Evaluation of an Emerging Market in Subsurface Utility Engineering

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Abstract: Subsurface utility engineering (SUE) is a fast growing industry segment in the civil engineering arena. Subsurface utility engineering is gaining credibility as a significant tool to reduce the risk from informational uncertainty associated with underground facilities in a construction project. Subsurface utility engineering can minimize the risk primarily through mapping existing underground utility facilities, utilizing surface geophysical technologies, surveying and data management systems. This paper presents a comprehensive evaluation of SUE to facilitate a better understanding of this emerging industry by the many in the construction domain that are relatively unfamiliar with it. Topics investigated include quality levels in SUE, incorporation of SUE strategy at different stages in the construction project, and cost–benefit analysis of SUE based on 71 actual construction projects where SUE was employed. In addition, the results obtained from questionnaire surveys of State Departments of Transportation (DOTs) and the SUE industry are analyzed, which reveal the trend of state DOTs in the use of SUE and various aspects of SUE business in private sectors.

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Introduction

Damage to underground infrastructure during construction continues to be one of the major problems for the construction industry (Lew and Anspach 2000). The American Institute of Constructors identifies damage to utility lines as the third most important crisis for contractors, the other upper two issues being on-the-job accidents requiring hospitalization and contractual disputes with a client resulting in litigation (Reid 1999).

Most of the infrastructure systems in the U.S. were built since World War II. Underground infrastructure networks are typically designed for lifetimes of 20–50 years but are often used with little maintenance for much longer periods (Sterling 2000). The expansion of infrastructure renewal projects has created an increasing concern by contractors that utility lines could be damaged as most projects involve excavation where underground utilities exist.

Utility demand in the U.S. is projected to expand 3% annually to 183 million ft of utilities in the year 2003, with a valuation exceeding $7 billion (Sterling 2000). About half of all federal-aid highway and bridge projects involved the relocation of utilities during fiscal year 1997–1998 [United States General Accounting Office (USGAO) 1999]. Both new utility construction and utility relocation projects involve the risk of damaging existing utilities. In addition, many design and construction projects are taking place in areas such as cities, process plants, airports, highways, etc., where underground utilities already exist (Lew 2000).

While reliable information pertaining to the location of underground utilities is critical for the success of a project, subsurface information is often inaccurate in as-built drawings, and composite drawings that incorporate all the utility records for different owners are not readily available. Existing records and visible feature surveys are typically 15–30% off mark and in some cases, considerably worse (Stevens and Anspach 1993).

Subsurface utility engineering (SUE) is an emerging engineering process that has been proved to be an effective tool to reduce underground utility accidents, damage, utility related claims, and construction delays. This process aims to accurately locate and depict utilities and disseminate the information prior to commencing construction so that (utility) conflicts and disasters can be minimized. The practice of SUE has been developed and refined over many years and was systematically put into professional practice in the 1980s (Lew and Anspach 2000). A state utility engineer in the Virginia Department of Transportation (VDOT) sensed the potential of SUE and allocated $10,000 for a trial project in late 1983. This was the first official SUE contract by a State DOT. VDOT reported to the Federal Highway Administration (FHWA) that over $1 million in savings to the taxpayer were realized from this project (FHWA 2002). State DOTs and FHWA since then have taken a leading role in the promotion of SUE, and the term Subsurface Utility Engineering was coined at the 1989 FHWA National Highway Utility Conference. Today, in addition to FHWA and state DOTs, SUE is officially utilized in many state agencies, such as the Federal Aviation Agency, the Department of Defense, the Department of Energy, the General Service Administration, and the Network Reliability Council, as well as many municipalities and engineering firms.

This paper evaluates various aspects of SUE. The first section of this paper presents an overview of SUE, including issues such as quality levels in SUE, incorporating SUE at different stages in

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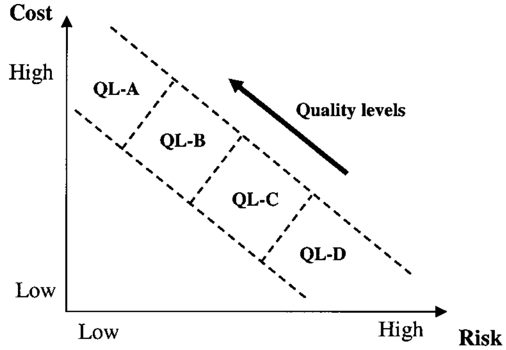


Fig. 1. Quality levels in subsurface utility engineering

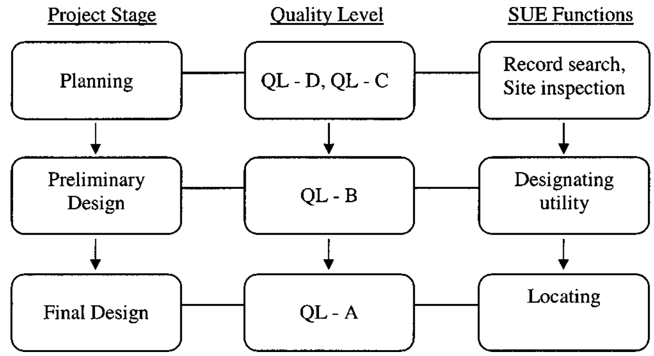


Fig. 2. Systematic use of subsurface utility engineering in construction project

the construction project, and major activities related to SUE. The second section presents a cost–benefit analysis based on 71 actual construction projects with a combined construction value in excess of $1 billion. The third section illustrates the trend of State DOTs in the use of SUE based on questionnaire surveys, and the last section presents the various aspects of SUE practice in the private sector. The paper concludes with the summary of findings and anticipated areas of future growth.

