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Cost and Time Benefits for Using Subsurface Utility Engineering in Louisiana

by

Allen Mutoni
Kirk Zeringue
Chester Wilmot

Louisiana State University

4101 Gourrier Avenue | Baton Rouge, Louisiana 70808
(225) 767-9131 | (225) 767-9108 fax | www.ltrc.lsu.edu

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2. Author(s)
Allen Mutoni, Kirk Zeringue, and Chester Wilmot

3. Performing Organization Name and Address
Department of Civil and Environmental Engineering
Louisiana State University
Baton Rouge, LA 70803

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13. Abstract
As an increasing number of utilities are installed below ground in urban areas, it is vital to identify the location of utilities prior to construction. The discovery of unforeseen underground utility lines during construction can not only lead to catastrophic damages, but also affect project costs and schedules. Subsurface Utility Engineering (SUE) has emerged as a means to reduce unexpected utility conflicts. SUE is an engineering process that utilizes data processing and site characterization technologies to accurately locate and depict underground utilities in the preliminary stages of a project. This research focuses on the potential benefits of SUE services in Louisiana Department of Transportation and Development (DOTD) projects. Actual costs were used to determine the benefits of SUE, hence only projects that used SUE services after encountering utility conflicts during construction were evaluated. A cost savings of $2.73 for every $1 spent on SUE was realized. This research also examined the effectiveness of SUE services on project cost and time and determined what type of projects would benefit the most from SUE. The results indicated that SUE is most applicable to larger, complex projects costing at least $3 million.

Project Review Committee

Each research project will have an advisory committee appointed by the LTRC Director. The Project Review Committee is responsible for assisting the LTRC Administrator or Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, oversight of approved research projects, and implementation of findings.

LTRC appreciates the dedication of the following Project Review Committee Members in guiding this research study to fruition.

LTRC Administrator/Manager

Julius Codjoe

Special Studies Research Manager

Members

Taylor James-Lightner

JoAnn Kurts

Directorate Implementation Sponsor

Christopher P. Knotts, P.E.

DOTD Chief Engineer

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By
Allen Mutoni
Kirk Zeringue
Chester Wilmot

College of Engineering
Louisiana State University
Baton Rouge, LA, 70803

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Abstract

As an increasing number of utilities are installed below ground in urban areas, it is vital to identify the location of utilities prior to construction. The discovery of unforeseen underground utility lines during construction can not only lead to catastrophic damages, but also affect project costs and schedules. Subsurface Utility Engineering (SUE) has emerged as a means to reduce unexpected utility conflicts. SUE is an engineering process that utilizes data processing and site characterization technologies to accurately locate and depict underground utilities in the preliminary stages of a project. This research focuses on the potential benefits of SUE services in Louisiana Department of Transportation and Development (DOTD) projects. Actual costs were used to determine the benefits of SUE, hence only projects that used SUE services after encountering utility conflicts during construction were evaluated. A cost savings of $2.73 for every $1 spent on SUE was realized. This research also examined the effectiveness of SUE services on project cost and time and determined what type of projects would benefit the most from SUE. The results indicated that SUE is most applicable to larger, complex projects costing at least $3 million.

Acknowledgments

The support and direction of the Project Review Committee is gratefully acknowledged. They provided the data on which the analysis reported in this document was based and provided input that directed this project in a productive manner.

Implementation Statement

This research will show project managers the importance of applying SUE to their projects and the type of projects that benefit the most when SUE is applied. If there is a dollar amount that shows the cost and time savings of SUE, then project managers will be more willing to incorporate these services and reduce the number of utility problems encountered during construction.

Implementation will be achieved by informing DOTD project managers of the results and then collaborating with them to monitor projects in the future to assess the extent to which the predicted benefits are being realized. It is proposed that a research project be launched in the future as part of the implementation of the findings of this project, in which projects of similar utility complexity are paired and one uses a high-quality level of SUE and the other does not, and then compare the costs.

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Introduction

The vast array of underground infrastructure has increased rapidly over the years. Over 20 million miles of underground pipelines, cables and wires make America the envy of the world [1]. However, as the assortment of utility lines in the ground continues to increase, identifying their location prior to construction is becoming more vital. A lack of knowledge on the location of underground infrastructure systems can lead to catastrophic damages as construction and excavation occur within their range. The damage to utility lines has, in fact, been identified as one of the most significant issues faced by the construction industry. According to data collected by Common Ground Alliance (CGA), an underground utility line is damaged about once every six minutes, creating a major concern for constructors.

The risk of damage to underground infrastructure is rising due to the uncertainty of the location of buried utilities. The majority of highway renewal projects depend heavily on the availability of reliable utility records or the One Call system, a damage prevention program. Typically, designers, contractors, and users contact utility owners to mark the location of their existing underground utilities prior to construction, but experience has shown that knowledge of these utilities could be inaccurate, incomplete, or outdated. In addition, companies have changed ownership several times, which may lead to a loss of utility information. In addition, some utilities may not be accounted for as there are numerous companies that are not members of One Call. This lack of reliable information for the location of buried utilities can lead to costly conflicts, project delays, utility service disruptions, claims, redesigns, and worst of all, injuries and loss of life during construction activities. In order to alleviate these risks, Subsurface Utility Engineering (SUE) was introduced about three decades ago.

SUE began in the early 1980s as a means to not only minimize the financial impact caused by the unforeseen buried utilities, but also provide a safer environment for contractors. SUE is an engineering process that utilizes data processing and site characterization technologies to accurately locate and depict underground utilities in the preliminary stages of a project. It combines geophysics, surveying, civil engineering, and nondestructive excavation technologies to map the location of existing utilities during the design phase. This allows for utility conflicts to be minimized, and if a conflict does exist, suitable alternatives can be established before any damage is done.

For a design engineer, constructor, and project owner to understand the concept of SUE, it is essential to first address the four quality levels (QL) of underground utility information. The quality levels represent various combinations of records research, site surveys, surface geophysical methods, and non-destructive locating methods. As the quality levels progress (from QLD to QLA), the accuracy, reliability, and cost of the data collected rises. The quality levels of SUE are as follows [2]:

Quality Level D: This quality level applies when making broad decisions about route selection. This information is derived from existing records and oral recollections.

Quality Level C: This quality level of information is used to determine general utility conflict areas. It is typically recommended that this level of information be requested on rural projects or on projects where there is thought to be minimum utility conflicts. This information is obtained by physically surveying visible above ground utility features and correlating this information to Level D information.

Quality Level B: This quality level of information is used by the designer to make educated decisions on where to place storm drainage systems, footings, and foundations, etc. to avoid conflicts with existing utility facilities. Due to the increased integrity of this level of information, it is recommended that it be requested on urban type projects or on projects where there is thought to be a high amount of utility conflicts. This level uses a variety of geophysical techniques to determine the existence and approximate horizontal position of subsurface utilities. Quality Level B includes quality levels C and D.

Quality Level A: This quality level of information provides exact three-dimensional (x, y, z) mapping of utilities. This level consists of "potholing" or "day lighting" the subject utility. This level of information is needed for final design and utility placement decisions in congested areas. It is recommended that this level of information be requested when there are specific conflict areas identified, and it is determined that by adjusting various design elements, a cost savings will be incurred for the project. This level of information indicates the precise horizontal and vertical location of utilities.

Although many designers and project managers have successfully collected QL data, there is still a lack of adequate understanding of the benefits of SUE services. Furthermore, most project managers are hesitant to apply high levels of SUE to construction projects due to their high costs.

Literature Review

A lot of research has been conducted on SUE, but the focus has been on introducing the program. Only a few studies have conducted a benefit-cost analysis of SUE. Since this is the focus of this study, studies that have addressed the benefits and cost-effectiveness of SUE services are reported on below.

