project costs or project schedule delays. Good underground information can reduce the possibility of risks related to utility relocations. The utility relocation costs are clarified as follows:

- **Low**: \( \leq 2\% \) of total project cost (Design & Construction Cost)
- **Medium**: \( > 2 \) and \( \leq 5\% \) of total project cost (Design & Construction Cost)
- **High**: \( > 5\% \) of total project cost (Design & Construction Cost)

5-4-8. **Estimated Project Traffic Volume (ETV)**

Project traffic volume is the Average Daily Traffic (ADT) volume per lane for the project. Any delay in the project in areas with higher traffic volume will result in greater travel delay to the public. Therefore, a higher level of SUE is required to minimize unnecessary project delays due to encountering unexpected buried utilities at the project site. The estimated project traffic volume is clarified as follows:

- **Low**: \( \leq 1,500 \) ADT per lane
- **Moderate**: \( > 1,500 \) and \( \leq 6,000 \) ADT per lane
- **High**: \( > 6,000 \) ADT per lane
5-4-9. Project Time Sensitivity (PTS)

Project time sensitivity pertains to the project schedule. Accurate utility information can reduce unnecessary project delays that can result from inaccurate design. Therefore, more reliable information is required in the design stage for projects that have tight schedules. Higher project time sensitivity means tighter schedules, which require avoiding project delays. Time sensitivity is clarified as follows:

**Low** : Project is not time sensitive

**Medium** : Some flexibility in schedule

**High** : Very tight schedule – no time extension

5-4-10. Project Area Description (PAD)

Project area description refers to the location or nature of the project. This factor is characterized into three different categories: (1) rural, (2) suburban, and (3) urban. In general, urban areas have more complex and congested utilities because of dense building and infrastructure density. Therefore, an urban area means more congested utilities, so that more reliable underground information is recommended. The project area description is as follows:

**Rural** : Rural areas with lots of open land

**Suburban** : Suburban areas with few businesses and residences
Urban: Urban areas with numerous businesses and residences

5-4-11. Type of Project/Section/Location (TOP)

Types of project/section/location are considered to identify properties of project, section, and location. The type of project quite often may indicate whether or not SUE is needed. As an example, a pavement resurfacing project that generally requires work only on the pavement surface will not need SUE. Project location and specifically the section at which the construction work will take place may reveal traffic volume, accessibility, and potential consequences of accidentally damaging the buried utilities. This factor is characterized into three different categories: (1) without excavation, (2) shallow excavation, and (3) deep excavation. The types of project are clarified as follows:

**Simple**: Without excavation, i.e. widening, or other minor construction work

**Moderate**: Shallow excavation, i.e. guide rail, low-depth pipe replacement, traffic light post, shoulder cutting, or minor drainage

**Complicated**: Deep excavation, i.e. new construction, full-depth reconstruction, bridge foundation, deep-depth pipe replacement, etc.
5-4-12. Quality of Utility Record (QUR)

Quality of utility record indicates the reliability of existing records on buried utilities. The availability of accurate historical utility records for the project can significantly reduce the potential for encountering unexpected underground utilities. This factor is characterized into three different categories: (1) good, (2) fair, and (3) poor. A poor quality of existing records requires more reliable underground information. The quality of utility record is categorized as follows:

**Good**: Very accurate record of utilities

**Fair**: Not very reliable record of utilities

**Poor**: Utilities information/data is not accurate

5-4-13. Excavation Depth within Highway Right-of-Way (EXD)

Depth of excavation within a highway right-of-way commonly may indicate whether or not SUE quality level A or B is needed. Note: this includes TCE or other easements. The accurate location of buried utilities at the project site should be determined to save project cost and time together with associated benefits. This depth factor can be characterized in three categories as follows:

**Low**: $\leq 18”$

**Medium**: $> 18”$ and $< 24”$
High : $\geq 24''$

5-4-14. Estimated Business Impact (EBI)

Business impact is concerned with the income and property loss for local businesses resulting from accidental hitting of unexpected buried utilities. At areas near or surrounding high business density, the more reliable underground information is essential. User impact, access to business, and length of service interruption should also be taken into consideration. Estimated business impact is categorized as follows:

Low : Very low business impact in the project area

Moderate : Possibility of some business impact in the project area

High : Great business impact in the project area

5-4-15. Estimated Environmental Impact (EEI)

Potential environmental problems caused by accidentally hitting an in-service utility such as gas explosion, oil spill, and/or water flooding need to be assessed. Project areas with high potential of environmental impacts require highly reliable underground information. Estimated environmental impact is categorized as follows:

Low : Very low environmental impact in the project area
Moderate: Possibility of some environmental impact in the project area

High: Great environmental impact in the project area

5-4-16. Estimated Safety Impact (ESI)

Safety impact is concerned with possible injury to people caused by accidentally hitting an in-service utility. Projects located in densely populated areas require highly reliable underground information to minimize such an impact. Estimated safety impact is categorized as follows:

Low: Very low safety impact in the project area

Moderate: Possibility of some safety impact in the project area

High: Great safety impact in the project area

5-4-17. Other Impact Factors (OIF)

The project with a high potential of other impact factors requires more reliable underground information to reduce project risks (e.g., blasting of rocks, other utilities relocation, etc.). Other impact factors are categorized as follows:

Low: Very low impact in the project area

Moderate: Possibility of some impact in the project area

High: Great impact in the project area
CHAPTER 6

COMPUTERIZED UTILITY IMPACT RATING FORM

This chapter presents a new computerized utility impact rating form. To quickly and accurately run repeated calculations, a computerized application tool is commonly developed by managers, designers, or engineers. The utility impact rating form is developed using Visual Basic (VB) software to provide a graphical interface for the purpose of enhancing the efficiency of the calculation and selection processes. VB is a programming language that allows automation of tasks and creation of new features in a Microsoft Windows environment. Figure 6-1 shows the system architecture of VB for the utility impact rating form.

FIGURE 6-1 System Architecture of Visual Basic
6-1. COMPUTERIZED UTILTIY IMPACT RATING FORM

The computerized utility impact rating form consists of 17 primary screens and 11 supplementary screens. The supplementary screens contain detailed descriptions of complexity factors and graphical representations related to risks. The success of the computerized form depends on the quality of the project information entered by the end-users. Step 1 of the computerized form seeks primary project information. As shown in Figure 6-2, this process consists of two screens. One is for project details such as project title, cost, general summary, actual work scope, and personnel information, and the other is for evaluation of the project.

![FIGURE 6-2 Screens for Step 1 of Visual Basic](image-url)
STEP 1 is codified to allow the system to limit projects for which it is not practical to apply SUE quality level B or A. If any boxes are checked in Column 2, it is moved to STEP 2 and if there are no boxes checked in Column 2, the system stops the process. STEP 2, shown in Figure 6-3, is also codified to limit projects for which it is not practical to apply SUE quality level B or A. This process depends on more detailed project information. If any boxes are checked in Column 2, it is moved to STEP 3 and if there are no boxes checked in Column 2, the system stops the process.

FIGURE 6-3 Screen for STEP 2 of Visual Basic
STEP 3 is codified to calculate the utility impact score and recommend appropriate quality levels. This process consists of two screens. One is for project/section/location details such as title, cost, general summary, and actual work scope and the other is for evaluation of the project. For the calculation of the utility impact score, STEP 3 requires end users to check the utility impact rating that best fits their opinion based on specific project information. This process includes 17 complexity factors and provides a detailed description for each complexity factor with HELP. Figure 6-4 and Figure 6-5 show screens of STEP 3 and screens for a detailed description of complexity factors, respectively.

**FIGURE 6-4 Screen for STEP 3 of Visual Basic**
Once the numbers of checked boxes for each column are entered into the blank boxes, the system calculates the utility impact score and shows the recommended SUE quality levels in a Final Result screen. As shown in Figure 6-6, the Final Result screen presents the utility impact score, recommended SUE quality levels and description, complexity levels, relative cost factors, and related risks. In addition, this system provides a graphical representation of project risk levels based on the relationship between recommended SUE quality levels and selected SUE quality levels. Figure 6-7 shows screens for graphical representation related to project risks. For another utility impact rating analysis for other projects, the user can click the button labeled New Utility Impact Score to reset the system and go back to STEP 1.
FIGURE 6-6 Screen for Final Result of Visual Basic

FIGURE 6-7 Screens for Graphical Representation of Visual Basic
6-2. SYSTEM VALIDATION

Although the proposed utility impact rating system is based on the expertise of project managers and experienced utility engineers, the system is required to be verified and tested through actual application to real projects. There are two different objectives in the validation process. The first objective is to verify the applicability of the utility impact rating form. This validation verifies whether the utility impact form can be utilized in actual field situations. This is achieved by comparing the results of actual projects with the outcomes of this system. The second objective is to verify the computerized utility impact rating form. Through this validation, the convenience and accuracy of the computerized system is verified in terms of comparing the manual-based outcomes with the computerized system-based outcomes of actual projects. Four case studies with actual projects are employed to validate the utility impact rating form and assess the computerized system. All project information was obtained from project managers or engineers of Penn DOT district offices who were involved in the projects, and they filled out utility impact rating forms for their own projects.

6-2-1. Project Stopped at STEP 1

As shown in Table 6-1, a project provided from Montoursville was used to verify Step 1. This project, which involved crack seals in various sections, did not have any evidence of
underground utilities in project areas or require any excavations. Based on the primary project information, the utility impact rating form indicated that this project should be stopped at Step 1, because it would not be practical or cost-effective to use SUE quality level B or A. In actuality, this project used quality level C&D information and was successfully developed without any problems related to underground utilities.

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Crack Seal, Various Sections (Bradford)</th>
</tr>
</thead>
<tbody>
<tr>
<td>District</td>
<td>District 3 – Montoursville</td>
</tr>
<tr>
<td>Total Project Cost</td>
<td>$75,000</td>
</tr>
<tr>
<td>Design Cost</td>
<td>$2,500</td>
</tr>
<tr>
<td>Project Scope</td>
<td>Seal Cracks</td>
</tr>
</tbody>
</table>

**Project Description**

This project was to seal cracks in various sections in Bradford. There was no evidence of underground utilities in the project area and the project did not require any excavation. It was not necessary to consider utility impacts. Without the use of SUE, there were no problems related to utilities.

<table>
<thead>
<tr>
<th>Utility Impact Score</th>
<th>N/A (Stop at STEP 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity Level</td>
<td>N/A (Stop at STEP 1)</td>
</tr>
<tr>
<td>Appropriate SUE Quality Levels</td>
<td>Quality Level C&amp;D</td>
</tr>
</tbody>
</table>
6-2-2. Project Stopped at STEP 2

Project SR 1012-MC2 was evaluated to verify STEP 2. As shown in Table 6-2, the purpose of this project was patching of concrete roads where utilities were known to exist.

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Concrete patching, SR 1012-MC2 (Blair)</th>
</tr>
</thead>
<tbody>
<tr>
<td>District</td>
<td>District 9 – Hollidaysburg</td>
</tr>
<tr>
<td>Total Project Cost</td>
<td>$550,000</td>
</tr>
<tr>
<td>Design Cost</td>
<td>$50,000</td>
</tr>
<tr>
<td>Project Scope</td>
<td>Patch SR 1012 and ramps from I-99 into Tyrone</td>
</tr>
</tbody>
</table>

Project Description

This project involved patching of concrete roads where utilities were known to exist. There was evidence of underground utilities in the project area and the project did require excavation. However, the depth of excavation was less than 18 inches, which is not extensive enough to use SUE; utility owners were able to show the location of their utilities in time; utility impacts were not expected; and the designer provided accurate design-construction related information. It was not necessary to consider utility impacts. Without the use of SUE, there were no problems related to utilities.