Overview of Subsurface Utility Engineering

Quality Levels in Subsurface Utility Engineering

Stutzman and Anspach defined the four quality levels of underground utility information that are available to the design engineer, constructor, and project manager (Anspach 1995). These are quality level D, C, B, and A. The quality levels represent different combinations of traditional records research, site surveys, geophysical imaging techniques and locating techniques. As the quality level advances from D to A, superior technologies and processes are involved, increasing the accuracy and reliability of the collected data. The cost for obtaining underground utility data varies greatly as a factor of climate, soil, project specifications, geography, etc., however, in general, the higher the quality level desired, the higher the costs will be to obtain data. The increased accuracy and reliability of the data typically result in lower probabilities of utility-related damages. The conceptual relationship between quality levels associated with risk of utility damage and cost of SUE service is illustrated in Fig. 1.

In practice, the highest quality level may be needed at those points where utility conflicts may occur in a project. In contrast, a lower level of quality may be adequate in those areas where little to no conflict is anticipated (Zembillas 2002). Therefore, in a project, all types of quality level information can be found in the final deliverables. The generally accepted definitions of quality levels are as follows (Stevens and Anspach 1993; Lew 1996; ASCE 2002).

Quality level D (QL-D) consists of information derived from existing records or oral recollection. It is often limited in terms of the comprehensiveness and accuracy required to eliminate the risks and dangers of conflict with underground infrastructure. This quality level is used for planning purposes such as route selection and utility relocation costs.

Quality level C (QL-C) consists of information obtained by surveying and plotting visible above-ground utility features and by using professional judgment in correlating this information to QL-D information. This level has been traditionally used for design purposes.

Quality level B (QL-B) consists of information obtained through the application of appropriate surface geophysical methods to determine the existence and approximate horizontal position of subsurface utilities. Quality level B data should be reproducible by surface geophysics at any point of their depiction. This information is surveyed to applicable tolerances defined by the project and reduced onto plan documents.

Quality level A (QL-A) provides precise horizontal and vertical location of utilities obtained by the actual exposure (or verification of previously exposed and surveyed utilities) and subsequent measurement of subsurface utilities, usually at a specific point. The three-dimensional data of location, as well as other utility attributes, are shown on plan documents. Accuracy is typically set at 15 mm vertical and set at applicable horizontal survey and mapping accuracy levels as defined or expected by the project owner.

Systematic Use of Subsurface Utility Engineering

The advantages of SUE can be fully realized when it is systematically incorporated during different construction stages in the project cycle as shown in Fig. 2. During the planning stage of a construction project, all recorded utility information (QL-D) and visual indications (QL-C) are collected from utility owners, state government and the site survey. The recorded information is depicted on a base topographic plan prepared by the project surveyor and is used by the project engineer to locate the proposed construction facilities.

The use of SUE in the preliminary design stage involves all existing utilities designated at the proposed areas of work. This is an approximate horizontal location performed using the surface geophysical methods (QL-B). The acquired data is transferred onto preliminary plans for the project through a computer aided design and drafting (CADD) system or geographic information systems (GIS). The location of proposed work can be optimized with respect to the horizontal location of the existing utilities.

At the final design stage, locations, where conflicts with existing utilities may occur, can be identified. At these locations, QL-A data obtained from non-destructive locating methods or typically the vacuum excavation system can be used to adjust the final location of the proposed work. This systematic approach allows SUE engineers to narrow down the geographic region where upper quality level information is required as the construction

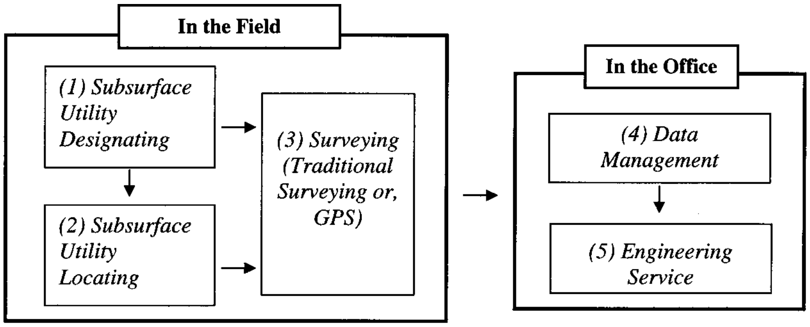


Fig. 3. Major activities in subsurface utility engineering

project advances to a higher stage. This approach is an optimized SUE strategy using minimal budget.

Major Activities in Subsurface Utility Engineering

The SUE process can be categorized into the five distinctive activities as shown in Fig. 3. It is a combination of geophysics, surveying, civil engineering, and data management. Fieldwork involves three different activities, i.e., subsurface utility designating, subsurface utility locating and surveying. Subsurface utility designating determines the existence and approximate horizontal position of underground utilities using surface geophysical techniques, which include pipe and cable locators, magnetic methods, metal detectors, ground penetrating radar (GPR), acoustic emission methods, etc. In the subsurface utility locating activity, minimally intrusive methods of excavation are used such as vacuum excavation, allowing the determination of the precise horizontal and vertical position of the underground utility line to be documented. This activity is to obtain the QL-A data.

Surveying instruments such as levels, staffs and theodolites are typically used for the surveying activities. The global positioning system (GPS) is now widely accepted for surveying purposes. Its improved accuracy, e.g., when using real time kinematic (RTK) technology, and the ease of data transfer to CADD and GIS environments have accelerated its use. The data management activity ranges from updating information on existing utility drawings or construction plans to the production of completely new utility maps. In the final engineering service activity, the SUE engineer provides consultation, conflict determinations, and utility coordination and design.