SUE Costs and Benefits

SUE costs and benefits have been documented in a number of studies. One study compared the One Call system to SUE and concluded that SUE is a more competitive damage prevention program [3]. Another study stated that there are numerous inadequacies of the current One Call system, which may affect the location of underground utilities [1]. The results of the research showed that the vacuum excavation system and geophysical technology of SUE have been successful in the past. A researcher addressed SUE on municipal and utility projects from an engineering firm's perspective [4]. He presented a case study that showed that the application of SUE services confirmed that the location of an existing water line was off by approximately 7 feet in the as-built drawing. He stated that it is essential for designers, engineers, and contractors to utilize SUE in order to increase the reliability of information on existing underground utility lines. To demonstrate how SUE can be effectively used to locate underground utilities, two regional SUE projects performed for the Washington State Department of Transportation and the Oregon Department of Transportation were studied [5]. Both projects showed that the application of SUE services led to maintenance of design and construction schedules, and increased safety during excavation.

The benefits of SUE extend beyond those of reducing the risks of conflicts and decreasing the damages to utility lines as a result of construction. In 1993, a study presented the cost savings that result on projects that employ SUE [6]. This study showed that, on average, SUE projects are completed up to 10% faster, leading to administrative cost savings in the order of 2% of total project costs. Engineering cost savings yield a 0.5% project savings since conflicts with underground infrastructure can be resolved by SUE techniques. Construction bids are reduced due to fewer utility conflicts, which result in construction cost savings of 2.25%. Cost overrun savings are 5%, resulting from reducing delay claims, engineering rework, and utility damages. Utility relocation costs realize savings of 5% due to designers using accurate underground information. When compared to projects not utilizing SUE, the results of this research showed that the total cost savings of SUE projects may range from 10% to 15% on a typical project. A research study discussed the current locating practices and the benefits that can be obtained through utilizing SUE [7]. Various documented examples of the benefits achieved from using SUE were discussed. One example was a Columbus Southern Power company that employed SUE during the design phase and determined that the bid price had been reduced by $400,000 due to the accuracy and completeness of the underground utility information. Not only were there no utility relocations, contractor claims, utility damages, or change orders, but the project was also completed ahead of schedule. His research concluded that when the SUE process is applied, contractors' risk is reduced, and a cost savings of approximately $10 for every $1 spent on SUE is realized.

Purdue Study

In 2000, the Federal Highway Administration (FHWA) commissioned Purdue University to study the effectiveness of SUE on highway projects [8]. Virginia, North Carolina, Ohio, and Texas were selected for the study. These four states had a total of 71 projects that were analyzed and studied in detail. In this study, 21 benefits obtained from utilizing SUE on highway projects were developed and used to measure the effectiveness of SUE for individual projects. The benefits used in the study are as follows:

(1) Reduction in unforeseen utility conflicts and relocations

(2) Reduction in project delays due to utility relocations

(3) Reduction in claims and change orders

(4) Reduction in delays due to utility cuts

(5) Reduction in project contingency fees

(6) Lower project bids

(7) Reduction in costs caused by conflict redesign

(8) Reduction in the cost of project design

(9) Reduction in travel delays during construction to the motoring public

(10) Improvement in contractor productivity and quality

(11) Reduction in utility companies' cost to repair damaged facilities

(12) Minimization of utility customers' loss of service

(13) Minimization of damage to existing pavements

(14) Minimization of traffic disruption, increasing DOT public credibility

(15) Improvement in working relationship between DOT and utilities

(16) Increased efficiency of activities by elimination of duplicate surveys

(17) Facilitation of electronic mapping accuracy

(18) Minimization of the chance of environmental damage

(19) Inducement of savings in risk management and insurance

(20) Introduction of the concept of a comprehensive SUE process

(21) Reduction in Right-of-Way acquisition costs

DOT project managers and engineers, utility owners, constructors, and designers were interviewed to study the 71 SUE projects. The results indicated that 68 of the 71 SUE projects had a positive return on investment. A total savings of $4.62 for every dollar spent on SUE was realized. In comparison with other studies, the $4.62 saving was slightly low. For example, a Virginia DOT study obtained a savings of $7 to $1; Maryland DOT obtained a savings of $18 to $1; and the Society of American Value Engineers obtained a $10 to $1 savings. However, the number of projects studied in the Purdue study was much higher, and the qualitative impacts were not included in the analysis. The study concluded that SUE is a viable technological practice that minimizes costs related to the risks associated with existing underground utility lines.

Toronto Study

In 2005, the University of Toronto evaluated the use of SUE in Canada [9]. Nine projects that utilized SUE were analyzed, taking both tangible and intangible benefits into account. In order to properly account for the benefits of performing SUE, a cost model that incorporates all the costs that could be incurred as a result of not performing SUE was proposed. These costs were grouped into three categories, each with different cost savings items. Table 1 shows the categories and cost savings items. Feedback from owners, designers and contractors revealed that 51% of cost savings are attained through the reduction of contractor claim costs, 31% through reduction in utility relocation costs, and the remaining 18% is attained through all other cost items. The results showed that all 9 projects had a positive return on investment ranging from $2.05 to $6.59 for every $1 spent on SUE. This study indicated that with careful scoping of SUE services, project risks can be appropriately reduced at reasonable cost.

Table 1. Categories and cost saving items of SUE

Category	Cost saving item
Cost of Information	Information Gathering cost
	Information verification cost
Savings to Project Costs	Design cost
	Utility relocation cost
	Savings to overall construction cost
	Contractor contingency costs
	Contractor claims & change order costs
	Construction personnel injury cost
	Public injury cost
	Utility damage cost
User Costs	Travel delay cost
	Business impact cost
	Service interruption cost

Penn State Study

The Pennsylvania Department of Transportation (PennDOT) contracted Penn State to study the use of SUE for highway projects [10]. The study developed a decision-making tool for suitable selection of SUE quality level and a benefit-cost analysis of SUE for highway projects. There were 10 SUE projects analyzed, and the results revealed a savings of $22.21 for every dollar spent on SUE. The study concluded that SUE is a practical and valuable process to reduce risks and maximize cost savings for underground utility projects. It also concluded that SUE quality levels A and B should be used based on the complexity of buried utilities at the construction site.

Texas Department of Transportation (TxDOT) Study

TxDOT presented a study that evaluated the potential benefits of SUE services in Texas, focusing on QL A and B [11]. The study used several measures of effectiveness and t-test statistics to compare 32 SUE projects against a group of control projects. The findings of the research showed SUE services tended to be used for large projects with significant design efforts and projects with complicated utility conditions. The results also showed that SUE services had fewer construction delays, fewer utility change orders during construction, and fewer utility conflicts. The study provides insight on how SUE services have been used in the past and how they might have improved project performance.

Limitations of Previous Research

The literature reveals that SUE is considered an effective process to reduce risks and expenses for underground utility projects. Some researchers have documented the benefits of SUE and the successful use of SUE in the past, and others have dealt with the cost-effectiveness of SUE services in specific states. No research has been conducted to estimate the costs and benefits of these services in Louisiana. Additionally, the majority of the research that investigated the cost savings of SUE have obtained their information through interviews with project managers, utility owners, constructors, and designers. The interviewees were asked to make assumptions on what the project costs could have been had SUE not been used. The data gathered using this approach can be inaccurate and biased since it is based on the judgment of people with an interest in the outcome. In this study, the benefits of SUE in Louisiana have been obtained by using information obtained from the Louisiana Department of Transportation and Development (DOTD) in the form of data and information gathered from officials in the department.

Identification of SUE Projects

To determine the benefits of SUE in Louisiana, the projects that used QLA and QLB SUE services were first identified. Since the SUE program is fairly new to Louisiana, only a few projects have applied SUE in the past. There were hardly any records on historical SUE contracts, which made the process somewhat challenging. SUE projects were identified by reviewing data from the Contracts Information System (CIS) and contacting project managers.

