REPORT S2-R01-RW

Encouraging Innovation in Locating and Characterizing Underground Utilities

SHRP2 RENEWAL RESEARCH

SHRP 2
STRATEGIC HIGHWAY RESEARCH PROGRAM
Accelerating solutions for highway safety, renewal, reliability, and capacity

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

The Second

STRATEGIC HIGHWAY RESEARCH PROGRAM

SHRP 2 REPORT S2-R01-RW

Encouraging Innovation in Locating and Characterizing Underground Utilities

Prepared by

R. L. Sterling, J. Anspach, E. Allouche, J. Simicevic,
C. D. F. Rogers, K. Weston, K. Hayes
TRENCHLESS TECHNOLOGY CENTER, LOUISIANA TECH UNIVERSITY,
LEAD INSTITUTION, IN COOPERATION WITH SO-DEEP, INC.,
UNIVERSITY OF BIRMINGHAM, U.K., AND CIVIL DESIGN AND CONSTRUCTION, INC.

SUBJECT AREA
Highway and Facility Design

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2009
www.TRB.org

The Second Strategic Highway Research Program

America's highway system is critical to meeting the mobility and economic needs of local communities, regions, and the nation. Developments in research and technology—such as advanced materials, communications technology, new data collection technologies, and human factors science—offer a new opportunity to improve the safety and reliability of this important national resource. Breakthrough resolution of significant transportation problems, however, requires concentrated resources over a short time frame. Reflecting this need, the second Strategic Highway Research Program (SHRP 2) has an intense, large-scale focus, integrates multiple fields of research and technology, and is fundamentally different from the broad, mission-oriented, discipline-based research programs that have been the mainstay of the highway research industry for half a century.

The need for SHRP 2 was identified in *TRB Special Report 260: Strategic Highway Research: Saving Lives, Reducing Congestion, Improving Quality of Life,* published in 2001 and based on a study sponsored by Congress through the Transportation Equity Act for the 21st Century (TEA-21). SHRP 2, modeled after the first Strategic Highway Research Program, is a focused, time-constrained, management-driven program designed to complement existing highway research programs. SHRP 2 focuses on applied research in four focus areas: Safety, to prevent or reduce the severity of highway crashes by understanding driver behavior; Renewal, to address the aging infrastructure through rapid design and construction methods that cause minimal disruptions and produce lasting facilities; Reliability, to reduce congestion through incident reduction, management, response, and mitigation; and Capacity, to integrate mobility, economic, environmental, and community needs in the planning and designing of new transportation capacity.

SHRP 2 was authorized in August 2005 as part of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The program is managed by the Transportation Research Board (TRB) on behalf of the National Research Council (NRC). SHRP 2 is conducted under a memorandum of understanding among the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), and the National Academy of Sciences, parent organization of TRB and NRC. The program provides for competitive, merit-based selection of research contractors; independent research project oversight; and dissemination of research results.

SHRP 2 Report S2-R01-RW

ISBN: 978030912886-5
Library of Congress Control Number: 2009935811

Note: SHRP 2 report numbers convey the program, focus area, project number, and publication format. Report numbers ending in "w" are published as Web Documents only.

SHRP 2 reports

are available by subscription and through the TRB online Bookstore at

www.TRB.org/bookstore

Contact the TRB Business Office
by telephone at 202-334-3213.

More information about SHRP 2 is available at:

www.TRB.org/SHRP2

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

SHRP 2 STAFF

ACKNOWLEDGMENTS

The authors of the report would like to acknowledge the many contributions made by other members of the project team and the broad array of organizations and individuals that have provided information for the study either by responding to questionnaires, providing information on new technology developments or discussing the problems faced in dealing with utility issues in transportation projects.

Thanks go to Dr. Monica Starnes, our contract administrator with the Transportation Research Board and herself an expert in nondestructive evaluation, who has helped us in many aspects of the project—participating in major team meetings, reviewing the research documents, and providing contacts for appropriate organizations and companies. Thanks also to our Project Advisory Committee whose members have followed the project from the creation of the Request for Proposal to the preparation of the project report and the presentation of its conclusions.