Cost–Benefit Analysis

The cost savings generated by SUE application in 71 highway construction projects in Virginia, North Carolina, Texas, and Ohio were examined by Lew (2000). The total construction costs of these projects were in excess of $1 billion. For this study, the raw data on each project were recollected and analyzed to evaluate the quantitative benefits of SUE in various aspects.

The projects analyzed in this study, involved a mixture of interstate, arterial, and collector roads in urban, suburban, and rural settings. In terms of construction budget, various sizes of projects were examined with the construction cost ranging from $0.3 million to $238 million. The cost of using SUE for each project ranged from $2,200 to $500,000. It was determined that the ratio of the cost of SUE to the total construction cost (SUE cost ratio) ranged from 0.02 to 10.76%, and the average ratio was 1.39% with the standard deviation of 1.86%. This result was close to the predicted value (1%) by Noone (1997).

In order to measure the SUE cost savings in the construction projects, 21 categories were developed to quantify the savings in terms of time, direct cost, user savings, and risk management aspects as shown in Table 1. These categories were derived from extensive interviews with DOTs, utility companies, SUE consultants, and contractors. The cost savings in each category were measured using two different methods—estimated cost and projected cost. Estimated costs include additional design and construction costs which can be reasonably estimated in each category in cases where SUE is not employed. These costs include utility relocation costs, project delay costs due to utility cuts, etc. Projected costs include items that may be difficult to quantify completely but can be with an acceptable degree of certainty. These costs were approximated by analyzing the projects in detail, interviewing the personnel involved in the project and applying historical cost data. Examples of these costs include contingency fees from all parties, damage to existing site facilities and damage to existing pavements.

Table 1. Categories for Quantification of Subsurface Utility Engineering (SUE) Cost Savings (Lew 2000)

Number	Description
1	Reduced the number of utility line relocations
2	Reduced project delays due to utility relocations
3	Reduced construction delay due to utility cuts
4	Reduced contractor's claims and change orders
5	Reduced delays caused by conflict redesign
6	Reduced accidents and injuries due to line cuts
7	Reduced travel delays to the motoring public
8	Reduced loss of service to utility customers
9	Improved contractor productivity and methods
10	Increased the possibility of reduced bids
11	Reduced contingency fees from all parties
12	Reduced the cost of project design
13	Reduced the damage to existing pavements
14	Reduced damage to existing site facilities
15	Reduced the cost of needed utility relocates
16	Minimized disruption to traffic and emergency
17	Facilitated electronic map accuracy, as-built
18	Minimized chance of environmental damage
19	Induced savings in risk management and insurance
20	Introduced concept of SUE
21	Reduced right-of-ways acquisition costs

Table 2. Summary of Cost-Benefit Analysis of Subsurface Utility Engineering (SUE)

Items	N	Mean	SD	SE	Min	Max
Construction cost	71	$16,028,648	$31,717,159	$3,764,134	$275,333	$238,000,000
Cost of SUE	71	$86,156	$111,443	$13,226	$2,279	$545,907
SUE cost ratio	71	1.39%	1.86%	0.22%	0.02%	10.76%
SUE savings	71	$398,920	$546,688	$64,880	$6,000	$3,136,000
% of CCS	71	4.26%	6.38%	0.76%	−4.11%	34.17%
ROI	71	$12.23	$29.25	$3.47	$0.59	$206.67

Note: CCS=construction cost savings; SD=standard deviation; SE=standard error; and ROI=amount of money saved by the expenditure of one dollar for SUE activity.

The measured project cost savings ranged from $6,000 to $3,000,000. In order to evaluate the total savings on a typical project using SUE when compared with costs from a project utilizing traditional utility data (QL-D and QL-C), the following equation was used:

$$\text{construction cost savings (CCS)}_i\ (\%)=\left(\frac{S_i-\text{CS}_i}{C_i+S_i}\right)\times 100 \quad (1)$$

where C_i=construction cost of the project$_i$; S_i=SUE savings from the project$_i$ (additional costs that would have been expected if SUE were not implemented); and CS_i=the amount of money spent on SUE for project$_i$. The average savings was 4.6% of the total construction cost with standard deviation of 6.38%. This figure is less than the predicted value by Stevens (1993) who stated that the total savings on a typical project using SUE might range from 10 to 15%.

Return on investment (ROI) was calculated using Eq. (2).

$$\text{ROI}_i(\%)=\frac{S_i}{\text{CS}_i} \quad (2)$$

Here, ROI=amount of money saved by the expenditure of one dollar for SUE activity. The analysis of the ROI on the 71 projects showed that only three projects had negative ROI. The average $12.23 ROI for every $1.00 spent on SUE was quantified with the standard deviation of $29.04. The high standard deviation in this case implies the high volatility of ROI. The ROI of the 71 projects ranged from $0.59 to $206.67, which can be attributed to the different characteristics of the project, including the degree of the congestion of underground utilities in the project area, the location of the project (rural or urban), the type of the project (bridge or new road construction), the presence of new underground utility construction, the area covering the project, etc. For instance, urban road construction with a heavy presence of new underground utility construction in a utility-congested area can benefit greatly through the use of SUE. The data of the cost–benefit analysis is summarized in Table 2.