Project managers were contacted to provide a list of projects that used SUE services in the past. However, most of the projects had not been let or were still under construction. The list was narrowed down to projects that were at least 90% complete. In addition to contacting project managers, data from the CIS was reviewed. The CIS contain various types of DOTD contracts. Keywords such as contractor names and project manager names were used to recognize SUE contracts. At the end of this process, 13 projects that used SUE in the past were identified.

Return on Investment of SUE

This research deals with a Return on Investment (ROI) equation consisting of the cost and time of encountering utilities during construction and the total costs of SUE services. To determine the ROI of SUE services in Louisiana, projects that have used QLA and QLB SUE services were identified. However, since this study aims to use actual costs to determine the benefits of SUE, only projects that used SUE services after encountering utility conflicts during construction were evaluated. The utility related costs were the actual costs of encountering unexpected utilities during construction, and the total cost of SUE was the actual amount spent on SUE services for each project. Therefore, the ROI in this study is a dollar amount of savings to show how much could have be saved if SUE had been used correctly. The ROI equation is as follows:

ROI = Utility related costs/Cost of performing SUE

where,
Utility-related costs = Actual costs of encountering utilities during construction

Utility-Related Costs

There are numerous costs related to utilities, but this study identified seven main costs due to availability and accuracy of data. These costs were obtained through DOTD data systems such as Site Manager. Once projects that used SUE were identified, the change orders were reviewed thoroughly to determine costs and conflicts related to utilities. The utility-related costs considered in this analysis are as follows:

(1) **Utility conflicts and relocation cost:** The cost of unexpected utility conflicts and relocations due to insufficient utility information.

(2) **Project delay cost:** The cost of project delays due to utility relocations.

(3) **Claims and change order costs:** The costs resulting from filing a claim or requesting a change order due to unexpected utility conflicts.

(4) **Project design costs:** The costs of project design work due to inaccurate utility information.

(5) **Travel delay costs:** The cost for road users due to project delays caused by utility conflicts.

(6) **Damage costs:** The costs of person injury and third-party damage.

(7) **Information gathering and verification cost:** The additional cost of gathering and verifying information due to unexpected utility conflicts.

Effectiveness of SUE

This research also set out to measure the effectiveness of SUE services on project costs and project time. To achieve this goal, a selection of Measures of Effectiveness (MOEs), similar to Li et al. (2013), were developed. These MOEs are used to compare the project cost and time of DOTD projects that used SUE services and those that did not use SUE. Table 2 shows a complete list of the MOEs and their associated data items and computation.

Table 2. Measures of Effectiveness (MOE) of SUE

Measure of Effectiveness	Data Item	Computation
Design cost	• Project design cost	Total project design cost
Construction cost	• Project construction cost	Total project construction cost
Construction cost increase	• Actual cost • Proposed cost	Actual cost – Proposed cost
Construction cost percent increase	• Actual cost • Proposed cost	(Actual cost – Proposed cost) * 100

Measure of Effectiveness	Data Item	Computation
Utility-related change order cost	• Utility-related change order cost	Total utility-related change order cost
Percent of utility related change order cost	• Utility-related change order cost • Construction cost	(Utility-related change order cost/Construction cost) * 100
Construction duration	• Actual construction days	Total actual construction days
Project delay	• Actual days • Proposed days	Actual days – Proposed days
Percent of project delay	• Actual days • Proposed days	(Actual days – Proposed days)/Proposed days * 100

In order to make the comparison between projects more significant and determine what type of projects benefit the most from SUE, various categories of projects were proposed. The first categorization was projects that used SUE and those that did not. However, after identifying the projects that have used SUE in the past, the sample size of these projects appeared to be very limited. Applying further categorization to this small sample would undermine the reliability of the research. For this reason, further categorization was only applied to the projects that did not use SUE since they had a larger sample size. The revised method proposed to compare the MOEs between the two general groups (projects that used SUE and projects that did not use SUE) and the different categories of the projects that did not use SUE. The categories were as follows:

- complex with a contract size of at least $3m ($C \geq 3M$)
- complex with a contract size less than $3m ($C < 3M$)
- simple with a contract size of at least $3m ($S \geq 3M$)
- simple with a contract size less than $3m ($S < 3M$)

The threshold for the contract size was determined by reviewing the pool of projects available, and the complexity of a project was determined by examining past projects. Projects that have encountered utility conflicts in the past and projects that used SUE were reviewed to determine trends. Based on the data available in DOTD data systems, the factors in Table 3 were involved in determining the complexity of a project.

Table 3. Project complexity

Factor	Simple	Complex
Project Location	Rural	Urban
Average daily traffic (ADT)	< 6000	≥ 6000
Estimated utility relocation cost	< 3% of project costs	≥ 3% of project costs
Project improvement type	Shallow excavation	Deep excavation

Project Location: This refers to the location of the project (urban or rural). Urban areas are known to be more complex than rural areas and are more congested with underground utilities. The majority of projects that have encountered utility conflicts in the past, have been in urban areas.

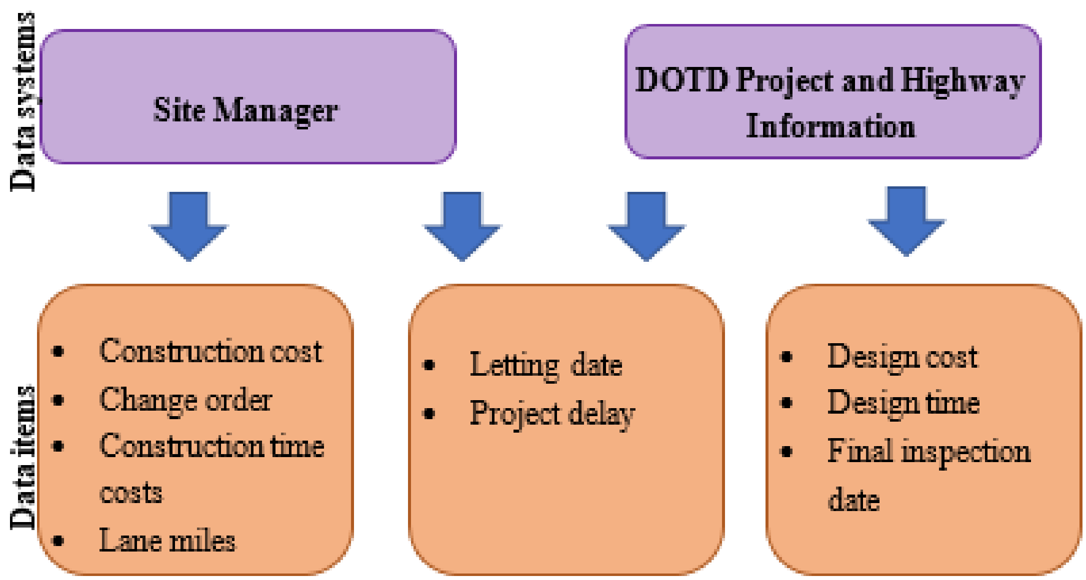
Average Daily Traffic (ADT): The average daily traffic that could be encountered on a project plays a role in the complexity of the project. Higher traffic volumes increase the complexity of a project; therefore, project delays in areas with a higher traffic volume would have a more significant impact on road users. The ADT of SUE projects that have encountered utility conflicts in the past were reviewed to determine the estimated traffic volume. An ADT of approximately 6000, which was in the 75th percentile, was used as the threshold.

Estimated Utility Relocation Cost: This refers to estimated utility relocation cost as a percent of total project costs. Projects with a high percent utility relocation costs would require more reliable utility information in order to avoid additional project costs and time. The majority of projects that encountered utility conflicts in the past had utility relocation costs of approximately 5% of project costs.

Project Improvement Type: The type of project improvement can contribute to the complexity of a project. Projects that involve deep excavation are more likely to encounter unexpected utilities. Approximately 80% of projects that had utility conflicts in the past were bridge, new construction or widening projects.