<table>
<thead>
<tr>
<th>Utility Impact Score</th>
<th>N/A (Stop at STEP 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity Level</td>
<td>N/A (Stop at STEP 2)</td>
</tr>
<tr>
<td>Appropriate SUE Quality Levels</td>
<td>Quality Level C&amp;D</td>
</tr>
</tbody>
</table>
This project required excavation work. However, the depth of excavation was less than 18 inches, which is not extensive enough to use SUE, utility owners were able to show the location of their utilities in time, utility impacts were not expected, and the designer provided accurate design-construction related information. Based on this project information, the utility impact rating form indicated that for this project, this process should be stopped at Step 2 because it was not practical or cost-effective to use SUE quality level B or A. This project actually used only quality level C&D information and was successfully finished without any problems related to underground utilities.

6-2-3. Project Stopped at STEP 3

In this section, two projects are evaluated to verify Step 3. One is a SUE project and the other is a non-SUE project. The SUE project shown in Table 6-3 had evidence of underground utilities in the project area and required excavation over 18 inches. In addition, utility impacts were expected and the designer was unreliable to provide accurate design-construction related information. Based on this project information this process proceeded to Step 3 to identify appropriate quality levels, and the utility impact rating form indicated a recommendation that at least SUE quality level B should be used for the project. This project actually used SUE quality level A and did not have any problems related to underground utilities. If only SUE quality level
D or C information were used for this project, some problems related to utility would have been encountered.

### TABLE 6-3 SUE Project Stopped at STEP 3

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Bellwood Road and Bridge, SR 0865-002 (Blair)</th>
</tr>
</thead>
<tbody>
<tr>
<td>District</td>
<td>District 9 – Hollidaysburg</td>
</tr>
<tr>
<td>Total Project Cost</td>
<td>$3.1 Million</td>
</tr>
<tr>
<td>Project Scope</td>
<td>Build new structure and realign road</td>
</tr>
</tbody>
</table>

**Project Description**

This project was to realign Bellwood bridge and road. There was evidence of underground utilities in the project area and the project did require excavation. In addition, the depth of excavation was more than 18 inches; utility impacts were expected; and the designer was unreliable to provide accurate design-construction related information. Given these factors, it was necessary to consider underground utility impacts and more detailed investigation. This project used SUE quality level A so that no problems related to utilities occurred.

<table>
<thead>
<tr>
<th>Utility Impact Score</th>
<th>1.80</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity Level</td>
<td>3</td>
</tr>
<tr>
<td>Appropriate SUE Quality Levels</td>
<td>Quality Level B</td>
</tr>
</tbody>
</table>

The project for construction of Hershberger Road and Sunray Drive Intersection in Blair County was used for verification with a non-SUE project. This project had evidence of underground
utilities in the project area. In addition, the depth of excavation was more than 18 inches, utility impacts were expected, and the project owner could not provide timely/accurate utility information. Table 6-4 shows a description of the non-SUE project.

**TABLE 6-4 Non-SUE Project Stopped at STEP 3**

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Hershberger Road and Sunray Drive Intersection, SR 3007-001 (Blair)</th>
</tr>
</thead>
<tbody>
<tr>
<td>District</td>
<td>District 9 – Hollidaysburg</td>
</tr>
<tr>
<td>Total Project Cost</td>
<td>$2.0 Million</td>
</tr>
<tr>
<td>Project Scope</td>
<td>Realign road, install drainage &amp; signals, construct entrance to HGA center</td>
</tr>
</tbody>
</table>

**Project Description**

This project was to realign the Hershberger Road and Sunray Drive intersection. There was evidence of underground utilities in the project area and the project did require excavation. In addition, the depth of excavation was more than 18 inches; utility impacts were expected; and the project owner could not provide timely/accurate utility information. Given these factors, it was necessary to investigate underground utility impacts in detail. However, this project did not use SUE quality level B or A, but SUE quality level C&D. There were problems related to utilities.

<table>
<thead>
<tr>
<th>Utility Impact Score</th>
<th>2.50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity Level</td>
<td>4</td>
</tr>
<tr>
<td>Appropriate SUE Quality Levels</td>
<td>Quality Level B or A</td>
</tr>
</tbody>
</table>
Based on the project information this project proceeded to Step 3 to identify appropriate quality levels, and the utility impact rating form recommended the use of at least SUE quality level B or A for this project. This project actually relied on only SUE quality level C&D. As a result, unknown gas lines were found during construction and the lines were relocated. This caused construction delay. In addition, water and sewer lines were omitted from the plan, which was completed with quality level C&D. If SUE quality level B or A information had been used for this project before construction, the problems caused by inaccurate and insufficient information could have been avoided so that project cost and time could have been saved.

The foregoing four case studies show that the utility impact rating form successfully recommends the most appropriate SUE quality levels. The computerized system has proved to be accurate and convenient for end users through comparing manual outcomes with computerized system-based outcomes. In general, the decision making on the selection of appropriate SUE quality levels is highly dependent on the experience of engineers or designers. Lack of experience can cause inappropriate levels of utility information so that project costs and time increase. The use of the utility impact rating form can help engineers or designers avoid these problems, make an accurate informed decision, and help convince project owners to pay for appropriate levels of utility information for their underground projects.
Utility owners, designers, managers, and engineers working with SUE for public or private projects expect numerous benefits on their own projects. SUE reduces unnecessary utility relocations, unexpected damages of existing utilities, mislocations of utilities, change orders and claims, personnel injuries, negative factors for productivity, social and environmental damages, and other problems related to utilities through accurate underground information. The benefits are combined with subsequent savings in time and cost for whole projects. Considerable previous research has shown that using SUE can save money on projects involving underground utilities.

This chapter describes a benefit-cost analysis (BCA) that quantifies the cost savings of SUE with projects developed in Pennsylvania. The BCA identifies how much money can be saved per dollar spent on SUE. This study uses both SUE projects and non-SUE projects to quantify the cost savings of SUE, while previous research used only SUE projects. This approach can increase the possibility to have more reliable benefit-cost numbers.
7-1. BENEFIT-COST ANALYSIS

Benefit-cost analysis is an approach that is preferred to prove the effectiveness of new systems or techniques. BCA estimates the equivalent money value of the benefits and costs of projects to determine whether or not the systems or techniques are worthwhile. The BCA of SUE is conducted with SUE projects and non-SUE projects that have problems related to underground utilities. B (Benefit) / C (Cost) is the fundamental relationship in BCA. When B/C > 1, utilizing SUE provides more beneficial results than not using SUE. If B/C ≤ 1, there is no reason to utilize SUE. All projects in this study were collected from district offices of Penn DOT. Estimated benefits and costs were investigated by conducting interviews with Penn DOT utility engineers who were involved in the projects, analysis of historical data, review of individual project studies, and actual benefits and costs derived from direct costs of projects.

7-1-1. Benefit-Cost Analysis of SUE projects

In SUE projects, benefits are estimated costs that are derived from utility engineer’s feedback, historical data, and individual project studies. The benefits are determined from the differences in underground utility information before and after using SUE. SUE costs were obtained form direct costs of using SUE in the projects. Equation 7-1 shows the equation for the Benefit-Cost Ratio (BCR) of SUE projects.
Where, \((BCR)_{SUE} = \frac{B_{SUE}}{C_{SUE}}\)  

7-1-2. Benefit-Cost Analysis of Non-SUE Projects

Previous research efforts utilized only SUE projects to quantify cost savings of SUE. Those studies inferred estimated costs as SUE benefits from utility conflicts that were revealed by SUE. However, as Osman and El-Diraby (2005) mentioned, the mere identification of utility conflicts does not necessarily result in a cost being incurred. In this study, non-SUE projects with problems are also used to determine the cost savings of SUE, because they can provide direct costs as SUE benefits incurred from problems related to utilities. SUE costs of non-SUE projects must be inferred since SUE was not used. The SUE costs used are estimated costs which are determined with input from PennDOT utility engineers, historical data, and individual project studies. Equation 7-2 shows the equation for benefit-cost ratio of non-SUE projects.

\((BCR)_{NON-SUE} = \frac{B_{NON-SUE}}{C_{NON-SUE}}\)  

Equation 7-2
Where, \[(BCR)_{NON-SUE} = \text{Benefit-cost ratio of non-SUE projects}\]
\[B_{NON-SUE} = \text{Actual benefits of quality level A of non-SUE projects}\]
\[C_{NON-SUE} = \text{Estimated SUE costs of non-SUE projects}\]

7-1-3. Benefit Factors of SUE

There are a number of benefits associated with utilizing SUE. In this study, 11 main benefit factors are identified to conduct BCA of SUE. The main benefit factors involve detail factors. Some benefits can be quantified in a reliable manner, while others are difficult to quantify.

7-1-3-1. Utility Relocation Cost

Utility relocation costs include utility redesign cost, utility relocation cost, project delay cost by utility relocation, project delay cost by discovering unexpected utilities, change orders, and claims costs of contractors and subcontractors. By using SUE in the design stage, the designer will be able to avoid costs incurred by unnecessary utility relocation and by discovering unexpected utilities or objects that are in conflict. For example, a design shows a utility line that must be relocated to avoid conflicts with the proposed utility, so the contractor starts to dig for the utility relocation. However, if the utility that was expected to be found does not actually exist, the contractor will identify the mistake in the design only after digging. Construction
would be shut down or delayed to address the problem and redesign the project with more accurate information. Sometimes, the discovery of unexpected utilities or objects happens during construction. If there is an unknown utility that is in conflict and is not identified in the design, it also takes time to uncover the problems and redesign the project. However, SUE allows the designer to identify exact locations of utilities so that unnecessary utility relocation design and unexpected utility conflicts would be avoided at the design stage. To identify SUE benefits related to utility relocation cost, SUE reports and interviews are used for SUE projects, and direct costs are used for non-SUE projects.

7-1-3-2. Utility Damage Cost

Utility damage costs include person injury costs, equipment damage costs, and third-party damage costs. By using SUE, the designer provides a better design to avoid costs incurred by utility damages. If a contractor does not know about the existence or exact location of buried utilities, utility-damaging accidents are likely to happen. These accidents can lead to person injuries, equipment damage, and third-party damages. However, SUE allows the designer and the contractor to reduce the costs incurred by utility damages. For SUE projects, interviews and historical data are used for benefit-cost analysis (BCA). For non-SUE projects, direct costs spent on personal injuries, equipment damage, and third-party damages are used for BCA.
7-1-3-3. Emergency Restoration Cost

Emergency restoration costs include utility restoration costs and project delay costs caused by the emergency. The use of SUE avoids emergency restoration costs incurred by utility damages. If the contractor conducts excavation work without accurate information, utility-damaging accidents are likely to happen, leading to utility damage and project delays. SUE allows the designer to have accurate underground information around construction sites so that costs incurred by utility damage would be reduced. For SUE projects, interviews and historical data are used for BCA. For non-SUE projects, direct costs spent on utility restoration and project delays resulting from the emergency are used for BCA.

7-1-3-4. Traffic Delay Cost

Traffic delay cost is primarily users’ time delay cost. The delay may include traffic speed reduction and queuing delay. Such a delay cost incurred by hitting utilities can be saved by using SUE. If the designer and the contractor do not know about the existence or exact location of utilities around target sites, utility-hitting accidents can easily happen. Hitting utilities can cause leakage of products such as water or gas and necessitate more work, leading to additional traffic delays; however, these traffic delays could be reduced by using SUE because the SUE can reduce utility accidents. It is very difficult to estimate traffic delay cost in SUE projects that do
not have actual damages; therefore, traffic delay cost is not analyzed for BCA in SUE projects but, rather, in non-SUE projects. Interviews are used for the analysis in non-SUE projects.