A cost savings analysis of each individual category was also performed. In order to evaluate the degree of impact of each category (DI) to cost savings, Eq. (3) was employed.

$$\text{DI of the category}=\frac{\Sigma(\text{CSC}_i)}{\Sigma(\text{TCPS}_i)}\times 100 \quad (3)$$

where CSC_i=cost savings in each category for the project$_i$; and TCPS_i=total cost savings in the project$_i$. As shown in Fig. 4, reduced number of utility relocations is the category that contributes most significantly to the cost savings (37.1%). The use of SUE enables the early identification of conflicts between existing utilities and new utilities. This can lead to a significant reduction of the amount and length of utility relocations. Reduced contractor's claims and change orders is the second most significant contributor to cost savings (19.3%). Incorrect utility information on the as-built drawings often leads to additional construction work and in some cases, claims and design change as project owners are typically responsible for unknown or differing site conditions. Precise information about utilities assists in quick and reliable decision making in the negotiating and permitting process with municipalities and utility companies. Besides, the reduced likelihood of claims also decreases the level of contingency that has to be set aside to deal with uncertainties in the construction phase.

Reduced accidents and injuries due to utility line cuts is the third significant cost savings factor in the use of SUE (11.6%). Subsurface utility engineering upgrades the accuracy and the reliability of the location of existing utility lines, lessening the probability of hitting utilities during the excavation stage. Reduced project delays due to utility relocates is the fourth significant cost saving factor (9.6%). Other cost savings categories that comprise a total of 22.3% include reduced right-of-way acquisition costs

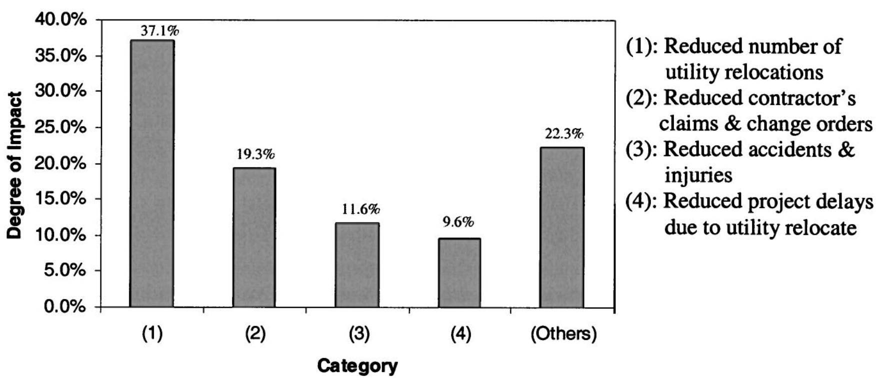


Fig. 4. Degree of impact of different categories to cost savings

Table 3. Summary of State Department of Transportation Survey

Year	Survey response	Subsurface utility engineering (SUE) program	Average SUE budget (in 1,000s)	Effective tool for cost reduction	Effective procedure for reducing delays	Meet your state expectations
2000	40 (80.0%)	23 (57.5%)	$1,501.1[a]	85.0%	72.5%	91.7%
2001	29 (58.0%)	16 (55.2%)	$1,686.6[a]	72.4%	75.9%	87.5%
2002	35 (70.0%)	22 (62.9%)	$2,020.9[a]	[b]	[b]	90.9%

[a]Converted in dollars of 2001 by Engineering News Record (ENR)'s Construction Cost Index.
[b]The item was not included in the 2002 survey.

(3.5%), induced savings in risk management and insurance (3.3%), reduced delays caused by conflict redesign (2.8%), etc.

Current Subsurface Utility Engineering Practice in Department of Transportation

For the purpose of evaluating the current SUE practices in state DOTs, questionnaire surveys were distributed to all 50 states in 2000, 2001, and 2002. Forty questionnaires were returned in the year 2000 survey (a response rate of 80%), 29 questionnaires were collected in 2001 (a response rate of 58%), and 35 states responded in 2002, representing a response rate of 70%. The statistics quoted in this paper are primarily based on the 2002 survey unless noted otherwise. The summary of the findings is shown in Table 3.

Twenty-two states, or 63% of respondents, reported that they have utilized SUE on their highway projects. Four states had initiated the SUE program in 2002 while two states started the use of SUE in 2001. Eight states, or 62% of the respondents that had not used SUE, reported that they were considering a pilot project for the use of SUE in 5 years. The average annual amount of budget spent on the SUE program in the states was about $1.5 million in 2000, about $1.7 million in 2001, and $2 million in 2002. The average annual budget for the SUE program grew as much as 135% higher during this period. No states reported a decrease in their SUE budget. The most active state in promoting SUE application in highway projects was Texas, spending more than $6 million annually.

Virginia, which has the longest history of use of SUE, is mandated by state regulation to apply SUE to every highway project. Delaware, Maine, Maryland, North Carolina, and Pennsylvania reported that all or most of their highway projects currently involved the use of SUE. The other states typically employ SUE based on its usefulness in highway projects. The common criteria for choosing SUE for a project are: (1) a urban highway construction project with a high potential for anticipated utility conflicts, (2) projects with complex utility networks—either aging or of significantly high potential for expensive utility relocations, (3) limited, narrow, and congested existing right-of-way, and (4) high-profile highway projects that have critical schedules.

State DOTs have different decision-making agencies to select projects for implementing SUE. More than 90% of respondents that have a SUE program reported that a design project manager made the decision to employ SUE or district utility agents were involved in the decision. Other responses include direct decision made by the state DOT central office or involvement by SUE consulting firms. States performing pilot projects indicated that the decision was made at the central office.