Based on all the data items needed for this analysis and the data systems available, a list of the potential data systems needed to obtain each data element was created. Figure 1 shows the data systems and their associated data items.

Figure 1. Data systems and associated data items



Objective

The goal of this research was to determine the cost and time benefits of utilizing SUE services to locate underground utilities in Louisiana. In pursuing this goal, it was also the aim of this research to examine the effectiveness of SUE services on project cost and time and determine what type of projects would benefit the most from SUE.

The specific objectives in service of the above goals were: (1) to investigate major DOTD projects that have used SUE services in the past to determine the returns on investment of the SUE program in Louisiana; (2) to compare the return on investment of applying SUE in Louisiana to the return on investment obtained by Lew (2000) and similar studies; (3) to investigate the projects that did not use SUE services and compare their project costs and delivery time to those that have used SUE in order to assess SUE effectiveness; and (4) to provide recommendations based on the research findings.

Scope

The majority of road construction projects in Louisiana involve excavation where underground utilities exist. The standard method for locating the underground utilities prior to construction is to have the utility company or the Louisiana One Call locate them. However, there are several issues with this methodology including the fact that not all agencies that place utilities in the road reserve submit the location of their facilities to One Call. This research will determine the relative benefit of utilizing SUE in Louisiana, which will show project managers the importance of applying SUE to their projects and what type of projects would benefit the most if SUE is applied. All project data for this study are provided by DOTD and the information used in the analysis is obtained from DOTD data systems.

Discussion of Results

Return on Investment of SUE

Three projects that used SUE during construction were used in this analysis. These projects were selected from a list of projects that have applied SUE QL A and/or QL B in the past. Change orders and SUE task orders were reviewed thoroughly to determine what projects applied SUE after encountering unexpected utilities during construction. Of the 13 projects that have used SUE in Louisiana in the past, three projects that used SUE during construction were identified. Table 4 shows some of the characteristics of these projects. The projects were let between 2006 and 2009 and had a project cost that ranged from $11,012,063 to $451,215,018.48. All three projects used the highest quality level of SUE, with SUE costs ranging from $58,590.00 to $197,944.81.

Table 4. Characteristics of SUE projects

Project No.	Construction amount	Year Let	SUE QL	SUE cost	SUE year	SUE % of construction amount
013-12-0032	$24,887,297	2006	A	$140,442.00	2007	0.56%
817-41-0008	$11,012,063	2009	A & B	$58,590.00	2009	0.53%
005-10-0037	$451,215,018.48	2008	A & B	$197,944.81	2010	0.04%

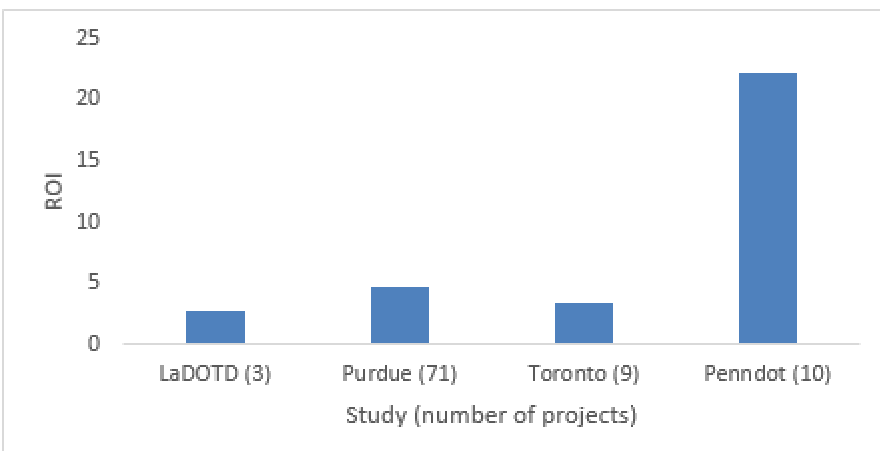
To estimate the utility-related costs, all change orders for the three projects were thoroughly reviewed. Utility-related change orders were first identified, followed by a thorough review of each change order to determine the costs and time of encountering utilities during construction. Table 5 shows the results. All three projects encountered costly conflicts and project delays due to unexpected underground utilities. The total utility-related costs of the projects ranged from $153,021.74 to $632,747.10. The ROI of SUE ranged from 2.13 to 3.20, with an average ROI of 2.73. This implies that $2.73 can be saved for every $1 spent on SUE services if SUE is used correctly during the early stages of a project.

Table 5. Summary of ROI results

Project #	Utility conflicts and relocation cost	Project delay due to utilities	Total Utility Related Costs (URC)	SUE costs	ROI	URC % of construction cost
013-12-0032	$196,595.18	$102,000.00	$298,595.18	$140,442.00	2.13	1.20%
817-41-0008	$60,021.74	$93,000.00	$153,021.74	$58,590.00	2.61	1.39%
005-10-0037	$624,219.90	$8,527.20	$632,747.10	$197,944.81	3.2	0.14%
Total	**$880,836.82**	**$203,527.20**	**$1,084,364.02**	**$396,976.81**	**2.73**	**0.22%**

This analysis is somewhat different from the Purdue study and other studies, but the results were similar. All previous studies obtained their cost savings information via interviews with project managers, utility owners, constructors, and designers; whereas, this study used the actual costs of encountering utilities during construction. Figure 2 shows the ROI results of this study and similar studies. The Purdue study, one of the most well-cited studies that examined the benefits of SUE, indicated a savings of $4.62 for every $1 spent on SUE. The PennDOT study had the highest ROI of $22.21, and the Toronto study had the lowest at $3.41. Although these studies slightly differ in their methodologies, they all show that SUE is an effective process to maximize cost savings for excavation projects.

Figure 2. Comparison with previous studies



Effectiveness of SUE

SUE projects, control projects, and the different categories of control projects were compared for each MOE to determine if there were any significant differences between the means. SUE projects and control projects were compared using a two sample t-test, and the different categories of control projects were compared using one-way analysis of variance (ANOVA). SAS software was used for this analysis.

The idea of a two sample t-test is to compare the difference between two means with the assumption that the two samples are independent and normally distributed. Before interpreting the test statistic and reaching a conclusion, the equality of variances must be determined. If we can assume that the two samples have equal variances, then the pooled test is used. If, on the other hand, we determine that the two samples have unequal variances, then the Satterthwaite test is used.

Similarly, ANOVA is used to compare the means of three or more independent groups and determine if there are any statistically significant differences. However, ANOVA is an omnibus test and can only conclude that at least two groups are significantly different. It does not show which groups are statistically significantly different from each other. In order to determine which specific groups differ, a post hoc test is used. There are several post hoc tests that could be used to examine mean differences between groups, but this analysis used Tukey's HSD (Honestly Significant Difference).

Table 6 shows the t-test results for the SUE and control projects, and Table 7 shows the ANOVA results for the different categories. Comparisons of means that were significantly different are illustrated in Table 8.