7-1-3-5. Business Impact Cost

Business impact cost is the cost to business incurred by loss of business. Business impact cost may occur due to accidentally hitting existing utilities. It may involve the cost due to hindering business access, damage to business such as inventory loss to flooding or fire, and others. SUE allows avoiding or reducing business impact costs incurred by hitting utilities. Hitting utilities because of inaccurate information can cause leaking of products such as water or gas and necessitate additional work so that the impact on businesses around construction sites would be increased. However, SUE allows the designer to efficiently design so that business impact costs caused by hitting utilities would be reduced. It is also difficult to estimate the business impact cost in SUE projects that do not have actual damages; therefore, business impact cost is not analyzed for BCA in SUE projects. For non-SUE projects, business impact costs are estimated through interviews with personnel who are involved in projects.

7-1-3-6. User Service Cost

User service cost refers to the monetary value for users’ inconveniences incurred by loss/delay of
service (for example, loss/delay of internet, gas, cable, telephone, water, etc.). Sometimes, utility hits result in service loss, so that service users cannot use the services until the restoration is completed. However, SUE allows the designer to identify the exact information for all utilities so that user service losses caused by hitting utilities would be reduced. It is very difficult to estimate user service cost in SUE projects that do not have actual damages; therefore, user service cost is not analyzed for BCA in SUE projects. For non-SUE projects, user service costs are considered based on interviews and historical data.

7-1-3-7. Environmental Impact Cost

Environmental impact cost is the cost to restore/remediate the impacted environment. An example is the cost for cleaning or removing contaminated ground. By using SUE reports in the design stage, the designer designs efficiently and accurately and avoids environmental impact costs that could be incurred by hitting utilities. Hitting utilities can cause leakage of products such as water or gas and necessitate additional work as well as lead to environmental problems. However, by using SUE, environmental costs caused by hitting utilities would be reduced. It is very difficult to estimate the environmental impact cost of resolving environmental problems in SUE projects; therefore, environmental impact cost is not analyzed for BCA in SUE projects. The direct costs are used for BCA in non-SUE projects.
7-1-3-8. Information Gathering and Verification Cost

Information Gathering and Verification Cost is the cost for gathering and verifying utility information without using SUE. Traditional costs for gathering and verifying related utility information can be avoided by using SUE in the design stage. SUE provides all related information so that the designer does not need to spend money and time to gather and verify information. For BCA, interviews are used for SUE projects, and direct costs to gather and verify underground information are used for non-SUE projects.

7-1-3-9. Legal and Litigation Cost

Legal and Litigation cost is money spent on the negotiation, arbitration, legal and litigation process to resolve dispute. SUE can reduce legal and litigation costs. Accurate utility information provided by SUE can reduce unexpected problems resulting from claims, change orders, or other reasons so that legal and litigation costs would be reduced. The savings in legal and litigation costs can then be considered a benefit of SUE. For SUE projects, interviews are used for BCA, and for non-SUE projects, direct costs of projects are used.

7-1-3-10. Efficient Utility Design and Construction

Efficient utility design and construction means that the design can minimize conflicts and can
result in reduction in amount of time spent for redesign and design change orders. By using reliable underground information, the designer saves time in designing and makes a design for one time only to avoid or minimize costs incurred by unnecessary work. For example, if the proposed utility is designed to detour around a utility that is expected to have existed but does not actually exist, the design can cause construction delay and cost increases. Using SUE allows the designer to identify the existence and exact locations of all utilities so that unnecessary work would be avoided in the design stage. For SUE projects, discrepancies between quality levels A and B and quality levels C and D can provide information for identifying and estimating unnecessary work. Also, interviews with personnel who are involved in projects are used to estimate cost savings and time savings for design and construction for BCA. For non-SUE projects, direct costs of projects are used for BCA. Efficient utility design leads to design cost savings and unnecessary construction cost savings.

7-1-3-11. Other Utility Related Costs and Benefits

Other Utility Related Costs and Benefits are the factors that are not described in previous items. Examples include savings in risk management and insurance, digital mapping accuracy, comprehensive utility management system, etc. For other utility related costs and benefits, interviews are used with personnel who were involved in SUE projects.
7-1-4. Cost Factors of SUE

In SUE, there are two kinds of costs. One is the designation cost that is involved in quality level A or B, and the other is the location cost involved in quality level A. Designation costs are for the use of geophysical techniques to designate the horizontal position of underground utilities/objects, and location cost is for the use of vacuum excavation systems to locate horizontal and vertical position as well as finding out other utility information and soil information. For SUE projects, the SUE costs are obtained from direct costs of projects, while for non-SUE projects the SUE costs are derived from interviews, historical data, and individual project studies.
This chapter describes BCA of SUE and utility impact scores. For this study, 30 projects from Penn DOT districts, including Clearfield, Montoursville, Dunmore, Allentown, King of Prussia, and Hollidaysburg, were analyzed to evaluate the quantitative benefits of SUE and utility impact scores. Twenty-two projects utilized SUE quality level A or B and eight projects utilized traditional methods, SUE quality level C and D for collecting underground information. All projects were selected randomly. All case studies were investigated via interviews with utility engineers of Penn DOT districts who were involved in the projects. Individual studies of the projects and historical data were also used to identify discrepancies in utility information before and after SUE and to estimate benefits of SUE.

8-1. BENEFIT-COST ANALYSIS

The projects investigated in this study involved road construction, bridge replacement, interchange construction, and intersection improvements in rural, suburban, and urban areas. Table 8-1 presents general information on the projects.
### TABLE 8-1 General Information for Projects

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Description</th>
<th>Total Project Cost*</th>
<th>Design Cost</th>
<th>Project Area</th>
<th>Quality of Utility Record</th>
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<td>$710,000</td>
<td>Suburban</td>
<td>Fair</td>
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<td>$600,000</td>
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<td>Fair</td>
</tr>
<tr>
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<td>Bridge Replace.</td>
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<td>$2,000,000</td>
<td>Urban</td>
<td>Fair</td>
</tr>
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<td>$200,000</td>
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<td>Fair</td>
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<td>$1,000,000</td>
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<td>Poor</td>
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<td>Suburban</td>
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<tr>
<td>SR 2027-A01</td>
<td>Bridge Replace.</td>
<td>$1,900,000</td>
<td>n/a</td>
<td>Rural</td>
<td>Fair</td>
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<td><strong>District 5 – Allentown</strong></td>
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<tr>
<td>SR 0145-05S</td>
<td>Roadway Con.</td>
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<td>$1,500,000</td>
<td>Urban</td>
<td>Fair</td>
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<td>$3,500,000</td>
<td>Suburban</td>
<td>Poor</td>
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<td>Suburban</td>
<td>Fair</td>
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<tr>
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<td>$1,200,000</td>
<td>Rural</td>
<td>Fair</td>
</tr>
<tr>
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<td>$216,800,000</td>
<td>$79,900,000</td>
<td>Urban</td>
<td>Fair</td>
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<tr>
<td><strong>NON-SUE PROJECT (8 Projects)</strong></td>
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<td>SR 3007-001</td>
<td>Roadway Con.</td>
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<td>$300,000</td>
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<td>Fair</td>
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<td>Roadway Con.</td>
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<td>SR 4013-001</td>
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<td>$19,600,000</td>
<td>$1,200,000</td>
<td>Urban</td>
<td>Fair</td>
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<tr>
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<td>$2,000,000</td>
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<td>Fair</td>
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<td><strong>District 5 – Allentown</strong></td>
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<td>SR 4012-DLY</td>
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<td>$1,800,000</td>
<td>Urban</td>
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<td>Fair</td>
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<tr>
<td>SR 0078-17M</td>
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<td>$5,200,000</td>
<td>Suburban</td>
<td>Fair</td>
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<tr>
<td>SR 0222-002</td>
<td>Roadway Con.</td>
<td>$60,400,000</td>
<td>n/a</td>
<td>Urban</td>
<td>Fair</td>
</tr>
</tbody>
</table>

* Total project cost includes construction cost and design cost.
Projects of various sizes were analyzed, with project costs ranging from $125,000 to $313.8 million. The quality of the utility records for the projects was poor or fair. Nobody thought that they had good utility information to conduct their projects. As shown in Tables 8-2 to 8-7, the expenditure for using SUE ranged from $13,050 to $240,400 for the SUE projects. The ratio of SUE cost to the total project cost ranged from 0.01% to 19.2%, with an average ratio of 0.16%. In non-SUE projects, the expected SUE costs were determined to range from $10,000 to $150,000. The ratio of expected SUE cost to the total project cost ranged from 0.06% to 3.00%, and the average ratio was 0.24%. For total projects, 0.17% was determined as the ratio of SUE cost to total project cost. The SUE projects showed cost savings that ranged from $50,000 to $4.5 million. The B/C ratio ranged from 3.21 to 33.93, with an average of 13.66. In non-SUE projects, the cost savings were determined to range from $40,000 to $1.29 million. The B/C ratio ranged from 2.35 to 8.60, and the average ratio was 5.13. The B/C ratio of SUE projects was much higher than that of non-SUE projects. The difference of B/C ratio can be explained by how the benefits of SUE are quantified. For SUE projects, all possible problems caused by inaccurate utility information were considered to quantify the benefits, while direct costs to resolve actual problems that happened during construction were factored into the benefits for non-SUE projects. Average B/C ratio of 11.39 was estimated for total projects. This means that $11.39 can be saved for $1 spent on SUE. Table 8-2 shows benefit-cost analysis and utility impact scores.
### TABLE 8-2 Benefit-Cost Analysis and Utility Impact Score for Projects

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Project Cost</th>
<th>SUE Cost (C)</th>
<th>Cost Saving (B)</th>
<th>B/C</th>
<th>SUE % of Total Project Cost</th>
<th>Saving % of Total Project Cost</th>
<th>Impact Score</th>
<th>Comp. Level</th>
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<tbody>
<tr>
<td><strong>SUE PROJECT (22 Projects)</strong></td>
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<td>District 9 – Hollidaysburg</td>
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<tr>
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<td>$3,100,000</td>
<td>$20,000</td>
<td>$65,000</td>
<td>3.25</td>
<td>0.65</td>
<td>2.10</td>
<td>1.80</td>
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<td>$34,243</td>
<td>$165,050</td>
<td>4.82</td>
<td>1.43</td>
<td>6.88</td>
<td>2.37</td>
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<td>$265,000</td>
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<td>1.92</td>
<td>10.19</td>
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<td>4</td>
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<td>$50,000</td>
<td>$1,515,000</td>
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<td>$1,600,000</td>
<td>$44,804</td>
<td>$1,515,000</td>
<td>33.81</td>
<td>2.80</td>
<td>94.69</td>
<td>2.81</td>
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<td>4.91</td>
<td>25.00</td>
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### TABLE 8-3 Summary of Cost Savings for SUE Projects

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<th>Change order &amp; claim cost ($)</th>
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<th>Traffic delay cost ($)</th>
<th>Business impact cost ($)</th>
<th>Environmental impact cost ($)</th>
<th>Design &amp; construction cost ($)</th>
<th>Information gathering &amp; verification cost ($)</th>
<th>Total Cost Savings ($)</th>
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### TABLE 8-4 Summary of Cost Savings for Non-SUE Projects

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<th>Change order &amp; claim cost ($)</th>
<th>Restoration cost ($)</th>
<th>Delay cost by emergency ($)</th>
<th>Traffic delay cost ($)</th>
<th>Business impact cost ($)</th>
<th>Environmental impact cost ($)</th>
<th>Design &amp; construction cost ($)</th>
<th>Information gathering &amp; verification cost ($)</th>
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### TABLE 8-5 Summary of Cost Savings for Total Projects