The survey indicated that more than 90% of state utility managers who responded are aware of SUE and they stated that SUE is an effective tool for cost reduction in a project (85% in 2000 and 72% in 2001). Seventy-five percent of states surveyed in 2001 (73% in 2000) reported that SUE is an effective procedure for reducing construction delays when it is used in the design stage. Decreased construction delays are based on a substantially positive increase in utility coordination and fewer anticipated utility conflicts when SUE is used. More than 90% of the states who have used a SUE program reported that SUE satisfactorily met their needs, emphasizing that SUE also benefits other groups, including utilities, contractors, engineers and the highway department by removing significantly additional workloads due to reduction of utility conflicts, delays, and safety hazards which are expected unless SUE is utilized and consequently providing more clear predictable project schedule.

Regardless of the obvious benefits of SUE, some disappointing results from the use of SUE were reported mainly due to lack of professional SUE providers. Qualification guidelines for the selection of SUE providers were not strongly established nor rigorously enforced in the states. The survey revealed that a SUE provider for state highway projects was typically selected based on the SUE firm's past experience, availability of key personnel, ability to perform the project, quality assurance or quality program, and prior work experience with the DOT. Based on FHWA recommendations (FHWA 2002), SUE firms must be able to provide the following: a thorough understanding and knowledge of designating, locating, surveying, and data management activities; well trained and experienced engineers in accordance with state professional registration requirements; adequate resources including wide range of equipment and systems for each SUE activity; and the financial capacity to provide the required services. The ability to provide the required accuracy of SUE services and adequate insurance covering all aspects of work are also key ingredients of successful SUE providers.

Current Subsurface Utility Engineering Practice in Private Sectors

In order to evaluate the nature of SUE business in the private sector, a questionnaire was developed and distributed to 45 SUE companies that currently provide SUE services in the U.S. Twenty-three questionnaires were returned, representing a response rate of 51%. Two of the respondents failed to complete the survey completely, thus 21 surveys were used in the analysis. The questionnaire consisted of three sections: (1) company profile; (2) clients and types of contracts; and (3) project practice and control of operations. The first section was intended to gather background information on the company and to measure the business growth in this industry. The second section was used to analyze the composition of clients using SUE and contract methods used on SUE projects. The third sections of the survey contained questions

Table 4. Annual Sales, Geographical Domain, and Number of Employees

Annual sales (millions)	Percentage	Number of employees	Average number of employees	Geographical domain	Average annual sales per employee	Company size
>10	5%	>150	172	Nationwide	$104,651	Large
6–10	16%	50–100	82	Nationwide/Regional	$85,622	Medium
<5	79%	<50	16	Regional	$60,063	Small

seeking information about technologies used in each SUE process, average productivity, unit price, man power and SUE operation challenges.

Company Profile

The majority of responding SUE providers (67% of the respondents) had been in business less than 10 years. Nineteen percent of participants had greater than 10 years and less than 15 years of experience while 14% had more than 15 years of experience. Subsurface utility engineering providers are in a young industry as SUE was initiated in the early 1980s and spread mainly through the effort of FHWA and state DOTs. There has been relatively slow acceptance of the technology thus far as there are a few established companies offering this specialized service.

Approximately 79% of the respondents reported annual sales in the year 2001 of less than $5 million. These companies can be characterized as small SUE providers. They employ less than 50 people, and their geographical domain is normally regional. Sixteen percent of the respondents indicated sales between $6 million and $10 million, while 5% of the respondents had annual sales in excess of $10 million. Typically, large firms involved in nationwide SUE business have more than 100 employees. The annual sales per employee increase as the size of company increases as shown in Table 4. Small companies generate an average of $60,063 per employee in a year. In contrast, the large firms create sales of more than $100,000 per employee. The difference can be partially attributed to the following factors:

1. A SUE project lasts for a couple of days or at most several weeks. This implies that a waiting period (no work period) between projects can be a significant factor affecting the sales volume of the company. The flow of SUE projects for small firms tends to be low due to the nature of their localized business.
2. Even small companies need to maintain a consistent staffing level for full SUE service irrespective of the number of projects since a typical SUE project consists of five different stages (which were shown in Fig. 3) with different engineers. Subsequently manpower is not optimized, resulting in lower productivity in small companies.

In the analysis of the employee composition of SUE firms, technicians for fieldwork comprise 69% of the total, and are in charge of designating, locating and surveying tasks and collecting data for utility properties. Project engineers, who typically manage all the SUE projects in a specific region, comprise 16%. Other engineers for data management system form 13% of the employee group. Only 3% of employees are geophysicists. The survey revealed that middle and large companies hire geophysicists, and small firms do SUE business without employing geophysicists. The essential element for a successful SUE project is the correct identification of underground utilities. Different site environments, including soil conditions, pipe material, joint type of pipe, depth of utility, etc., commonly require the expertise of a geophysicist in the proper use of geophysical equipment for the detection of subsurface utilities. The low number of geophysicists employed in SUE firms is a growing concern in the industry particularly when it is necessary to provide high quality SUE deliverables.

The growth rate in SUE business during the past 5 years is plotted based on the annual sales of SUE companies as shown in Fig. 5. The annual sales in each year were converted in dollars of 2001 using Engineering News Record construction cost index, which is widely employed to incorporate inflation factors in construction industry. The growth rate was based on 1997 sales. Three criteria were utilized in the selection of appropriate respondents for this analysis:

1. The companies had annual sales in 2001 of more than $1 million;
2. They have been in SUE business for more than 5 years; and
3. These companies have not been involved in merge and acquisition activities (since these activities may distort the magnitude of sales of SUE business during that period).

The growth rate of the SUE business of selected companies ranged from 115 to 276%, averaging 173%. No company showed a decline in sales during the period. This rapid growth can be attributed to increasing consensus among project owners of the benefits of SUE such as cost savings and damage prevention, as well as growth of underground construction in urban areas, utility rehabilitation and replacement. It also strongly indicates that the SUE marketplace has just entered a robust adolescence period, but has yet to achieve the status of a mature industry.