The research team, in addition to those listed as authors of the report, have participated in the literature review and technology evaluations, preparation of data tables, creation of method selection software, and so forth. This team comprises Louisiana Tech students: John Matthews, Arun Jaganathan, Arturo Jimenez, Marycynthia Ifeoma Ezike, and Grace Gacheru. There was also a contribution by Dr. Jian Shuai, visiting professor to Louisiana Tech University from the China University of Petroleum, to the section in Chapter 5 on the inspection of oil and gas pipelines.

More than 70 organizations have been directly contacted during this study and an excellent response with pertinent information was received from most of those contacted. Other individuals responded to the questionnaire concerning utility problems faced in transportation projects or responded to the Statement of Need for Utility Location and Characterization Technologies. These individuals and organizations freely gave of their time and knowledge and their help is gratefully acknowledged. A list of the key organizations contacted is provided in Appendix C.

FOREWORD

Monica A. Starnes, Ph.D., *SHRP 2 Senior Program Officer*

This report presents the findings of the first two phases of SHRP 2 Project R01: Encouraging Innovation in Locating and Characterizing Underground Utilities. The project identified existing and emerging technologies and developed recommendations for subsequent research in this area. The report provides a thorough and insightful review of locating practices, current and emerging technologies, and recommended improvements. A third phase was added to this project to develop software to serve as decision support for identifying effective utility-locating methods for particular site or project environments. The software will expand on capabilities already developed under the R01 project.

Throughout the years, underground utilities have proliferated within highway rights-of-way. The location and nature of many such utility lines have not always been properly documented. Moreover, the presence of underground utilities within the highway right-of-way and the lack of pedigree information about some utility lines present unique challenges for highway renewal activities, which often require relocation of underground utilities to ensure public safety. The untimely discovery of an unknown underground utility needing relocation is one of the major causes of delay during highway renewal projects and, as such, one of the major contributors to traffic disruptions and budget overruns. Decision makers in both transportation agencies and utility companies need timely access to accurate utility location information in order to minimize the risk of disruption during highway renewal activities.

To address the issue of encouraging innovation in locating and characterizing underground utilities, a research team led by Dr. Ray Sterling of the Trenchless Technology Center at Louisiana Tech University conducted a thorough review of existing and emerging locating and mapping technologies, evaluated the existing locating needs, and developed a research and development (R&D) plan to address those needs.

The first phase of the research focused on data-gathering activities to identify current problems related to locating underground utilities, identify current and emerging technologies that could effectively locate underground utilities, and document case histories. Data-gathering activities were conducted via literature reviews and interviews with department of transportation staff, utility owners, industry, and academia. The research team also collected data via a problem statement circulated through the Consortium of Federal Laboratories. Preparing for the development of the R&D plan, the research team then ranked current and envisioned technology needs in this field. The ranking was conducted with the assistance of an independent advisory group composed of state department of transportation personnel, municipal and major infrastructure facility personnel, utility owners, contractors, and one-call center and locating personnel.

During the second phase of the project, the research team developed an R&D plan. Detailed scopes of work for nine research topics are included in the plan. While the R&D plan was aimed to inform SHRP 2 leadership on specific recommendations for future research, the report provides a road map and specific recommendations that may be useful to other research or funding organizations.

CONTENTS

Executive Summary

Utility Issues in Transportation Projects

Many of the extensive utility designating and locating procedures that are carried out during excavation for construction projects are intended to ensure public safety and prevent utility damage. It is also important, however, to fully identify the location and condition of all utilities early in the project planning and design process—preferably prior to excavation—to allow transportation projects to go forward with minimal delays and cost overruns. This early "locating" and characterization of utilities is best accomplished through better coordination with the transportation agencies with which utility companies often share the right-of-way space, through the implementation of effective management policies; and, largely, through the use of emerging, powerful technologies, which will be the focus of this report. Taken together, these elements comprise the subsurface utility engineering (SUE) framework.