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<th>Delay cost by unexpected utility ($)</th>
<th>Change order &amp; claim cost ($)</th>
<th>Restoration cost ($)</th>
<th>Delay cost by emergency ($)</th>
<th>Traffic delay cost ($)</th>
<th>Business impact cost ($)</th>
<th>Environmental impact cost ($)</th>
<th>Design &amp; construction cost ($)</th>
<th>Information gathering &amp; verification cost ($)</th>
<th>Total Cost Savings ($)</th>
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</thead>
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<td>SUE Project</td>
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<td>75,000</td>
<td>85,000</td>
<td>1,500,000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7,460,000</td>
<td>225,000</td>
<td>23,155,050</td>
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<td>Non-SUE Project</td>
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<td>1.04</td>
<td>6.81</td>
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<td>0.26</td>
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<td>29.46</td>
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Table 8-6 Ratio of SUE Cost and Cost Saving to Project Cost

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<th>Average SUE Cost % of Total Project Cost</th>
<th>Average Cost Saving % of Total Project Cost</th>
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<tbody>
<tr>
<td>SUE Projects</td>
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<tr>
<td>Non-SUE Projects</td>
<td>0.24 %</td>
<td>1.41 %</td>
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<td>Total Projects</td>
<td>0.17 %</td>
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Table 8-7 B/C for Projects

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<th>B/C to Complexity Levels</th>
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<td>Max</td>
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<td>Non-SUE Projects</td>
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<td>Total Projects</td>
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Table 8-3 and Table 8-4 present a summary of the cost savings itemized for SUE projects and non-SUE projects respectively. Some items are deleted from the tables, because nobody responded to the items. As shown in Table 8-5, project relocation cost is the most important item
to the cost savings as 40.33% of total saving. Based on these results SUE definitely can reduce unnecessary utility relocation by using accurate underground information in the early stage of design. Cost savings in construction and design costs are the second contributors (29.46%). SUE enables designers to design efficiently and accurately with reliable information, so that design time can be saved and unnecessary construction works can be avoided or reduced. Redesign costs and delay cost by relocation represent 9.59% and 9.08% of total cost savings of SUE, respectively. Other cost saving items include delay cost by emergency (6.81%), delay cost by unexpected utility (1.41%), information gathering and verification cost (1.41%), restoration cost (1.04%), etc. Table 8-6 and Table 8-7 show the ratio of SUE cost and cost saving to project cost and B/C of projects. For SUE projects, the ratios of cost savings to the total project cost ranged from 0.06% to 96.69%, with an average ratio of 2.74%. Non-SUE projects showed cost savings ratios that ranged from 0.19% to 13.00%, with an average ratio of 1.41%. An average cost saving ratio of 2.49% was estimated for total projects.

8-2. COMPLEXITY LEVEL

Table 8-8 and Table 8-9 show complexity factors and Penn DOT districts’ responses to each factor for SUE projects and non-SUE projects. Based on the complexity factors, the utility impact scores were calculated in the utility impact rating form.
### TABLE 8-8 Complexity Factors of SUE Projects

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L: Low Impact, M: Medium Impact, H: High Impact

*Density of utilities : DOU  Project area description : PAD
Type of utilities : TOU  Type of project/section/location : TOP
Pattern of utilities : POU  Quality of utility record : QUR
Material of utilities : MOU  Excavation depth : EXD
Access to utilities : ATU  Estimated business impact : EBI
Age of utilities : AOU  Estimated Environmental Impact : EEI
Estimated utility relocation costs : ERC  Estimated Safety Impact : ESI
Estimated project traffic volume : ETV  Other impact factor : OIF
Project time sensitivity : PTS
### TABLE 8-9 Complexity Factors of Non-SUE Projects

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Estimated utility relocation costs : ERC  Estimated Safety Impact : ESI
Estimated project traffic volume : ETV  Other impact factor : OIF
Project time sensitivity : PTS

As shown in Table 8-2, for the SUE projects, the utility impact scores ranged from 1.63 to 2.94, with an average of 2.38. Complexity levels 2, 3, 4, and 5 were analyzed. Utility impact scores for the non-SUE projects ranged from 2.29 to 2.81, with an average of 2.57. Complexity levels 4 and 5 were analyzed for the non-SUE projects. The average impact score for all projects was 2.43, which matched with complexity level 4. Almost all of the projects showed relatively high utility impact scores and complexity levels. The SUE projects used SUE because the project sites were expected to have utility conflicts. For the non-SUE projects, projects that had problems related to...
utility conflicts were analyzed for this study. This is why the utility impact scores and complexity levels were all relatively high.

8-3. BENEFIT-COST ANALYSIS AND COMPLEXITY LEVEL

Figure 8-1 and Figure 8-2 show that there is no relationship between project cost and B/C. Some states have required the use of SUE based on total project costs. It has been assumed that the B/C of SUE in projects increases as project cost increases. However, this study shows that project cost and the B/C of SUE do not have any obvious relationship. The project cost also does not have any relationship with the complexity level of the project. Figure 8-3 and Figure 8-4 show the relationship between project cost and utility complexity level. Figure 8-5 and Figure 8-6 show a relatively proportional relationship between complexity level and B/C for both SUE projects and non-SUE projects. The B/C of SUE increases as the complexity level of the project increases. As shown in Table 8-2, for the SUE projects, the B/C of projects with complexity levels 2 and 3 ranged from 3.21 to 3.46. The B/C that almost all projects with complexity level 4 had was plotted on the graph from 4.06 to 5.56. Only three projects showed high B/C, with values over 20.00. In the three projects, cost savings related to utility relocation costs and design costs were much higher than those of other projects. The projects with complexity level 5 showed an extremely high B/C ranging from 30.30 to 33.93.
FIGURE 8-1 Project Cost vs. B/C of SUE Projects

FIGURE 8-2 Project Cost vs. B/C of Non-SUE Projects

FIGURE 8-3 Project Cost vs. Complexity Level of SUE Projects
FIGURE 8-4 Project Cost vs. Complexity Level of Non-SUE Projects

FIGURE 8-5 Complexity Level vs. B/C of SUE Projects

FIGURE 8-6 Complexity Level vs. B/C of Non-SUE Projects
There was a significant difference in average B/C between complexity levels 4 and 5. As shown in Table 8-7, the average B/C of projects with complexity level 4 was 9.29, while the average of B/C with complexity level 5 was 32.12. For non-SUE projects, projects with complexity level 4 ranged from 2.35 to 3.25 with the average value of 2.80, while projects with complexity level 5 ranged from 4.00 to 8.60 with the average value of 5.91. For total projects, the average of B/C of complexity level 4 projects is 8.47, while the average of B/C of complexity level 5 projects is 17.83. A small difference in complexity levels resulted in a great difference in benefits of SUE. Therefore, for projects with complexity level 5, the most accurate utility information is required to reduce risk and maximize benefits. However, if more projects and more complexity levels are applied for this analysis, the difference in benefits between complexity level 4 and 5 would be less and the graph also would be changed less. In general, the B/C of non-SUE projects was lower than that of SUE projects. As mentioned before, all possible problems encountered during construction were considered to analyze the benefits of SUE for SUE projects, and only actual problems encountered in projects were used for non-SUE projects. In addition, for SUE projects, the entire project was considered to estimate B/C. However, for non-SUE projects, a section or location of the project which had some problems was considered for the estimation of B/C. The difference in B/C between SUE and non-SUE projects also likely would become less with the inclusion of more SUE and non-SUE projects.
9-1. SUMMARY

Traditional damage prevention practices on underground utilities have relied on existing records and one-call systems which often provide incorrect, incomplete, and inadequate information. As an improved damage prevention practice, SUE has been utilized to reduce risks and increase cost-savings for underground projects. The objective of this study is to develop a decision-support tool called utility impact rating form and a benefit-cost analysis to effectively utilize SUE. Utility impact rating form was developed throughout literature reviews and interviews with Penn DOT utility managers, and benefit-cost analysis was conducted for 22 SUE projects and 8 non-SUE projects obtained from different Penn DOT districts.

To provide better understanding of SUE, this study addresses comprehensive information in various aspects of SUE presented by ASCE, AAHOTO, FHWA, GAO, and other previous studies. Geophysical techniques and factors affecting accuracy of SUE were identified to help utility engineers and designers to select appropriate techniques for underground projects. In this study, utility impact rating form has been developed to determine which projects should include SUE and what the appropriate level of SUE should be selected, based on the complexity
level at the construction site. A computerized utility impact rating form has been developed using Visual Basic software to provide a graphical interface to enhance the efficiency of the calculation and selection processes.

From benefit-cost analysis, the SUE projects showed cost savings that ranged from $50,000 to $4.5 million. The B/C ratio ranged from 3.21 to 33.93, with an average of 13.66. Non-SUE projects showed cost savings that ranged from $40,000 to $1.29 million. The B/C ratio ranged from 2.35 to 8.60, and the average ratio was 5.13. The results revealed that $11.39 can be saved for every $1 spent on SUE in project costs. This means that SUE can provide accurate utility information to achieve cost savings in construction projects. The average ratio of SUE cost to total project cost was determined to be 0.17% and the average cost saving ratio of 2.49% was estimated for total projects. Project relocation cost was the most important item in achieving cost savings as high as 40.33% of total saving. For the SUE projects, the utility impact scores ranged from 1.63 to 2.94, with an average of 2.38. Complexity levels 2, 3, 4, and 5 were analyzed. Utility impact scores for the non-SUE projects ranged from 2.29 to 2.81, with an average of 2.57. Complexity levels 4 and 5 were analyzed for the non-SUE projects. The average impact score for all projects was 2.43, which matched with complexity level 4.

This study shows that there is no apparent relationship between project cost and B/C nor between project cost and complexity level. However, the results indicate that there is a strong
relationship between complexity levels of buried utilities at the construction sites and B/C of SUE. The greater the complexity level of buried utility, the higher the SUE benefits. For 30 projects, the average B/C for complexity level 4 projects is 8.47 and the average B/C for complexity level 5 projects is 17.83. A small difference in complexity levels has resulted in a great difference in benefits of SUE. For projects with complexity level 5, the most accurate utility information is required to reduce risk and maximize benefits.

9-2. CONCLUSIONS

Based on the results of this study, it is concluded that SUE is a practical and effective process to reduce risks and maximize cost savings for underground projects. From benefit-cost analysis, it is also concluded that SUE quality levels A and B should be used based on the complexity of the buried utilities at the construction site, because there is a strong relationship between the SUE benefits-cost ratio and the complexity of the buried utilities at the construction site. Therefore, the utility impact rating form developed in this study can be utilized to determine which projects should include SUE and the appropriate level of SUE investigation needed, because the form has been developed based on complexity levels of construction sites. The results of this study can help owners and designers to enable safer construction conditions and save project costs.
9-3. RECOMMENDATIONS

This study contributes to a growing area of SUE research not only by developing the utility impact rating form, but also by conducting a benefit-cost analysis of SUE. However, more in-depth verification should be conducted by expanding the number of SUE and non-SUE projects evaluated and, where appropriate, modifying the utility impact rating form. Although the utility impact form was developed from discussion with experts and the benefit-cost analysis is conducted with actual SUE and non-SUE projects, a more effective impact rating form and more accurate analysis can be achieved by more rigorous investigations. Future research should pursue further the selection of geophysical techniques, because the available techniques vary according to soil and construction site conditions. For SUE quality level A and B, a decision matrix tool to select appropriate geophysical techniques should be developed for managers, designers, and engineers for successful SUE projects.
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APPENDIX A

Case Studies from Penn DOT Districts

(22 SUE Projects and 8 Non-SUE projects)
SUE PROJECTS

1. SUE Project 1 – SR 0865-002

Project Title : Bellwood Road and Bridge, SR 0865-002 (Blair)
District : District 9 – Hollidaysburg
Total Project Cost : $3.1 Million
Design Cost : $330,000
SUE Cost : $20,000 (Designating: $10,000, Locating: $10,000)
Project Scope : Build new structure and realign road
Project Description :
The project involved relocation of a roadway and reconstruction of a bridge in the rural area of Bellwood. The SUE was used on the roadway portion to design drainage facilities. In the early project stage, there was some information on a gas line on one side of the existing road and a waterline on the other side at the project site. The technology used for SUE quality level B included basic electro-magnetic equipment such as the pipe & cable locator and metal detector. For SUE quality level A, the vacuum excavation method was used at 15 different locations. Based on the results of SUE investigation, the decision was made to place the drainage facilities on the side of the road where the waterline was located. On that side of the road, there was less impact length and more room for relocation and also work could be done by the Department contractor.