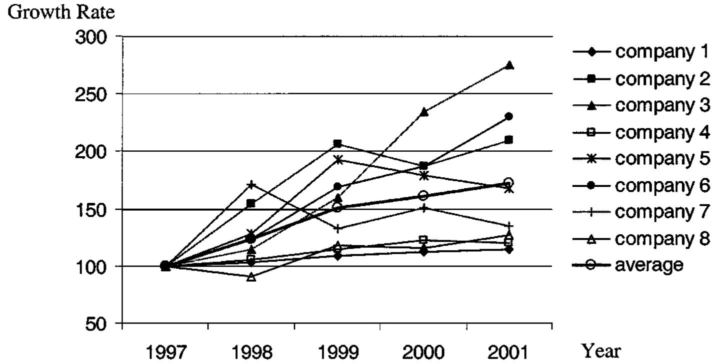
Clients and Types of Contracts

Clients

Federal Highway Administration and several DOTs were early proponents and advocates for the use of SUE. They primarily promoted the use of SUE in highway construction projects as a cost reduction tool. More than half of the projects undertaken by SUE providers were State DOT and federal agency projects (55%). Sixteen percent of the projects were for institutions, military and industrial facility projects. Engineering firms comprised 11% of the clients and the other clients were municipalities (11%), utility companies (4%), and construction companies (3%).

Type of Contract

Subsurface utility engineering projects are typically obtained through negotiated contracts. Even though there are some projects performed under the competitive bidding, the bidding is avoided in this industry because it triggers the service to fall behind the necessary quality level. It is common for owners to approach SUE providers and negotiate the terms of a contract. Strategic alliances, typically in state DOT contracts, are a growing trend. These relationships are usually defined by a contract and extend over a period of 2 or 3 years (open-end method). Under such an arrangement, the owner can obtain a consistent level of underground utility information and consultation from a qualified SUE



Company	Year				
	1997	1998	1999	2000	2001
Company 1	100.0%	103.3%	109.3%	112.4%	114.8%
Company 2	100.0%	154.6%	206.0%	187.3%	209.9%
Company 3	100.0%	114.8%	160.2%	234.1%	275.5%
Company 4	100.0%	105.4%	114.4%	122.6%	120.3%
Company 5	100.0%	128.3%	192.2%	179.1%	167.7%
Company 6	100.0%	123.0%	168.2%	187.3%	229.6%
Company 7	100.0%	171.6%	132.7%	150.2%	135.3%
Company 8	100.0%	90.8%	118.3%	115.2%	127.2%
Average	100%	124.0%	150.2%	161.0%	172.6%
ENR's Construction Cost Index	5825	5920	6060	6221	6342
	Base: year 1913 = 100				

Fig. 5. Business growth of subsurface utility engineering providers

provider. The owner can eliminate a repetitive selection process during that period while securing the services of qualified provider.

The survey revealed that the most common type of contract used in the SUE industry is a cost-plus-fee contract method (42%). Per diem, or daily rate, contracts comprise 14%. The wide use of cost-plus-fee, which is the typical contract method for engineering services, is based on the characteristics of SUE services. In 1989, a court of competent jurisdiction recognized SUE services are professional services rather than contractor services since information placed on plans that are relied upon by the public clearly fall into the professional services category (FHWA 2002). The type of contract for SUE operations is also highly related to the type of project owner. States DOTs and Federal agencies, which comprise more than half of the SUE clients, prefer a cost-plus-fee method because they have the resources to audit and do cost analyses. This type of contract also enables SUE firms to earn reasonable profits while recovering all costs expended on the project. The major disadvantage of cost-plus-fee and per diem method is the difficulty in proper budgeting and the provision of fewer incentives for SUE providers to work efficiently (see Fig. 6).

Thirty-two percent of the contracts were made based on unit price contracts while 12% of the contracts used the lump sum contracting method. When only quality level A and B mapping are required, these types of contracts can be easily adapted since the fees for engineering service are not included. In unit price contracts, clients typically have the best control over budget and meeting the budget expectations, and SUE providers are encouraged to optimize their available resources to provide highly efficient and productive services. However, if the site environment is not favorable for the SUE firms, this method may negatively impact the profit of the SUE firm or the quality of the final deliverables. The primary advantage of the lump sum contract method is the ease in budgeting for project owners. However, it may be difficult to obtain the final deliverables at the exact level of effort anticipated by the SUE provider.

Project Practices and Control of Operations

Designating Methods and Locating Methods

There are various designating methods available in industry to acquire data regarding two-dimensional location of underground utilities. It is crucial for a SUE provider to be equipped with different kinds of instruments for successful designation of an underground utility and reliable SUE service because no single technology currently available can function in different site environments and utility materials. The participants in the survey were asked to identify the availability of different designating equipment and to evaluate the use of different designating equipment on typical highway projects for all utilities.