Table 6. Summary of t-test results

Measures of Effectiveness	SUE		Control		t-test	
	Sample Size	Mean	Sample Size	Mean	p-value	Significance
Design cost	8	$305,250	457	$313,137	0.977	No
Construction cost	11	$57,210,616	203	$6,749,694	0.23	No
Construction cost increase	11	$2,175,084	203	$317,483	0.1806	No
Construction cost percent increase	11	0.0358	203	0.0243	0.734	No
Construction duration	11	837	203	214.4	0.0031	Yes
Project delay	11	10.5455	203	-9.3498	0.00028	Yes
Percent of project delay	11	0.0351	203	-0.096	<.0001	Yes
Utility related change order cost	11	$101,537	92	$30,541	0.2732	No
Percent of utility related change order cost	11	0.00279	92	0.005	0.5447	No

Table 7. Summary of ANOVA results

Measures of Effectiveness	C≥3M		C<3M		S≥3M		S<3M		ANOVA	
	Sample Size	Mean	Sample Size	Mean	Sample Size	Mean	Sample Size	Mean	p-value	Significance
Construction cost	35	$15,043,985	67	$689,589	46	$4,390,793.04	74	$804,320.55	<.0001	Yes
Construction cost increase	35	$1,104,446.57	67	$31,249.46	46	$81,822.65	74	($5,901.19)	0.0003	Yes
Construction cost percent increase	35	7.50%	67	2.60%	46	0.82%	74	-0.38%	0.0225	Yes
Construction duration	35	533.9714286	67	72.656716	46	122.2826087	75	50.2133333	<.0001	Yes
Project delay	35	7.9428571	67	-5.4029851	46	-13.5652174	75	-6.9866667	0.3633	No
Percent of project delay	35	0.0287257	67	-0.0581091	46	-0.1137787	75	-0.1695027	0.0012	Yes
Utility related change order cost	35	$11,626.03	67	$1,199.66	47	$939.67	75	$0.00	0.0255	Yes
Percent of utility related change order cost	35	0.08%	67	0.15%	47	0.01%	75	0.00%	0.0704	No

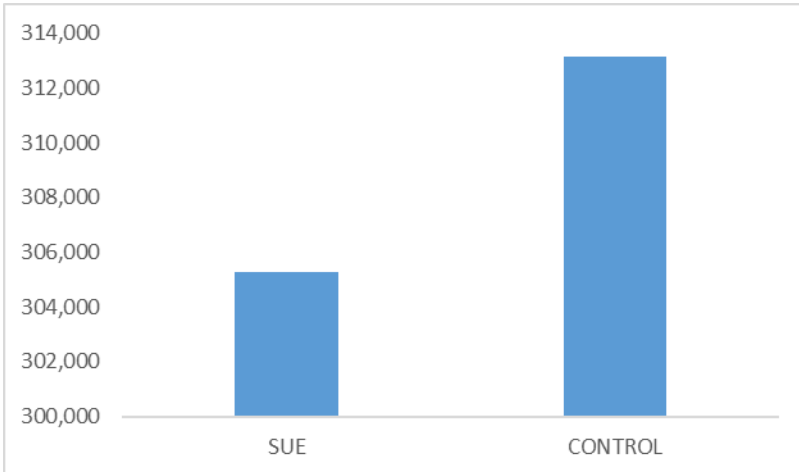
Table 8. Difference between significantly different means

Measures of Effectiveness	Comparison	Difference between means
Construction cost	C≥3M - S≥3M	$10,653,192
	C≥3M - S<3M	$14,239,664
	C≥3M - C<3M	$14,354,396
	S≥3M - S<3M	$3,586,472
	S≥3M - C<3M	$3,701,204
Construction cost increase	C≥3M - S≥3M	1022624
	C≥3M - C<3M	1073197
	C≥3M - S<3M	1110348
Construction cost percent increase	C≥3M - S<3M	7.88%
Construction duration	C≥3M - S≥3M	411.69
	C≥3M - C<3M	461.31
	C≥3M - S<3M	483.76

Design Cost

The mean design cost was compared between SUE and control projects. Control projects had a higher mean design cost than the SUE projects, but the t-test results showed that there was no significant difference between the two means. ANOVA was not performed on the mean design cost due to insufficient data. There was not enough data on design cost for the projects to be divided into four different categories. The mean design cost is illustrated in Figure 3 below.

Figure 3. Mean design cost (SUE vs. control projects)



Construction Cost

The mean project construction cost was compared between SUE and control projects and the four different categories. SUE projects had a higher mean construction cost, but t-test results showed that there was no significant difference between SUE and control projects. For the different categories of control projects, the mean construction cost was highest for C ≥ 3M projects followed by S ≥ 3M projects. Tukey's HSD showed that the mean construction cost of C ≥ 3M projects and S ≥ 3M projects were both significantly different from the mean construction cost of each category. Figure 4 and Figure 5 show the mean construction costs.

Figure 4. Mean construction cost (SUE vs. control projects)

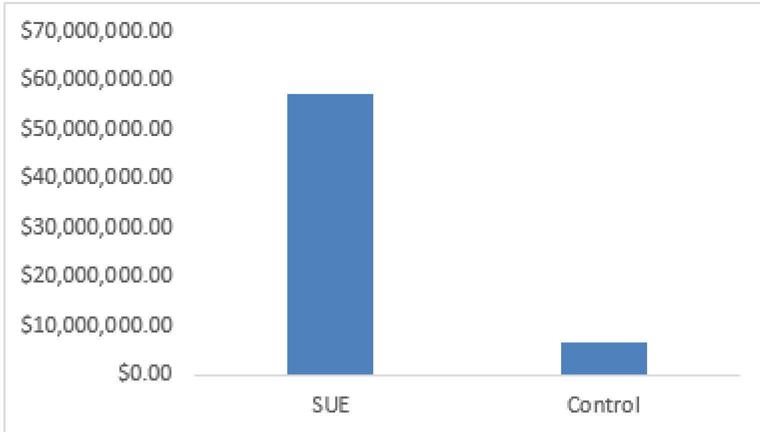
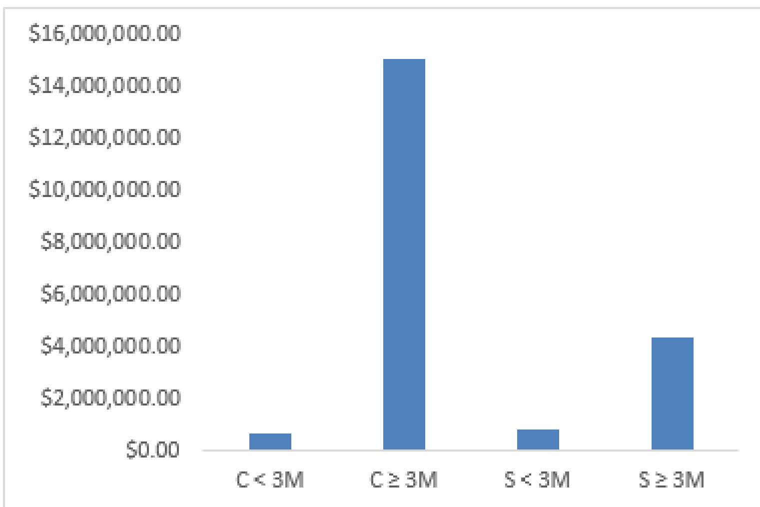


Figure 5. Mean construction cost by project category



Construction Cost Increase

Similar to construction cost, the mean construction cost increase was compared between SUE and control projects, and the four different categories of control projects. SUE projects had a higher mean construction cost, but t-test results showed that there was no significant difference between the means. In respect to the project categories, the mean construction cost increase was highest for C ≥ 3M projects. Tukey's HSD showed that the mean construction cost of C ≥ 3M was significantly different from the mean construction cost of all other categories. Figure 6 and 7 show the mean construction cost increase.