Cost Savings by SUE
Utility relocation cost : $5,000
Design & construction cost : $50,000
Information gathering & verification cost : $10,000
Total Saving : $65,000
B/C Ratio : $65,000 / $20,000 = 3.25
Impact Score : 1.80
Complexity Level : 3
2. SUE Project 2 – SR 2014-04M

Project Title : Cresson Culvert, SR 2014-04M (Cambria)
District : District 9 – Hollidaysburg
Total Project Cost : $2.4 Million
Design Cost : $710,000
SUE Cost : $34,243 (Designating: $11,000, Locating: $23,243)
Project Scope : Rebuild roadway under RR overpass
Project Description :
The project was to rebuild a roadway under a railroad overpass. Work involved complete reconstruction of a portion of roadway and installation of drainage facilities. Preliminary information revealed a gas line parallel to the roadway plus underground telephone line and water pipeline within the project site. However, the exact location and the depth of the pipe lines were unknown. SUE investigation was conducted by means of an electro-magnetic equipment and close coordination with utility for quality level B. For quality level A, the vacuum excavation method was performed at 15 different locations. Based on the results of SUE investigation, the drainage facilities were designed to avoid utilities at various locations. Meanwhile, the results of SUE allowed the gas company to map a better plan for relocation.

Cost Savings by SUE
Utility relocation cost : $5,050
Design & construction cost : $150,000
Information gathering & verification cost : $10,000
Total Saving : $165,050
B/C Ratio : $165,050 / $34,243 = 4.82
Impact Score : 2.37
Complexity Level : 4
3. SUE Project 3 – SR 0022-024

Project Title : 3rd Ave. Bridge, SR 0022-024 (Blair)
District : District 9 – Hollidaysburg
Total Project Cost : $2.6 Million
Design Cost : $600,000
SUE Cost : $50,000 for designating and location
Project Scope : Bridge replacement
Project Description :

The project was a replacement of an entire existing bridge located at an urban area with high traffic volume. There were three water authorities that crossed at this bridge, one around and two under. The two lines were 12 in. in diameter. There was also a telephone conduit system and vault near the bridge with 10 conduits attached to the existing bridge. Homes and businesses were adjacent to the bridge and allowed little or no room to relocate the facilities. The project length was approximately ¼ miles. The bridge had to be fully open to traffic by a certain date, so it was a time-sensitive project. The initial SUE information was incorrect. SUE firm found that the utility marked plans were wrong. Utility had depicted the facilities assuming the top of the page was north. In fact, on this plan the top of the page was south. The quality level B SUE investigation was conducted by using the electro-magnetic equipment along with close coordination with utility. For quality level A, the vacuum excavation method was performed at 9 different locations. As a result of SUE investigation it was able to design shoring around existing telephone conduits, design the bridge to accommodate telephone facilities, and positively identify the gas line and determine that it was not impacted.

Cost Savings by SUE
Utility relocation cost : $150,000
Design & construction cost : $100,000
Information gathering & verification cost : $15,000
Total Saving : $265,000
B/C Ratio : $265,000 / $50,000 = 5.30
Impact Score : 2.50
Complexity Level : 4
4. **SUE Project 4 – SR 4013-002**

**Project Title**: 7th St Bridge, SR 4013-002 (Blair)

**District**: District 9 – Hollidaysburg

**Total Project Cost**: $11.6 Million

**Design Cost**: $2.0 Million

**SUE Cost**: $50,000 (Designating: $23,000, Locating: $27,000)

**Project Scope**: Replace sidewalks, place lighting, and narrow road to provide parking
- Replace bridge, remove 2 bridges, and realign road

**Project Description**:
The project took place in an urban area and involved replacing an existing bridge, widening traffic lanes, and constructing new bridge approaches. The bridge crossed over Norfolk Southern main railroad tracks and led directly to the area hospital. A large underground phone system had been relocated near the project site two years prior to the project. The project length was approx 1/2 mile. Available information revealed 16-in. gas line, 12-in. water and sewer line, three underground fiber-optic lines in different conduit runs, buried telephone and vault as well as some unknown lines in the project area. However, the exact location and direction of the existing lines are unknown. For quality level B SUE investigation, the electro-magnetic equipment was used together with field meeting between SUE firm and utilities, and coordination with utility to carry “beacon” into pipelines. For quality level A, the vacuum excavation method was conducted at 44 different locations. As a result of the SUE investigation, the roadway drainage facilities were successfully designed to save time and relocation expenses; the potential impact of bridge piers construction on the existing lines was avoided; and also the culvert was tied onto the existing pipes.

**Cost Savings by SUE**

- **Utility relocation cost**: $500,000
- **Design & construction cost**: $1.0 Million
- **Information gathering & verification cost**: $15,000

**Total Saving**: $1,515,000

**B/C Ratio**: $1,515,000 / $50,000 = 30.30

**Impact Score**: 2.69

**Complexity Level**: 5
5. **SUE Project 5 – SR 0036-25M**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Project Title</strong></td>
<td>18th St Culvert, SR 0036-25M (Blair)</td>
</tr>
<tr>
<td><strong>District</strong></td>
<td>District 9 – Hollidaysburg</td>
</tr>
<tr>
<td><strong>Total Project Cost</strong></td>
<td>$1.6 Million</td>
</tr>
<tr>
<td><strong>Design Cost</strong></td>
<td>$200,000</td>
</tr>
<tr>
<td><strong>SUE Cost</strong></td>
<td>$44,804 (Designating: $15,000, Locating: $29,804)</td>
</tr>
<tr>
<td><strong>Project Scope</strong></td>
<td>Lower road under RR Culvert and install drainage</td>
</tr>
</tbody>
</table>

**Project Description:**
The project was to add drainage to an existing road and also to lower the roadway as much as possible to provide additional overhead clearance for trucks to go freely under a railway overpass. The available information revealed that there was a complex existing utility network at the project site. This included a 12-in. diameter gas line, a 16-in. diameter water pipeline, a large buried telephone system, an underground electric system, and an abandoned 36-in. sewer culvert along with a 72-in sewer pipe, all within a 22 ft wide roadway. For SUE quality level B investigation, the electro-magnetic equipment was used along with close coordination with utility. For quality level A investigation, the vacuum excavation method was conducted at 15 different locations. Results of SUE investigation indicated that many of those facilities were abandoned and that the proposed gas line relocation would not work. Also, SUE provided proper location for inlet and drainage facility. Time was the most valuable saving for this project. An additional benefit was that based on the SUE results, the water authority was convinced to replace a 24-inch waterline while the road was open and to prevent the road from being torn up by water in the event of a break in the 100-year-old waterline.

**Cost Savings by SUE**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Utility relocation cost</td>
<td>$275,000</td>
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<td>Project delay cost by utility relocation</td>
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<td>Redesign cost</td>
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<tr>
<td>Design cost</td>
<td>$5,000</td>
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<tr>
<td>Construction cost</td>
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<tr>
<td>Information gathering &amp; verification cost</td>
<td>$15,000</td>
</tr>
<tr>
<td><strong>Total Saving</strong></td>
<td>$1,515,000</td>
</tr>
</tbody>
</table>

**B/C Ratio**

\[ \frac{\text{Total Saving}}{\text{SUE Cost}} = \frac{1,515,000}{44,804} = 33.81 \]

**Impact Score**

2.81

**Complexity Level**

5
6. SUE Project 6 – SR 0061-079

Project Title: Cameron Bridge Shamokin, SR 0061-079 (Northumberland)
District: District 3 – Montoursville
Total Project Cost: $9.0 Million
Design Cost: $1.0 Million
SUE Cost: $66,000 (Designating: $20,000, Locating: $46,000)

Project Scope: Construct 4 lane bridge with approaches and intersection improvement

Project Description:
Replace River Bridge and improvements in the city of Shamokin. While there were many U/G problems with the existing U/G utilities/storm sewers and many unknowns, the district feels the funds spent for SUE far outweighed the cost if there had been no SUE. This project was in a city with many U/G obstacles that were not documented. Also there were five + existing water lines that needed to be temporarily and then permanently relocated. The new construction is now well documented by plans, and in the future, there should not be as many challenges in the construction area. The water, sewer, and telephone were incorporated into this contract, and this would have been more difficult without SUE. The telephone had to relocate off the bridge in order to construct the new bridge, and this took additional coordination and money.

Cost Savings by SUE

<table>
<thead>
<tr>
<th>Cost</th>
<th>Amount</th>
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</thead>
<tbody>
<tr>
<td>Utility relocation cost</td>
<td>$250,000</td>
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<tr>
<td>Redesign cost</td>
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<tr>
<td>Restoration cost</td>
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<tr>
<td>Construction cost</td>
<td>$200,000</td>
</tr>
<tr>
<td>Total Saving</td>
<td>$1,500,000</td>
</tr>
</tbody>
</table>

B/C Ratio: $1,500,000 / $66,000 = 22.72
Impact Score: 2.24
Complexity Level: 4
7. **SUE Project 7 – SR 6006-001/002**

Project Title : Towanda River Road, SR 6006-001/002  
District : District 3 – Montoursville  
Total Project Cost : $13.0 Million  
Design Cost : $1.0 Million  
SUE Cost : $141,000 (Designating: $66,000, Locating: $75,000)  
Project Scope : Reconstruct, widen, curbs, sidewalks, relocate R/R install drainage  
Project Description : 

Construct a road by the river with a scenic view and a walk path. While there were many U/G problems with the existing U/G utilities/storm sewers - also railroad concerns and many unknowns - the district feels the funds spent for SUE far outweighed the cost if there had been no SUE. This project was in a town with many U/G obstacles that were not documented. The new construction is now well documented by plans, and in the future, there should be not as many challenges in the construction area. The water and sewer line relocations were incorporated into this contract, and this would have been more difficult if there had been no SUE. This project consisted of many unknowns as far as U/G water and sewer lines. There were abandoned water and sewer lines throughout the project, and no one knew their exact locations.

Cost Savings by SUE

- Utility relocation cost : $1.5 Million  
- Project delay cost by utility relocation : $100,000  
- Change orders & claims cost : $75,000  
- Restoration cost : $35,000  
- Project delay cost by the emergency : $1.5 Million  
- Design cost : $1.0 Million  

Total Saving : $4,210,000  
B/C Ratio : $4,210,000 / $141,000 = 29.86  
Impact Score : 2.44  
Complexity Level : 4
8. SUE Project 8 – SR 0054-014

Project Title : Danville River Bridge, SR 0054-014 (Montour)
District : District 3 – Montoursville
Total Project Cost : $9.0 Million
Design Cost : $1.0 Million
SUE Cost : $101,000 (Designating: $21,000, Locating: $80,000)
Project Scope : Construct 4 lane bridge, intersection and R/R improvements
Project Description :
Replace River Bridge and improvements in the Borough of Danville. While there were many U/G problems with the existing U/G utilities/storm sewers, railroad concerns, and many unknowns, the district feels the funds spent for SUE far outweighed the cost if there had been no SUE. This project was in a town with many U/G obstacles that were not documented. The new construction is now well documented by plans, and in the future, there should be not as many challenges in the construction area. Also, bridge attachments are now documented.