Pipe and cable locators, GPR, and metal detectors were found to be the main designating equipment for SUE projects as most of the responding companies are equipped with those systems. Acoustic pipe tracers (62%), magnetometers (48%), terrain conductivity meters (TCMs) (33%), and electronic marker systems

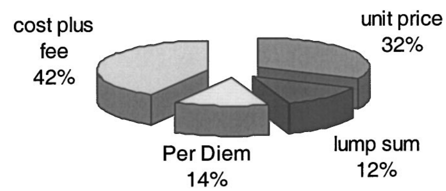


Fig. 6. Breakdown of contract methods in subsurface utility engineering

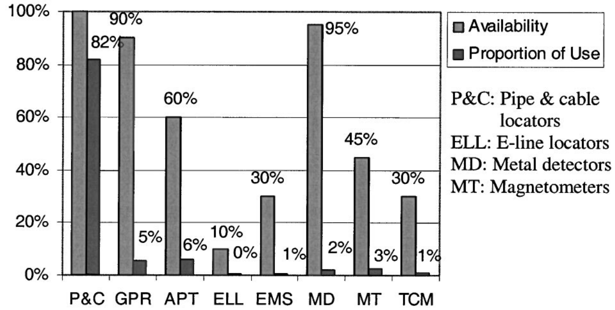


Fig. 7. Availability and proportion of use of designating methods

(EMSs) (29%) were also available for use. An E-line locator system, which is utilized for designating plastic gas pipe without tracing wires or electronic markers installed above the pipe, was not commonly available (10%).

Eighty-two percent of designating operations on highway projects were performed using pipe and cable locators. Typically, this method is used to detect metallic utilities or tracing wire installed pipes. But nonmetallic pipes can also be designated by inserting a sonde (a type of transmitter) through an access point to the underground utility, such as a manhole. Acoustic pipe tracers (6% of use), whose operation is based on elastic wave theory, are primarily designed for detecting plastic gas or water pipes. A low tracing length (typically less than 300 m) and low accuracy due to noise in an urban area limit the use of this method. Ground penetrating radar is currently the third most common method for designating purposes (5%). The major advantage of GPR is that it can image different types of materials buried underground. The drawbacks of using this equipment include inapplicability to high conductive soils (clay and saturated soils), practical limitation of imaging objects located 2 m below the surface, and high operating costs compared to pipe and cable locators (see Fig. 7).

The other designating methods, which are used less than 3% of the time, include E-line locator, EMS, metal detector, magnetometer, and TCM. Electronic marker systems is only applicable in areas where electronic markers were installed at the time of the utility construction. Metal detector and magnetometers are typically used for searching metallic surface appurtenance such as manhole lids or valve boxes, but they are not useful for tracing utility lines, which explains the low rate of use in designating operation activity. A TCM is useful for detecting isolated metallic utilities, underground storage tanks, wells, and vault covers.

The vacuum excavation system is the predominant method for locating underground utilities in order to obtain three-dimensional data and utility properties. Ninety percent of respondents reported that they were equipped with vacuum excavation systems. This process uses vacuum in combination with high-pressure water or air to expose underground utilities. The method guarantees that there will be no damage to existing utilities and that the "hole" in the street pavement is kept to a minimum and is easily repaired.

Surveying and Data Management Systems

Ninety-five percent of respondents indicated that they work with traditional surveying tools, such as levels and theodolites, for mapping identified underground utilities, after the designating and locating process. For developing a permanent record of utilities locations requested by the project owner, GPS is more likely to be used. Eighty six percent of respondents were equipped with GPS. The rapid development of GPS technology such as the RTK method makes it possible to obtain horizontal and vertical accuracy of ± 30–50 mm ("GPS" 2002). The surveying process is sometimes sub-contracted. Small SUE firms find it difficult to maintain a full-time professional survey crew; sub-contracting the surveying process is a better choice for such companies. In such cases, these firms typically team up with a local surveyor. Some portion of the surveying is also strategically sub-contracted on DOT work to meet historically underutilized business, disadvantaged business enterprise, and women business enterprise requirements or to involve a registered surveyor in the state where the work is being performed. Involving outside surveying firms in SUE projects, however, may create a question of responsibility or liability for the data delivered.

The dominant data management tool at present is CADD (86% availability). According to United States General Accounting Office (USGAO 1999), 43 states (84%) had used CADD for their construction projects while 15 states (29%) had also used GIS for their construction projects. As the state DOTs are major clients for SUE services, SUE companies are more likely to provide their deliverables in CADD rather than GIS. Of the respondents, 57% have GIS capability, which is currently used at the request of the client. GIS technology can provide advanced features such as easy data transformation with GPS, data manipulation, and data analysis, which distinguishes it from CADD system. For example, utility attributes such as size, material, condition, installation date, utility owner, and maintenance histories are also recorded with the coordination data and quality levels in GIS. This data inventory can be used to produce a new set of data in tabular forms or visual formats to assist underground infrastructure managers in deciding utility inspection scheduling, areas of rehabilitation, maintenance budgeting, utility routing and permitting, emergency response planning, etc. (GPS 2002).

Productivity/Unit Cost

The productivity and unit costs for a designating service typically using pipe and cable locators and for locating services using vacuum excavation system are shown in Table 5. As the scope of SUE and the environment in which SUE is used change significantly from project to project, the productivity and the unit cost of both activities vary significantly. The large coefficient of variance of productivity of the designating activity implies a significant impact by site conditions on each activity. Traffic congestion, degree of utility congestion, utility material, depth of utility, surface condition, weather, and level of urbanization, all affect the productivity of designating activity. In the locating activity, the depth of the utility and the soil condition were found to be the critical factors. Utilities which are located at depths greater than normal utility depth (<1.5 m) under the pavement require a relatively longer time period for location due to pavement breakage, large area of excavation and lack of illumination when locating the utilities. Sticky soils such as clay are also likely to clog the vacuum hose while soil is disposed.