Figure 6. Mean construction cost increase (SUE vs. control projects)

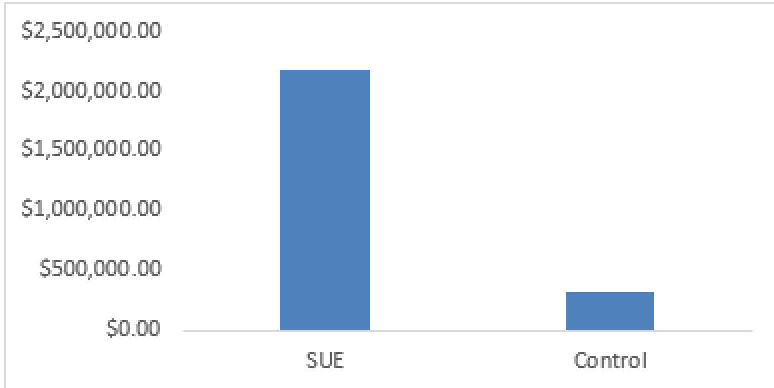
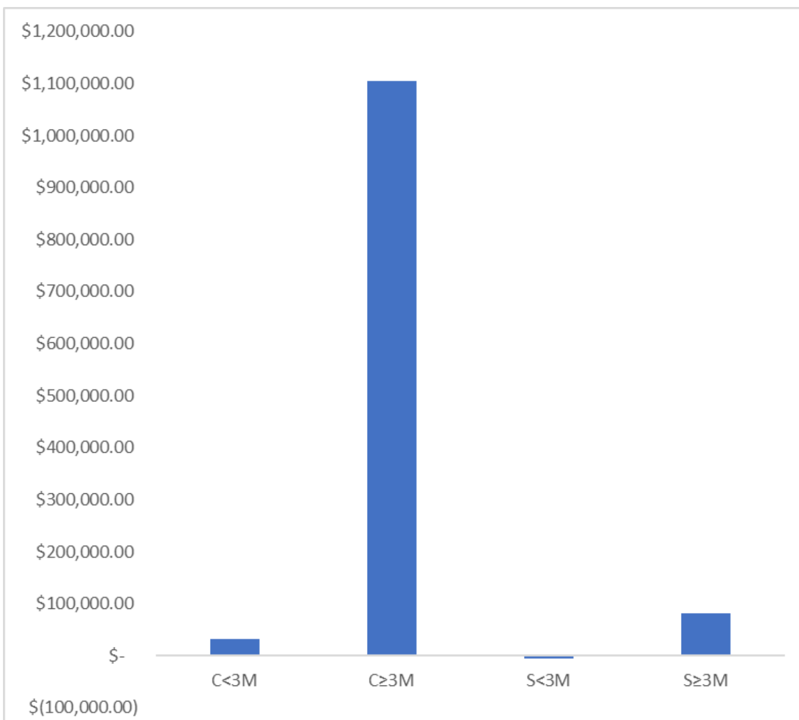


Figure 7. Mean construction cost increase by project category



Construction Cost Percent Increase

The construction cost percent increase results are similar to the construction cost and construction cost increase results. SUE projects had a higher mean construction cost percent increase, but t-test results showed that there was no significant difference between SUE and control projects. In comparing the categories of control projects, the mean construction cost percent increase was highest for C ≥ 3M projects. Tukey's HSD only showed that the mean construction cost percent increase of C ≥ 3M projects was significantly higher than that of S < 3M projects. Figure 8 and 9 show the mean construction cost percent increase.

Figure 8. Mean construction cost percent increase (SUE vs. control projects)

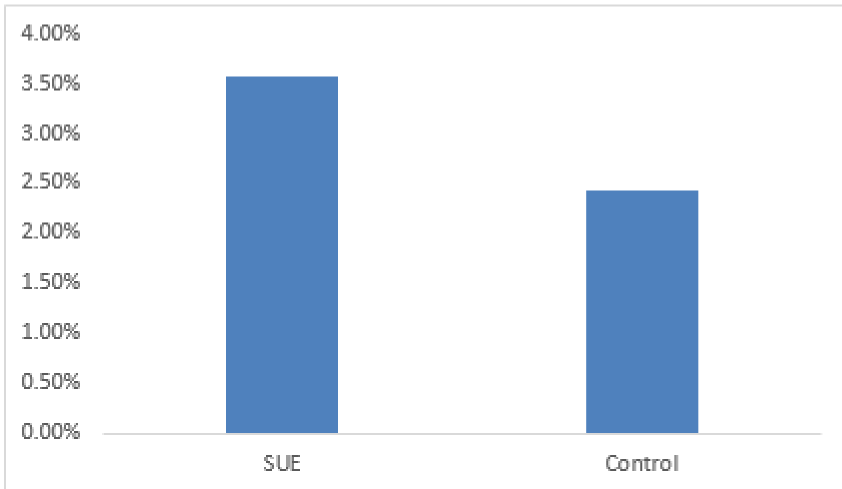
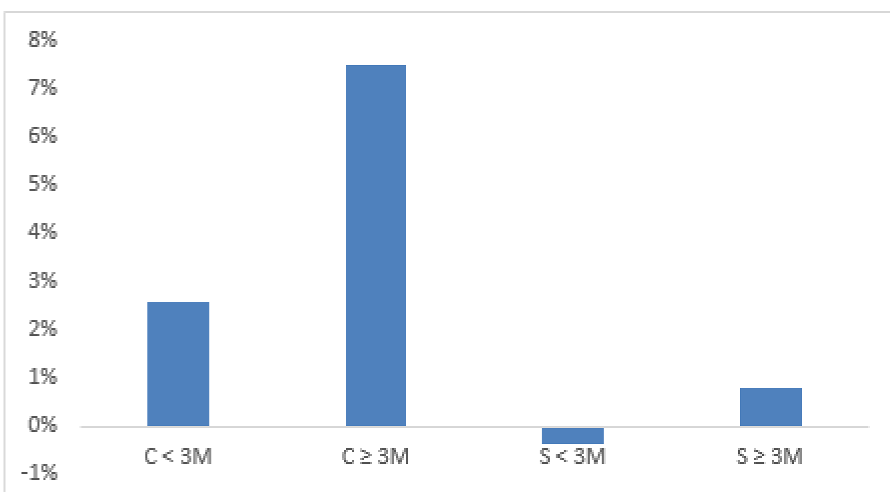


Figure 9. Mean construction cost percent increase by project category



Construction Duration

The mean construction duration of SUE projects was higher than that of control projects, and t-test results showed that there was a significant difference between the two means. C ≥ 3M projects had the highest mean construction duration for the project categories. Tukey's HSD showed that the mean construction duration of C ≥ 3M was significantly different from the mean construction duration of all other categories. Figure 10 and 11 show the mean construction duration.

Figure 10. Mean construction duration (SUE vs. control projects)

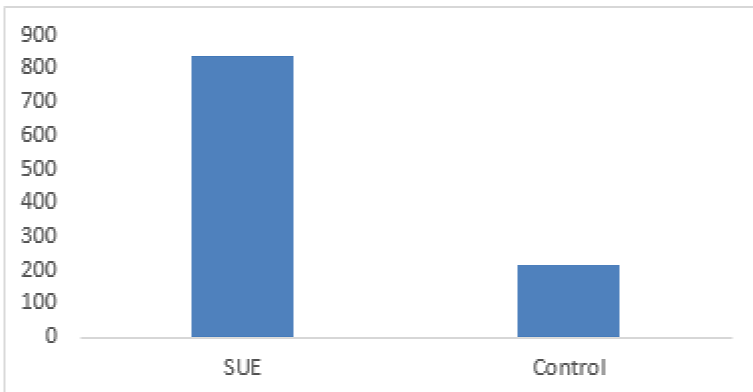
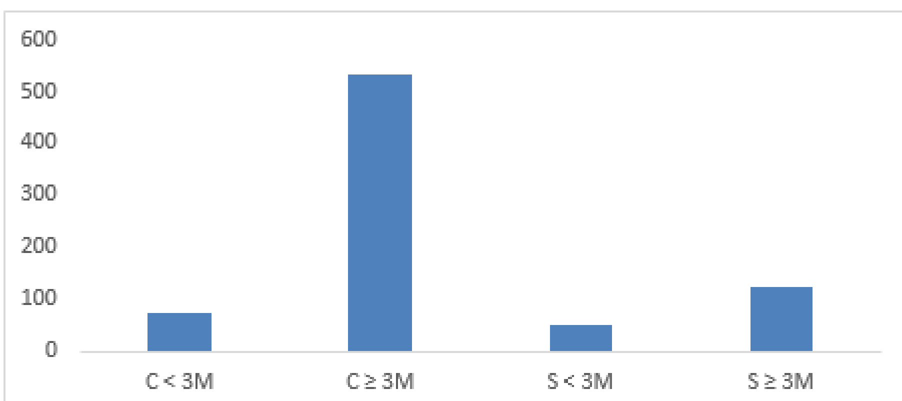


Figure 11. Mean construction duration by project category



Project Delay

The mean project delay of SUE projects was higher than that of control projects, and t-test results showed that there was a significant difference between the two means. However, ANOVA results showed that there was no significant difference between the category means. Figure 12 and 13 show the mean project delay.