Cost Savings by SUE
Utility relocation cost : $1.0 Million
Design cost : $1.5 Million
Construction cost : $150,000
Total Saving : $2,650,000
B/C Ratio : $2,650,000 / $101,000 = 26.23
Impact Score : 2.24
Complexity Level : 4
9. SUE Project 9 – SR 0015-077

Project Title : Market St River Williamsport, SR 0015-77 (Lycoming)
District : District 3 – Montoursville
Total Project Cost : $63.0 Million
Design Cost : $10.0 Million
SUE Cost : $141,000 (Designating: $46,000, Locating: $95,000)

Project Scope : Construct 4 lane bridge, approaches, drainages and 3 traffic circles

Project Description :
Replace River Bridge and improvements in the city of Williamsport. While there were many U/G problems with the existing U/G utilities/storm sewers and many unknowns - also railroad concerns - the district feels the funds spent for SUE far outweighed the cost if there had been no SUE. This project was in a city with many U/G obstacles that were not documented. The new construction is now well documented by plans, and in the future there should not be as many challenges in the construction area. The water, sewer, telephone, electric, and TV were incorporated into this contract, and this would have been more difficult without SUE. The gas company and telephone had to relocate off the bridge in order to construct the new bridge, and this took additional coordination and funds.

Cost Savings by SUE
Utility relocation cost : $3.0 Million
Redesign cost : $500,000
Design cost : $1.0 Million
Total Saving : $4.5 Million
B/C Ratio : $4.5 Million / $141,000 = 31.91
Impact Score : 2.94
Complexity Level : 5
10. SUE Project 10 – SR 0049-50M

Project Title : Reconstruct Main St in Elkland, SR 0049-50M (Tioga)
District : District 3 – Montoursville
Total Project Cost : $5.2 Million
Design Cost : $700,000
SUE Cost : $56,000 (Designating: $26,000, Locating: $30,000)
Project Scope : Reconstruct SR 49 and replace Sanitary and Storm sewer, sidewalks and curbs

Project Description :
Widen, reconstruct, and replace water and sanitary sewers. While there were many U/G problems with the existing U/G utilities/storm sewers and many unknowns, the district feels the funds spent for SUE far outweighed the cost if there had been no SUE. This project was in a town with many U/G obstacles that were not documented. The new construction is now well documented by plans, and in the future, there should not be as many challenges in the construction area. The water and sewer were incorporated into this contract, and this would have been more difficult without SUE. There were many abandoned gas, sewer, and water lines that were not discovered until SUE.

Cost Savings by SUE
Utility relocation cost : $1.8 Million
Construction cost : $100,000
Total Saving : $1.9 Million
B/C Ratio : $1.9 Million / $56,000 = 33.92
Impact Score : 2.94
Complexity Level : 5
11. SUE Project 11 – SR 0202-610

Project Title : US202 Reconstruction, SR 0202-610 (Montgomery)
District : District 6 – King of Prussia
Total Project Cost : $63.5 Million
Design Cost : $6.0 Million
SUE Cost : $240,400 (Designating: $66,400, Locating: $174,000)
Project Scope : Widen to 4 lanes, add turn lanes, intersection improvements, and improve drainage

Project Description :
This project was a total reconstruction of an Urban Arterial U.S. Route that was 2 lanes and increasing it to 4 lanes. The project was about 4 miles in length in a largely commercial area and broken into two construction sections. Quality level A was utilized on this project and provided exact location, utility types, depths, and material types of existing underground utilities that included electric, water, gas, sewer, petroleum, telephone, and fiber optic. By using SUE, this project saved relocation cost of utilities with 1,500 ft. In addition, they saved design time of one month and construction time of three months through SUE. The time savings saved the costs of design and construction in the project.

Cost Savings by SUE
Utility relocation cost : $450,000
Redesign cost : $15,000
Design cost : $20,000
Construction cost : $450,000
Information gathering & verification cost : $40,000

Total Saving : $975,000
B/C Ratio : $975,000 / $240,400 = 4.06
Impact Score : 2.38
Complexity Level : 4
12. SUE Project 12 – SR 0202-400

Project Title : US202 Reconstruction, SR 0202-400 (Montgomery)
District : District 6 – King of Prussia
Total Project Cost : $313.8 Million
Design Cost : $25.3 Million
SUE Cost : $35,952 for designating and location
Project Scope : Widen to 6 lanes, add exit ramps, new roadway alignment, reconstruct 3 bridges, and improve drainage

Project Description :
This project was to widen US202 from Valley Forge Road to Mall Blvd of five miles in length. Without SUE, the designer would need to assume certain parameter to provide an approximate design for bid. This design would require the contractor to field verify these parameters and essentially fine tune or totally adjust the design during construction. SUE allowed the design to provide accurate design to avoid these problems and save design time. This heavily traveled section of highway carries over 180,000 vehicles per day. However, SUE information led to accurate design that minimized associated traffic delays and business interruptions which was extremely important in this heavily traveled and urbanized project area. The project area also was traversed by a Sunoco natural gas pipeline which had previously been ruptured causing the detour of many critical highway as well as environmental and safety issues. During design phase, the SUE accurately located this facility which was valuable to the designer during design but even more valuable in aiding the contractor to avoid hitting this facility during construction activities. In this study, these social costs such as traffic delay cost, business cost, service loss cost, and environmental cost are not provided for SUE projects because it is very difficult to estimate the costs in this study.

Cost Savings by SUE
Redesign cost : $10,000
Design cost : $100,000
Information gathering & verification cost : $90,000
Total Saving : $200,000

B/C Ratio : $200,000 / $35,952 = 5.56
Impact Score : 2.44
Complexity Level : 4
13. SUE Project 13 – SR 1012-202

Project Title : Intersection Improvement, SR 1012-202 (Lackawanna)
District : District 4 – Dunmore
Total Project Cost : $600,000
Design Cost : n/a
SUE Cost : $17,000 for designating
Project Scope : Improve intersection

Project Description:
This project was for intersection improvement consisting of increasing radius, new curb, new drainage feature, full depth pavement in areas of increasing radius and new traffic signal. The length of project site was approximately 4,200 ft. This project used quality level B. Underground utilities which included sewer, gas, water, and telephone line were successfully designated with SUE. The information was valuable to plan the relocations of gas and water lines. Without SUE, the relocation plan would be adjusted during construction, causing construction delay. Design and construction costs also were saved by SUE.

Cost Savings by SUE

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Utility relocation cost</td>
<td>$15,000</td>
</tr>
<tr>
<td>Project delay cost by utility relocation</td>
<td>$37,000</td>
</tr>
<tr>
<td>Redesign cost</td>
<td>$15,000</td>
</tr>
<tr>
<td>Information gathering &amp; verification cost</td>
<td>$10,000</td>
</tr>
<tr>
<td><strong>Total Saving</strong></td>
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</tr>
<tr>
<td><strong>B/C Ratio</strong></td>
<td><strong>$77,000 / $17,000 = 4.53</strong></td>
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<tr>
<td><strong>Impact Score</strong></td>
<td>2.24</td>
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<tr>
<td><strong>Complexity Level</strong></td>
<td>4</td>
</tr>
</tbody>
</table>
14. SUE Project 14 – SR 0247-291

Project Title : Road Improvement, SR 0247-291 (Lackawanna)
District : District 4 – Dunmore
Total Project Cost : $125,000
Design Cost : n/a
SUE Cost : $24,000 for designing and locating
Project Scope : Drainage improvement and pavement replacement

Project Description :
This project was for drainage improvement and pavement replacement. The main work of the project is 400 ft drainage improvement. Two water lines, gas lines, and a sewer line were considered to be existed in project area, but exact locations were not known. The project utilized quality level A. SUE provided their exact location so that two water lines and two gas lines were relocated without any problems.

Cost Savings by SUE
Utility relocation cost : $20,000
Project delay cost by utility relocation : $40,000
Redesign cost : $13,000
Information gathering & verification cost : $10,000
Total Saving : $83,000
B/C Ratio : $83,000 / $24,000 = 3.46
Impact Score : 2.00
Complexity Level : 3
15. SUE Project 15 – SR 0006-607

Project Title : RRR Project, SR 0006-607 (Wayne)
District : District 4 – Dunmore
Total Project Cost : $1.1 Million
Design Cost : n/a
SUE Cost : $54,000 (Designating: $20,000 and Locating: $34,000)
Project Scope : Road widening, new curb, drainage feature, and guide rail

Project Description :
This project was RRR project consisting of road widening, new curb, drainage features and guide rail. The length of the project is approximately 3,100 ft. The project area included 4” gas main, 3” sewer, and telephone. All utilities were considered to be existed in project area, but exact locations were not known. The project utilized quality level A with about forty test holes to avoid any utility conflicts. SUE provided their exact location of them so that the project was successfully completed without any problems.

Cost Savings by SUE
Utility relocation cost : $25,000
Project delay cost by utility relocation : $150,000
Redesign cost : $20,000
Design & construction cost : $70,000
Information gathering & verification cost : $10,000

Total Saving : $275,000
B/C Ratio : $275,000 / $54,000 = 5.09
Impact Score : 2.24
Complexity Level : 4
16. SUE Project 16 – SR 0026-C02

Project Title : Mt. Nittany Expressway, SR 0026-C02 (Centre)
District : District 4 – Clearfield
Total Project Cost : $84.1 Million
Design Cost : n/a
SUE Cost : $13,050 for designating and locating
Project Scope : Mt. Nittany expressway to research park connector 4 lane relocation.

Project Description :
This project was four lanes relocation from Mt. Nittany expressway to research park connector. 2.7 miles of Mainline roadway and 12.5 miles of interchange ramps were included in the project. The project area included water lines, gas lines, electric cables, and telephone cables. Quality level A was used for this project and provided exact locations of existing utilities in project area. This project area did not have many impacts with proposed structures.

Cost Savings by SUE
Redesign cost : $20,000
Design & construction cost : $40,000
Total Saving : $60,000
B/C Ratio : $60,000 / $13,050 = 4.60
Impact Score : 2.38
Complexity Level : 4
17. SUE Project 17 – SR 2027-A01

<table>
<thead>
<tr>
<th>Project Title</th>
<th>Bridge Replacement, SR 2047-A01 (Clearfield)</th>
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</thead>
<tbody>
<tr>
<td>District</td>
<td>District 4 – Clearfield</td>
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<tr>
<td>Total Project Cost</td>
<td>$1.9 Million</td>
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<tr>
<td>Design Cost</td>
<td>n/a</td>
</tr>
<tr>
<td>SUE Cost</td>
<td>$15,600 for designating and locating</td>
</tr>
<tr>
<td>Project Scope</td>
<td>Replace bridge</td>
</tr>
</tbody>
</table>

Project Description:
This project was for bridge replacement. Quality level A was used for sanitary lines, water lines, gas lines, and electric cables. The purpose of the SUE was to determine if the horizontal and vertical location of these existing facilities would be impacted by the proposed structure and roadway work required by the project. This work was required since the Woodland Bigler Area Authority did not have records showing precise location of their private facilities. Final results of SUE did not require additional relocations or many modifications in designing.

Cost Savings by SUE
Redesign cost : $20,000
Design & construction cost : $30,000
Total Saving : $50,000
B/C Ratio : $50,000 / $15,600 = 3.21
Impact Score : 1.63
Complexity Level : 2
18. SUE Project 18 – SR 0143-05S

Project Title : Jordan Park Widening, SR 0143-05S (Lehigh)
District : District 5 – Allentown
Total Project Cost : $6.8 Million
Design Cost : $1.5 Million
SUE Cost : $24,000 for designating and locating
Project Scope : Jordan park widening and safety improvement

Project Description :
This project was for Jordan park widening and safety improvement. The SUE consultant used eight test holes to locate Verizon conduit. The information of test holes revealed that conduit was in conflict with proposed parallel drainage. However, the Department was willing to redesign drainage if Verizon paid for extra costs. An agreement was reached stating that Verizon would pay the Department for lowering the storm sewer four feet and installing eight special Type C Inlets to avoid the underground utility.