The large coefficients of variance of unit costs for both activities are related to the large standard deviations of productivity, as well as the scope of SUE work. When a simple QL-B/QL-A service is required in relatively favorable site conditions, the low unit cost was derived while the high unit cost is applied to full SUE service that includes engineering services such as utility coordination in relatively unfavorable site environments. The survey participants reported that two technicians are required for a typical designating activity and three or four technicians are necessary for the locating activity. However, in many cases, the designating and locating processes occur at the same time and the technicians are trained for both processes. In general, a SUE team

Table 5. Productivity and Unit Cost

Subsurface utility engineering activity		N	Mean	SD[a]	%CV[b]	Minimum	Maximum	Number of technicians
Designating	Productivity (m/day)	21	994	794.6	79.9%	250	3,333	2
	Unit cost ($/m)	21	3.84	2.389	62.2%	0.75	11.25	
Locating	Productivity (holes/day)	21	6	2.0	31.7%	4	12	3–4
	Unit cost ($/hole)	21	560	442.9	83.3%	300	2,300	

[a]SD: standard deviation.

[b]%CV: % coefficient of variation.

is composed of three or four technicians who work under the direction of a project manager.

Challenges Experienced on Subsurface Utility Engineering Projects

In the survey, the participating SUE providers were asked to assess the significance of many factors potentially challenging their SUE projects. The factors were scored on five different scales, from 'extremely significant' (5 points) to 'not significant' (1 point). The level of significance of the factors was calculated using the following formula in order to determine the overall ranking of the factors:

$$\text{significance index} = \Sigma \alpha * (f/N) * 100/5 \quad (4)$$

where α=constant expressing the weight given to each scale; f=frequency of the responses; and N=total number of responses for each factor. The results are provided in Table 6.

It can be seen that the most significant factor for a successful SUE project is obtaining appropriate records such as as-built drawings of the project area. The unavailability of adequate information for existing underground utilities causes problems in searching and finding surface appurtenances (starting point of utility tracing) and selecting appropriate equipment for tracing utilities. This also results in low productivity of the designating process and many omissions of underground utilities in the final deliverables. Maintaining a good relationship with local utility companies is a crucial key to obtaining suitable information.

Lack of understanding of SUE by clients was found to be the second biggest challenge in SUE projects. Many potential clients confuse the engineering concept of SUE with the "one-call" system which is a contract service. One-call's benefits are limited to mere avoidance of utility hits during the construction stage, while SUE is a consulting service provided in the design stage of a project, providing benefits through the whole project. Clear understanding of SUE by clients allows the proper budget by appropriate contract method, and consequently avoids failure to meet the required level of quality of the deliverables.

Traffic control (safety) is of great concern particularly in heavy traffic areas since high concentrations of main lines of underground utilities are found in the right-of-way or under the pavement. Unfavorable site conditions, which include conditions such as nonmetallic pipes buried in high conductive soils, deeply buried pipes, and highly congested utility lines, also affect the execution of SUE projects. Currently available designating technologies cannot adequately pinpoint the exact location of underground utilities under these conditions.

Conclusions

The paper presents a comprehensive insight into the various aspects of a new and rapidly growing market in SUE. The cost–benefit analysis, based on 71 actual construction projects where SUE was employed, revealed that more than ten times the funds invested in the SUE service were returned to project owners. The highest cost savings factor was the reduced number of utility relocations. This strongly indicates that SUE is a promising tool for cost savings in highway construction projects particularly where utilities are congested. Questionnaire surveys of state DOTs revealed an average increase of 17% in the annual SUE program budget during the 1999–2001 period, high satisfaction with the use of SUE (>90%), and an increasing number of states that have initiated the use of SUE for their highway construction projects.

The questionnaire survey of the SUE industry revealed various aspects of SUE practices in the private sector. The majority of SUE firms have less than 10 years of experience. The rapid growth rate of SUE business (173%) in the past 5 years is a good

Table 6. Factors Challenging Subsurface Utility Engineering (SUE) Projects

Factors	Degree of significance[a] (frequency of responses)					Significant index	Rank
	EX	SI	MO	LI	NO		
Getting appropriate record	12	8	1	—	—	92	1
Lack of understanding of SUE	9	6	5	1	—	82	2
Traffic safety	6	5	7	3	—	73	3
Unfavorable site conditions	3	6	9	3	—	69	4
Work scope splitting	4	6	6	4	1	68	5
Project time frame	3	7	5	5	1	66	6
Inclement weather	3	1	8	9	—	58	7
Deliverable formats	4	4	2	8	3	58	7
Sufficient amount of mobilization, travel, relocation cost	2	3	4	8	4	51	9

[a]EX=extremely significant; SI=significant; MO=moderate; LI=little; and NO=not significant.

indicator for the bright future of this area. State DOTs and federal agencies are major clients (>50%), but other clients such as municipalities, utility companies and engineering firms are also increasing their use of SUE. Subsurface utility engineering firms are highly dependent on pipe and cable locators for the designating process and vacuum excavation system for the locating process. Currently, traditional survey methods and CADD are the prevailing data management system, but GPS and GIS appear to be the next generation for data management systems due to their apparent advantages over traditional surveying methods and CADD. Several factors challenging SUE projects were identified. They are highly related to the productivity and quality of SUE projects. Identification of these factors in the early stage of the project and an effective management strategy were pointed out to be essential for the successful completion of a SUE project.

Followup interviews with experts in the SUE industry emphasized the importance of research in developing versatile equipment for the designating activity due to inherent limits of current technologies, as well as education of SUE for the continued evolution of this industry. Some interviewees even suggested that a college curriculum incorporating geophysical theories, surveying, data management, utility design/coordination, and liability issues in civil engineering programs would be necessary to provide qualified engineers in this arena. It is hoped that the findings from this study will provide a foundation in shaping a better future for this emerging industry.

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