Figure 12. Mean project delay (SUE vs. control projects)

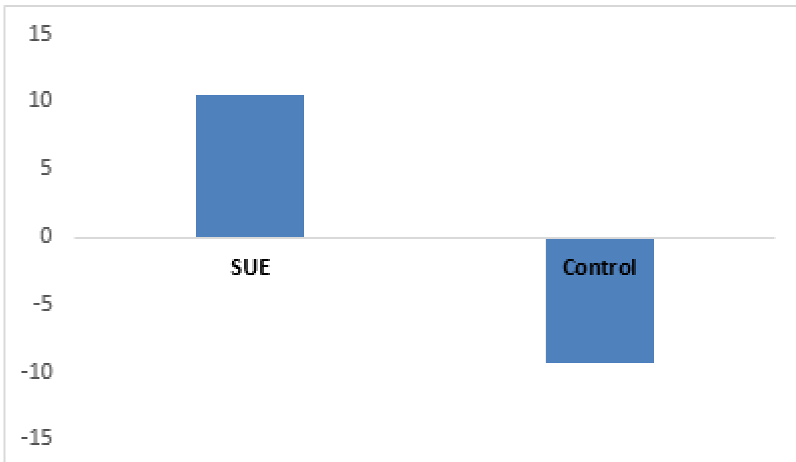
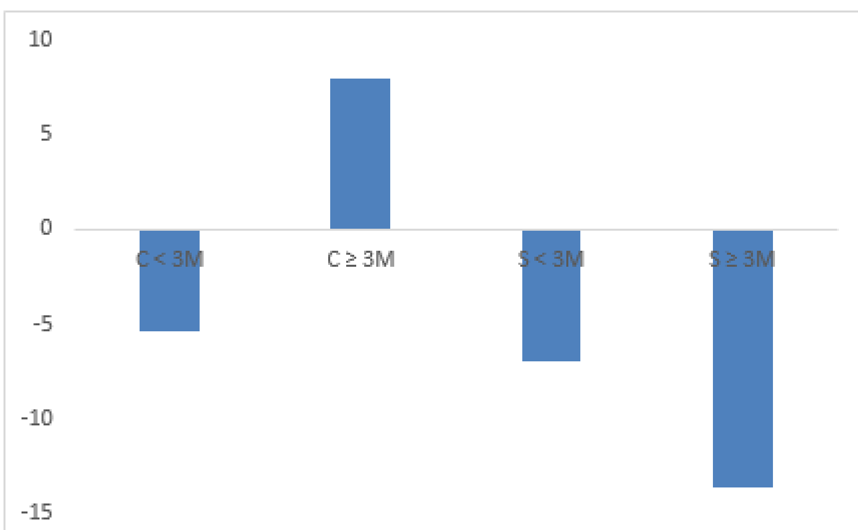


Figure 13. Mean project delay by project category



Percent of Project Delay

The mean percent of project delay for SUE projects was higher than that of control projects, and t-test results showed that there was a significant difference between the two means. For project categories, C ≥ 3M projects had the highest mean percent of project delay and Tukey's HSD showed that the means of C ≥ 3M and C<3M projects were both significantly higher than the mean of S < 3M projects. Figure 14 and 15 show the mean percent of project delay.

Figure 14. Mean percent of project delay (SUE vs. control projects)

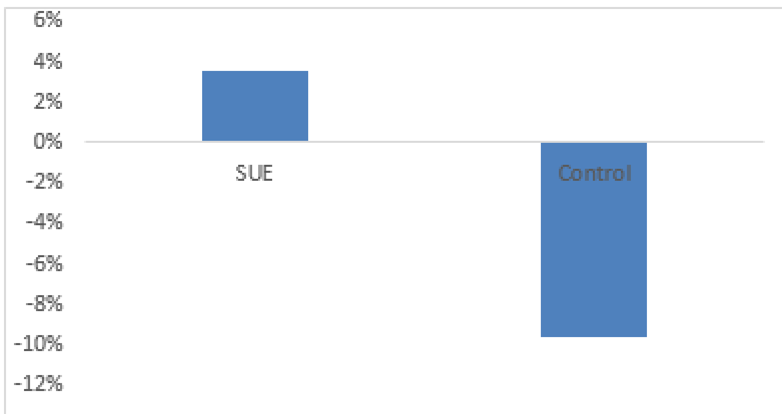
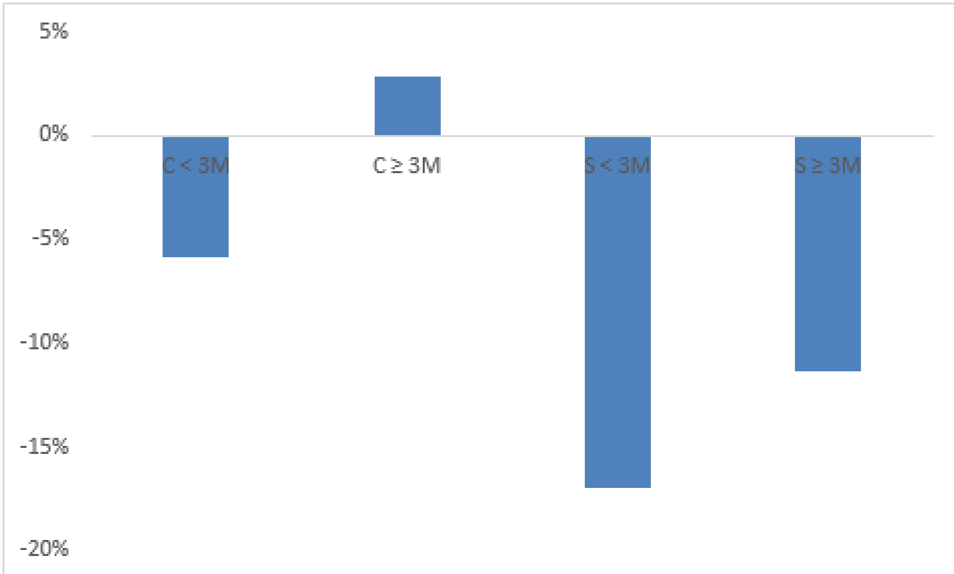


Figure 15. Mean percent of project delay by project category



Utility-Related Change Order Cost

SUE projects had a higher mean utility-related change order cost, but t-test results showed that there was no significant difference between the two means. In comparing the different categories, C ≥ 3M projects had the highest mean and S < 3M had the lowest mean due to no utility related change orders. Tukey's HSD showed that the mean of C ≥ 3M projects was significantly higher than that of S < 3M projects. Figure 16 and 17 show the mean utility-related change order cost.