Cost Savings by SUE
Utility relocation cost : $20,000
Project delay cost by utility relocation : $30,000
Redesign cost : $50,000
Total Saving : $100,000
B/C Ratio : $100,000 / $24,000 = 4.17
Impact Score : 2.47
Complexity Level : 4
19. SUE Project 19 – SR 0061-13S

Project Title : Dusselfink Safety, SR 0061-13S (Schuylkill)
District : District 5 – Allentown
Total Project Cost : $13.5 Million
Design Cost : $3.5 Million
SUE Cost : $38,144 for designating and locating
Project Scope : Installation of median barrier and resurface

Project Description:
This project was for installation of median barrier and resurface. The Department hired So-Deep, Inc. to designate and locate an 8-inch steel gas line that paralleled the west shoulder of SR 61. Based on the information from 32 test holes the designer was able to safely pinpoint the location of the new guide rail. The Department was held harmless by using and providing SUE information. In addition five test holes were dug to locate Verizon underground conduit and the information was used to redesign drainage to avoid impact to existing utility.

Cost Savings by SUE
Utility relocation cost : $30,000
Project delay cost by utility relocation : $90,000
Redesign cost : $50,000
Total Saving : $170,000

B/C Ratio : $170,000 / $38,144 = 4.46
Impact Score : 2.41
Complexity Level : 4
20. SUE Project 20 – SR 0033-006

Project Title : 33/512 Interchange, SR 0033-006 (Northampton)
District : District 5 – Allentown
Total Project Cost : $19.7 Million
Design Cost : $3.7 Million
SUE Cost : $30,316 for designating and locating
Project Scope : Restoration and reconfiguration

Project Description :
This project was for restoration and reconfiguration. Their highway consultant Alfred Benesch & Co. hired So-Deep, Inc. to designate and locate gas, water, sewer, petroleum, and storm facilities. 32 test holes were dug and they are currently using this information to avoid impacts to utilities where possible and to identify what utility relocations will be required.

Cost Savings by SUE
Utility relocation cost : $30,000
Project delay cost by utility relocation : $50,000
Redesign cost : $50,000

Total Saving : $130,000
B/C Ratio : $130,000 / $30,316 = 4.29
Impact Score : 2.24
Complexity Level : 4
21. SUE Project 21 – SR 3012-02B&03B

Project Title : Cacoosing Ck. Bridges I & II, SR 0033-006 (Berks)
District : District 5 – Allentown
Total Project Cost : $2.5 Million
Design Cost : $1.2 Million
SUE Cost : $34,716 (Designating: $15,628, Locating: $19,088)
Project Scope : Bridge replacement

Project Description :

This project was for bridge replacement. PennDOT hired So-Deep, Inc. to designate and locate gas, petroleum and water facilities. Then test holes were dug and the information was provided to their design consultant URS Corporation. The water company installed a new water line in 1999 using PENNDOT's available plans at the time. Through test holes dug in 2002 they were able to determine that the waterline was not affected by the proposed highway work. Sunoco's 14-inch pipeline was located and our 18-inch drainage (sanitary) was altered to avoid impact to the pipeline. We avoided Buckeye's pipeline, however after reviewing the test hole information they elected to remove the existing casing pipe. This was coordinated with their construction activities. TEPPCO' pipeline was shallow and very close to several proposed drainage pipes. They also didn't like the pipe under the widened roadway and relocated the lines. PENNDOT had plenty of time to coordinate this work and to relocate prior to construction.

Cost Savings by SUE

Utility relocation cost : $20,000
Project delay cost by utility relocation : $80,000
Redesign cost : $50,000

Total Saving : $150,000
B/C Ratio : $150,000 / $34,716 = 4.32
Impact Score : 2.24
Complexity Level : 4
**22. SUE Project 22 – SR 0222-001&002**

- **Project Title**: US 0222 Trexlertown, SR 0222-001&002 (Lehigh)
- **District**: District 5 – Allentown
- **Total Project Cost**: $216.8 Million
- **Design Cost**: $79.9 Million
- **SUE Cost**: $84,803 (Designating: $39,505, Locating: $45,298)
- **Project Scope**: 4 lane relocation of 6.5 miles of US 0222 & 2.2 miles of SR100

**Project Description**

This project was for restoration and reconfiguration. They used So Deep to verify horizontal locations of all the utilities. They compiled plans from the utility companies and then used metal detectors etc. to verify the horizontal locations. Once PENNDOT received that information from So-Deep, they transposed the information onto their roadway plans and identified areas of concern (usually at drainage crossings or areas where they were cutting into existing grade). So Deep went out and did borings at the locations in question to obtain elevations of the utility lines. It was around 10 locations. From this information, they were able to determine if there was going to be a conflict between the utility and the proposed design and proceed with either a redesign of the drainage system to avoid the utility or, if they were unable to redesign our facility to avoid the impact, have the utility begin design for relocation of their facility. The information that So-Deep provided was very useful, since the utility companies’ information on depths to their facilities was usually not the best.

**Cost Savings by SUE**

- **Utility relocation cost**: $200,000
- **Project delay cost by utility relocation**: $1,500,000
- **Redesign cost**: $500,000
- **Design & construction cost**: $400,000

**Total Saving**: $2,600,000

**B/C Ratio**: $2,600,000 / $84,803 = 30.66

**Impact Score**: 2.65

**Complexity Level**: 5
NON-SUE PROJECTS

1. Non-SUE Project 1 – SR 3007-001

Project Title : Hershberger Rd and Sunray Drive Inter., SR 3007-001 (Cambria)
District : District 9 – Hollidaysburg
Total Project Cost : $2.0 Million
Design Cost : $300,000
Estimated SUE Cost : $50,000 for designating and locating
Project Scope : Realign road, install drainage and signals, construct new entrance to HGA center

Project Description :
This project was developed in urban setting with relatively high ADT. During construction, a gas line was discovered so that they had to stop the work, find suitable contractor, and relocate the line. It could have been a dangerous situation and very costly, if the gas line was broken. Also, it could have impacted an underground telephone system that they were not clear about. In addition, some water and sewer lines were omitted from their plan. They expected one week of traffic impact and business impact.

Cost Savings by SUE
Utility relocation cost : $25,000
Project delay cost by utility relocation : $10,000
Redesign cost : $5,000
Project delay cost by unexpected utility : $60,000
Traffic delay cost : $10,000
Business impact cost : $2,500
Information gathering & verification cost : $5,000
Total Saving : $117,500
B/C Ratio : $117,500 / $50,000 = 2.35
Impact Score : 2.50
Complexity Level : 4
2. **Non-SUE Project 2 – SR 1002-HST**

**Project Title**: Hollidaysburg Streetscape, SR 1002-HST (Blair)

**District**: District 9 – Hollidaysburg

**Total Project Cost**: $1.5 Million

**Design Cost**: n/a

**Estimated SUE Cost**: $45,000 for designating and locating

**Project Scope**: Replace sidewalks, place lighting, narrow road to provide parking

**Project Description**:

This project was developed in urban setting with relatively high ADT. Benefits were limited as water and sewer scheduled to be replaced. They had difficulty with service laterals, gas line, water, and telecommunications. Although they were able to work around the site, they felt that SUE would have allowed a more efficient design.

**Cost Savings by SUE**

- Utility relocation cost : $50,000
- Project delay cost by utility relocation : $50,000
- Redesign cost : $10,000
- Project delay cost by unexpected utility : $5,000
- Traffic delay cost : $30,000
- Business impact cost : $35,000
- Information gathering & verification cost : $15,000

**Total Saving** : $195,000

**B/C Ratio** : $195,000 / $45,000 = 4.33

**Impact Score** : 2.56

**Complexity Level** : 5
3. Non-SUE Project 3 – SR 4013-001

Project Title : Chestnut Ave., SR 4013-001 (Blair)
District : District 9 – Hollidaysburg
Total Project Cost : $19.6 Million
Design Cost : $1.2 Million
Estimated SUE Cost : $85,000 for designating and locating
Project Scope : Widening of Chestnut Ave. to 4 lanes with drainage, structures and adjacent to RR yard

Project Description :
This project was developed in urban industrial setting with 1 mile in length. Utility relocations required 15 months to complete. Utilities dug some test holes but information was not clear as there was no survey of holes, only approximate depth. The use of SUE may have reduced the impacts and time frames. Telephone impacts were costly and time consuming. More utility information early could have helped design around the facilities. Several unanticipated impact would have been more efficiently dealt with. Some road design was altered to avoid impacts after discovery of unexpected utilities during construction.

Cost Savings by SUE
Utility relocation cost : $35,000
Project delay cost by utility relocation : $100,000
Redesign cost : $25,000
Project delay cost by unexpected utility : $100,000
Restoration cost : $25,000
Project delay cost by the emergency : $100,000
Information gathering & verification cost : $15,000
Total Saving : $400,000
B/C Ratio : $400,000 / $85,000 = 4.71
Impact Score : 2.81
Complexity Level : 5
4. Non-SUE Project 4 – SR 1001-012

Project Title : Plank Rd Widening, SR 1001-012 (Cambria)
District : District 9 – Hollidaysburg
Total Project Cost : $27.0 Million
Design Cost : $2.0 Million
Estimated SUE Cost : $150,000 for designating and locating

Project Scope : Bridge widening, intersection improvement, widening to five lanes, and realignment of road

Project Description :
This project was developed in urban setting with business impacts. They relocated two sewer lines, a water line, and about 1.75 miles of 12 in gas line. They found private electric primary service that was thought to be public utility. Utility relocations disturbed contaminated soils and the material had to be mitigated. Environmental issues also led to more costly relocation costs using certified contractors and special gaskets. Original design hit all facilities possible. SUE would have increased awareness of utility locations. Unforeseen impact on electric service caused scheduling problems.

Cost Savings by SUE
Utility relocation cost : $1.0 Million
Restoration cost : $120,000
Project delay cost by the emergency : $100,000
Business impact cost : $30,000
Environmental impact cost : $20,000
Information gathering & verification cost : $20,000
Total Saving : $1,290,000
B/C Ratio : $1,290,000 / $150,000 = 8.60
Impact Score : 2.71
Complexity Level : 5
5. **Non-SUE Project 5 – SR 0412-DLY**

- **Project Title**: 4th St/Daly Ave. Bridge, SR 0412-DLY (Northampton)
- **District**: District 5 – Allentown
- **Total Project Cost**: $9.6 Million
- **Design Cost**: $1.8 Million
- **Estimated SUE Cost**: $35,000 for designating and locating
- **Project Scope**: Bridge replacement

**Project Description**

This project was developed for two bridge replacements in Bethlehem city. Gannett Fleming designed this project for PENNDOT. Existing utilities were plotted with best available utility information. No designating or locating was used. During construction we encountered several utility problems related to inaccurate utility information. This would have been an excellent candidate for SUE given its location near the abandoned Bethlehem Steel and two railroad companies. Some problems encountered were: 1) an underground storage tank supply line was hit and leaked petroleum products 2) water line shown deeper than anticipated when it was hit by contractor thereby requiring additional water line relocation work 3) gas line shown deeper than it actually was when contractor hit valve which required major grading and swale changes to resolve 4) a private fiber optic line serving the last remaining Bethlehem Steel office was struck and subsequently repaired.

**Cost Savings by SUE**

- **Utility relocation cost**: $20,000
- **Project delay cost by utility relocation**: $60,000
- **Redesign cost**: $20,000
- **Restoration cost**: $40,000
- **Project delay cost by the emergency**: $60,000
- **Environmental impact cost**: $20,000
- **Information gathering & verification cost**: $15,000

**Total Saving**: $235,000

**B/C Ratio**: $235,000 / $35,000 = 6.71

**Impact Score**: 2.53

**Complexity Level**: 5
6. Non-SUE Project 6 – SR 1004-01B

Project Title : Race Street Bridge, SR 1004-01B (Lehigh)
District : District 5 – Allentown
Total Project Cost : $1.6 Million
Design Cost : $644,383
Estimated SUE Cost : $10,000 for designating and locating
Project Scope : Bridge replacement
Project Description :

This project was a bridge replacement in an urban area which involved several utilities. Water and gas lines were located on the existing bridge and were relocated around the proposed structure. Locating these utilities at the bridge approaches would have helped us with grade changes and drainage issues. Communication cables were also located on the existing bridge and were supported and accommodated during the bridge reconstruction. Locating the conduits at the bridge approaches would have been useful again when coordinating drainage and other utility installations. Their big problem was that they did not know the exact location of the sewer line. The contractor had difficulty installing the tie-back straps for an abutment. The sewer was temporarily suspended while the abutment and wing wall work proceeded slowly.

Cost Savings by SUE
Design & construction cost : $30,000
Information gathering & verification cost : $10,000
Total Saving : $40,000
B/C Ratio : $40,000 / $10,000 = 4.00
Impact Score : 2.53
Complexity Level : 5
7. Non-SUE Project 7 – SR 0078-17M

Project Title : Interstate 78, SR 0078-17M (Berks)
District : District 5 – Allentown
Total Project Cost : $69.7 Million
Design Cost : $5.2 Million
Estimated SUE Cost : $40,000 for designating and locating
Project Scope : I-78 Reconstruction

Project Description :
This project was developed for I-78 reconstruction with 2.9 miles in length. Near the end of the first construction season they discovered a water line within a culvert crossing beneath the highway. The original water line was nearly 90 year old and made of cast iron with lead joints. The Department of Highways lowered a portion of the 8” line during the 1956 time frame of the original I-78 construction, by placing the line inside a 5’ x 4’ culvert. Although the line was shown on the plan no one ever determined if the proposed highway work would affect this line. They scrambled for accurate depths of the culvert and the water line and compared the data to the cross sections. It was agreed to install a new casing pipe and an 8” inch carrier pipe within the existing culvert.

Cost Savings by SUE
Design & construction cost : $100,000
Information gathering & verification cost : $30,000
Total Saving : $130,000
B/C Ratio : $130,000 / $40,000 = 3.25
Impact Score : 2.29
Complexity Level : 4
8. Non-SUE Project 8 – SR 0222-002

Project Title : US 0222 Trexlertown, SR 0222-001&002 (Lehigh)
District : District 5 – Allentown
Total Project Cost : $60.4 Million
Design Cost : n/a
Estimated SUE Cost : $40,000 for designating and locating
Project Scope : 4 lane relocation of US 0222

Project Description:
This project was developed for 4 lane relocation of US 0222. Although they used SUE on this project they encountered a problem with a gas line located on Hamilton Blvd. and Mill Creek Rd. This was beyond the scope of the SUE investigation. While their highway contractor was installing a box culvert a gas line was encountered which halted construction while the gas company lowered the line about 15 feet. The gas line was not shown on the plans and was only spotted in the field after the PA One Call marked out.

Cost Savings by SUE
Redesign cost : $30,000
Project delay cost by unexpected utility : $200,000
Design & construction cost : $25,000
Information gathering & verification cost : $30,000
Total Saving : $285,000
B/C Ratio : $285,000 / $40,000 = 7.13
Impact Score : 2.65
Complexity Level : 5
APPENDIX B

Utility Impact Rating Form
SUE UTILITY IMPACT RATING FORM

Project Title: ____________________________

County: ____________________________
SR: ____________________________
Section: ____________________________

Project Cost: ____________________________

Design Cost: ____________________________
Construction Cost: ____________________________

Project Description: ____________________________
(General Summary)

Project Scope: ____________________________
(Actual Work Scope)

*Note: If the scope of the project changes then it is recommended to do the SUE impact analysis again.

Date of Analysis: ______________ Analysis Done By: ____________________________

Revised Analysis Date: ______________ Analysis Done By: ____________________________

*Note: Step 1&2 are screening processes and Step 3 is an evaluation of project passing Steps 1&2.

SUE UTILITY IMPACT FORM – STEP 1

STEP 1 determines whether SUE (Quality levels A & B) should be utilized for a project or not. For each question, check the box with best describes the project conditions.

<table>
<thead>
<tr>
<th>No.</th>
<th>QUESTIONS</th>
<th>Column 1</th>
<th>Column 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Is there evidence of underground utilities in the project area? (based on information from SUE quality level D&amp;C)</td>
<td>□ NO</td>
<td>□ YES or Unknown</td>
</tr>
<tr>
<td>2</td>
<td>Does the project require any excavation “regardless of depth”? Note: This includes any TCE or other easements.</td>
<td>□ NO</td>
<td>□ YES or Unknown</td>
</tr>
</tbody>
</table>

STEP 1: If there are no boxes in Column 2 checked, then it is generally not practicable to perform SUE quality levels A and B investigation.

STEP 1: If one or both the boxes in Column 2 are checked, please proceed to STEP 2 to conduct further analysis.
**SUE UTILITY IMPACT FORM – STEP 2**

*STEP 2 further analyzes whether SUE (Quality levels A & B) should be utilized for a project. For each question, check the box with best describes the project conditions.*

<table>
<thead>
<tr>
<th>No.</th>
<th>QUESTIONS</th>
<th>Column 1</th>
<th>Column 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Depth of project excavation.</td>
<td>□ ≤ 18”</td>
<td>□ &gt; 18”</td>
</tr>
<tr>
<td>2</td>
<td>Do you feel that the utility owners in the project area will be able to accommodate the project’s schedule in regards to showing the location of their utility facilities?</td>
<td>□ Confident</td>
<td>□ Doubtful</td>
</tr>
<tr>
<td>3</td>
<td>What is the likelihood that project will have an impact on the existing utilities?</td>
<td>□ No Impact</td>
<td>□ Impact</td>
</tr>
<tr>
<td>4</td>
<td>How often have the utility owners in the project area provided accurate utility information?</td>
<td>□ Always</td>
<td>□ Seldom</td>
</tr>
<tr>
<td>5</td>
<td>Reliability of designer providing accurate design-construction related information.</td>
<td>□ Good</td>
<td>□ Poor</td>
</tr>
</tbody>
</table>

**STEP 2:** If there are no boxes checked in Column 2, then it is generally not practicable to perform SUE quality levels A and B investigation.

**STEP 2:** If there are any boxes in Column 2 are checked, please proceed to STEP 3 to calculate utility impact score and determine the appropriate SUE Quality Levels.
SUE UTILITY IMPACT FORM – STEP 3

STEP 3 determines which SUE quality level should be selected for a project/section/location.

Project/Section/Location  :

County:  
SR:  
Section:  

Project/Section/Location  :
Description & Scope  :

Utility Impact Score  :

Please check on the utility impact rating to the right that best fits your opinion of the issue. If the answer for the complexity factor is unknown, always check Column 3.

<table>
<thead>
<tr>
<th>No.</th>
<th>Complexity Factors</th>
<th>Column 1 (Low)</th>
<th>Column 2 (Medium)</th>
<th>Column 3 (High)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density of Utilities (number)</td>
<td>☐</td>
<td>☐ 2 or 3</td>
<td>☐ &gt; 3</td>
</tr>
<tr>
<td>2</td>
<td>Type of Utilities</td>
<td>☐ Less Critical</td>
<td>☐ Sub Critical</td>
<td>☐ Critical</td>
</tr>
<tr>
<td>3</td>
<td>Pattern of Utilities (number)</td>
<td>☐ 1 parallel or crossing</td>
<td>☐ 2 parallel or crossing</td>
<td>☐ &gt; 2 parallel or crossing</td>
</tr>
<tr>
<td>4</td>
<td>Material of Utilities</td>
<td>☐ Rigid</td>
<td>☐ Flexible</td>
<td>☐ Brittle</td>
</tr>
<tr>
<td>5</td>
<td>Access to Utilities</td>
<td>☐ Easy</td>
<td>☐ Medium</td>
<td>☐ Restricted</td>
</tr>
<tr>
<td>6</td>
<td>Age of Utilities (year)</td>
<td>☐ ≤ 10 years</td>
<td>☐ &gt; 10 years, ≤ 25 years</td>
<td>☐ &gt; 25 years</td>
</tr>
<tr>
<td>7</td>
<td>Estimated Utility Relocation Costs (% of total project cost)</td>
<td>☐ ≤ 2 %</td>
<td>☐ &gt; 2, ≤ 5 %</td>
<td>☐ &gt; 5 %</td>
</tr>
<tr>
<td>8</td>
<td>Estimated Project Traffic Volume (ADT per lane)</td>
<td>☐ ≤ 1,500</td>
<td>☐ &gt; 1,500, ≤ 6,000</td>
<td>☐ &gt; 6,000</td>
</tr>
</tbody>
</table>
### Utility Impact Score Table

<table>
<thead>
<tr>
<th></th>
<th>Project Time Sensitivity</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Project Area Description</td>
<td>Rural</td>
<td>Suburban</td>
<td>Urban</td>
</tr>
<tr>
<td>11</td>
<td>Type of project/Section/Location</td>
<td>Simple</td>
<td>Moderate</td>
<td>Complicated</td>
</tr>
<tr>
<td>12</td>
<td>Quality of Utility Record</td>
<td>Good</td>
<td>Fair</td>
<td>Poor</td>
</tr>
<tr>
<td>13</td>
<td>Excavation Depth within Highway Right-of-Way, including Easement (inches)</td>
<td>≤ 18”</td>
<td>&gt; 18”, &lt; 24”</td>
<td>≥ 24”</td>
</tr>
<tr>
<td>14</td>
<td>Estimated Business Impact</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>15</td>
<td>Estimated Environmental Impact</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>16</td>
<td>Estimated Safety Impact</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>17</td>
<td>Other Impact Factors (Specify):</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
</tbody>
</table>

The utility impact score based on response from STEP 3.

<table>
<thead>
<tr>
<th></th>
<th>Utility Impact Score: Column 1 – (1), Column 2 – (2), Column 3 – (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total Box Checked</td>
</tr>
<tr>
<td>2</td>
<td>Utility Impact Score</td>
</tr>
</tbody>
</table>

*$n = \text{Number of the complexity factors considered/checked}$

The project complexity level, recommended SUE level to used, relative cost of using SUE level, and project risk level based on the utility impact score.

<table>
<thead>
<tr>
<th>Utility Impact Score</th>
<th>Low, &lt;1.4</th>
<th>1.4 ≤, &lt; 1.8</th>
<th>1.8 ≤, &lt; 2.2</th>
<th>2.2 ≤, &lt; 2.6</th>
<th>2.6 ≤, ≤ 3.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complexity Levels</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
</tr>
<tr>
<td>SUE Quality Levels</td>
<td>D&amp;C</td>
<td>C/B</td>
<td>B</td>
<td>B/A</td>
<td>A</td>
</tr>
<tr>
<td>Relative Costs</td>
<td>1</td>
<td>6.67</td>
<td>16.67</td>
<td>33.33</td>
<td>66.67</td>
</tr>
<tr>
<td>Project Risk Levels</td>
<td>Low (L)</td>
<td>Fair (F)</td>
<td>Medium (M)</td>
<td>High (H)</td>
<td>Very High (V)</td>
</tr>
</tbody>
</table>
VITA

Yeun Jae Jung

EDUCATION

Ph.D. Candidate, Civil Engineering
Pennsylvania State University, University Park, PA
Dissertation: Development of Methodology for Damage Prevention Best Practice of Underground Utilities
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M.S., Civil Engineering
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