Figure 16. Mean utility related change order cost (SUE vs. control projects)

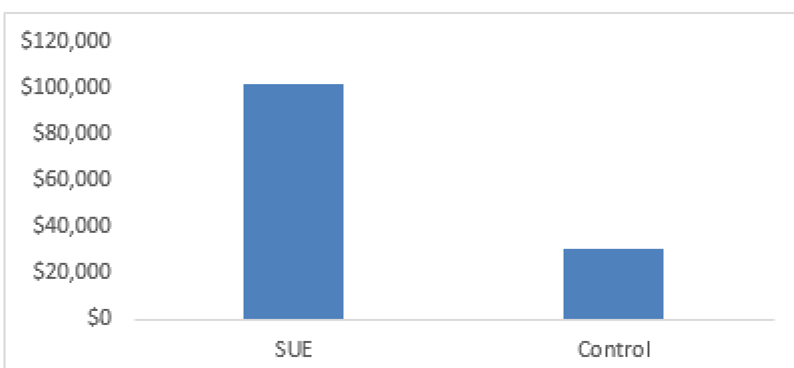
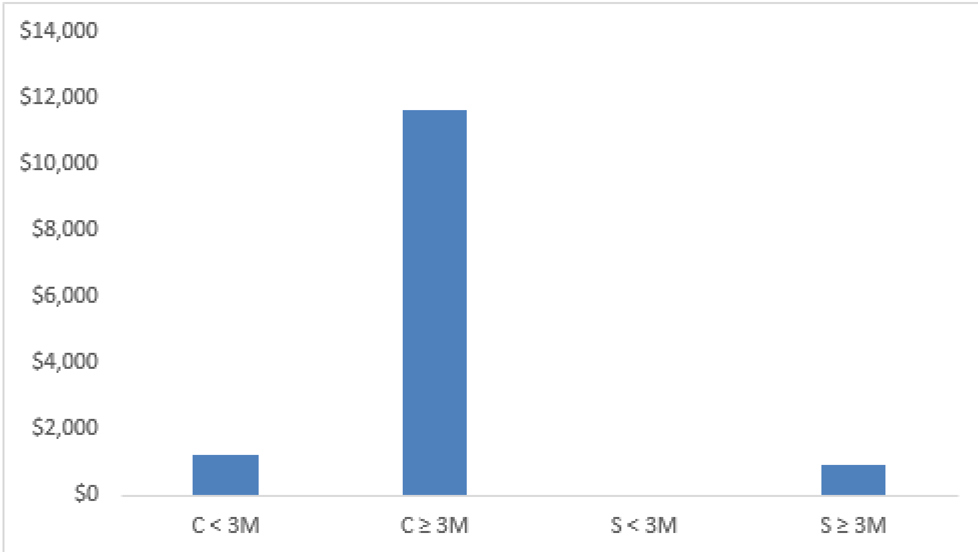


Figure 17. Mean utility-related change order cost by project category



Percent of Utility-Related Change Order Cost

SUE projects had a lower mean percent of utility-related change order cost, but t-test results showed that there was no significant difference between the two means. In comparing the different categories, C < 3M projects had the highest mean followed by C ≥ 3M projects. However, ANOVA results showed that there was not enough evidence to conclude that at least one of the means is different. Figure 18 and 19 show the mean percent of utility-related change order cost.

Figure 18. Mean percent of utility-related change order cost (SUE vs. control projects)

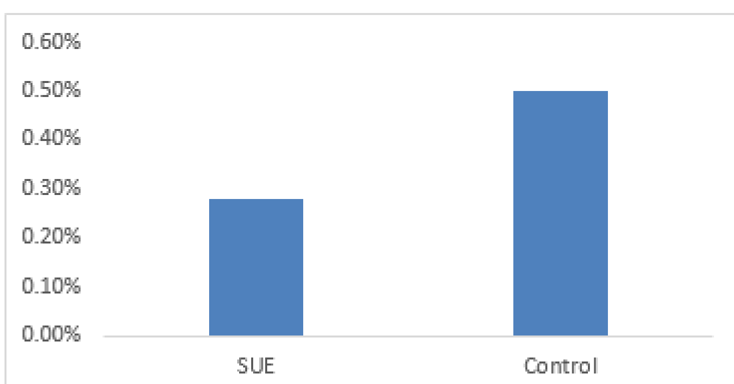
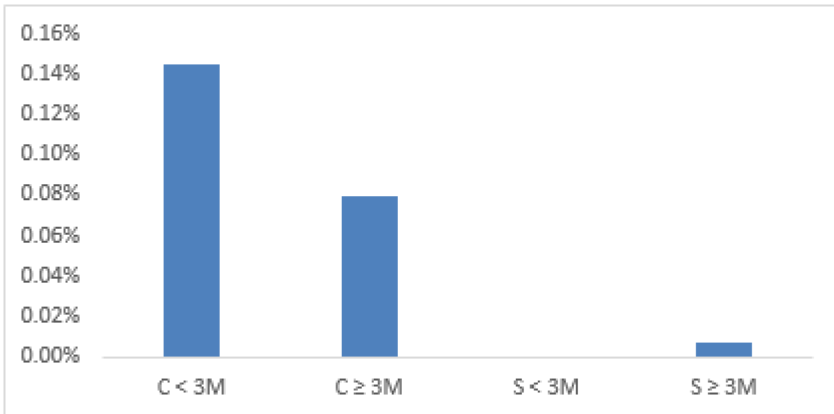


Figure 19. Mean percent of utility-related change order cost by project categories



Conclusions

- The results of this study show that SUE is an effective process to minimize the financial impact caused by unforeseen buried utilities. Since the SUE program is fairly new to Louisiana, only a few projects have used SUE in the past. Three projects that used SUE during construction were analyzed, and they all showed a positive return on investment ranging from $2.13 to $3.20. In all the three projects, SUE services were applied within the first two years of construction. If SUE had been used at a later time, or not even used at all, the utility-related costs might have been much greater. ROI analysis results showed that a savings of $2.73 for every $1 spent on SUE is realized if SUE is used correctly.
- To study the effectiveness of SUE services on project costs and time and what type of projects would benefit the most from SUE, statistical analysis was performed on various projects. However, the sample size for SUE projects was relatively low, which might have had an effect on the significance of the data.
- SUE services were applied to larger projects. The construction duration, project delay and percent of project were significantly higher for SUE projects. All other MOEs showed no statistical significance. This may have been due to the very small sample size of SUE projects.
- In respect to the control projects categories, C ≥ 3M projects were the largest projects. They had the highest construction cost, construction cost increase, construction cost percent increase, construction duration, percent of project delay, and utility-related change order cost.
- Utility-related change order costs were highest for C ≥ 3M projects, but the percent of utility-related change order costs was highest for C < 3M projects. However, percent of utility-related change order costs showed no statistical significance.
- S < 3M projects had no utility-related change orders. This could imply that these type of projects have a low chance of encountering utility conflicts during construction. As the project categories progressed (from S < 3M to C ≥ 3M), the number of utility related change orders increased.
- Several projects that used SUE in the past were in the C ≥ 3M project category. Some of the SUE projects were missing some data items, so all projects could not be

correctly categorized. However, they all had a project cost greater than 3 million and were either bridge, new construction, or widening projects.

Recommendations

The following recommendations are made based on the results obtained in this research:

1. The sample size of SUE projects for this study was limited due to the age of the program and unattainable data. Several data project elements were not being tracked, which had an effect on the scope and results of the study. SUE data items, such as cost and time stamp, were obtained by reviewing all SUE contracts, some of which could be lost over time. It is essential for DOTD to track this information to facilitate future research on SUE services.
2. Carefully review project characteristics and consider using SUE QLA & QLB on complex projects with a project cost that is greater than or equal to 3 million. However, project managers should also use their discretion and expertise when determining what projects should use SUE. Some projects may not meet all the complexity criteria, but could still benefit from using SUE services.
3. Develop a program to increase awareness of SUE and its potential benefits.
4. Further research is recommended to validate the results of this study.

Acronyms, Abbreviations, and Symbols

Term	Description
ADT	Average Daily Traffic
DOTD	Louisiana Department of Transportation and Development
FHWA	Federal Highway Administration
LTRC	Louisiana Transportation Research Center
PennDOT	Pennsylvania Department of Transportation
SUE	Subsurface Utility Engineering
TxDOT	Texas Department of Transportation

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