Coordination Between Transportation Agencies and Utility Companies

Because the public transportation right-of-way is where nearly all buried utility systems are located, the planning, design, construction, maintenance, rehabilitation, and renewal of both transportation systems and utility systems are closely connected. Better information sharing and coordination between the owners of these two systems could accomplish a great deal. However, a companion SHRP 2 study (Project R15: Strategies for Integrating Utility and Transportation Agency Priorities in Renewal Projects) addresses this utility coordination process; this report focuses on technologies.

Utility Locating Technologies

The existence of a low-cost, easy-, and quick-to-use surface geophysical tool that identifies all utilities during a planned-route field survey at any site regardless of soil conditions would remove most barriers to effectively managing utility issues in transportation projects. Unfortunately, such a technology does not exist. And the current technology used to locate buried utilities may be ineffective at finding targets beneath the clutter of other utilities and buried objects or at significant depths in incompatible soil conditions, as is the case with electromagnetic locating equipment working in conductive soils.

Trying to locate a fixed-location object by repeatedly employing various detection methods is clearly inefficient. Dealing with utility records that fail to incorporate quality assurance into the information shown on a set of plans or contained in a database is also problematic. However, rapid developments in utility marking and radio frequency tagging systems (RFID) and new technologies involving global positioning systems (GPS) and three-dimensional (3-D) geographical information systems (GIS) have changed what is technically possible in this regard. Together, these technologies allow for the development of accurate 3-D databases for newly installed utilities and for the rapid capture of accurate positional information when existing utilities are exposed.

Even in ideal environmental conditions, however, cost and training issues limit the extensive use of existing technology. The transportation community faces the significant challenge of having to identify and assign cost to the real risks associated with not knowing whether a utility exists within the right-of-way (or proposed right-of-way) or, if one does, not fully knowing its location or characteristics. Faced with this challenge, a rational decision must be made on which tools to employ for a particular effort and an appropriate budget established to identify, locate, and characterize a utility.

Utility Characterization Technologies

"Utility characterization" describes the determination of a utility's characteristics, with the exception of its location. Characteristics might include the utility's type, owner, size, material, age, pressure, voltage, capacity, condition, or activity status (that is, whether it is active, inactive, abandoned, or out-of-service).

Unfortunately, there are few aspects of utility characterization data that can be reliably determined from a surface-based utility location or characterization survey. However, this could change substantially with the introduction of utility smart-marking and tagging systems to identify new utilities with programmable and updatable electronic markers and to mark existing utilities as they are exposed for maintenance or during other excavation activities.

Smart tagging systems together with utility companies' ongoing asset management approaches offer the prospect of substantial improvement in managing the utilities that are located beneath rights-of-way.

Targeting Improvements

A national 14-member panel was asked to rank potential research initiatives for this report. The scored ranking of initiatives is shown in Table ES.1. The scores reflect consensus on the relative importance of the topics. However, the scores are relative and, thus, can best be interpreted by considering them in relation to target-activity groupings with similar scores. Overall, greatest importance was placed on storage, retrieval, and use of utility data and the development of multisensor platforms, followed closely by the development of guidelines. The second-highest priority was smart tagging, education and training, and locating deep utilities. The third-highest priority included detecting external voids, benchmarking current technologies, and deformation characterization technologies. The research team then developed project descriptions to be considered by the SHRP 2 committee for funding available through the appropriate SHRP 2 program area.

Conclusions

Although it is unlikely that technology to locate and characterize utilities will ever present a comprehensive solution for all site conditions, it continues to evolve. And despite the significant administrative and legal hurdles that remain, implementing comprehensive utility mapping and marking of utilities and improving GIS-based utility databases containing SUE utility-quality designations offers a significant and worthwhile advantage. Project owners can also mitigate utility-related challenges by effectively coordinating with transportation and utility agencies, realistically evaluating utility project risks and costs, and integrating policies, procedures, scopes of work, and utility field-investigation qualification and training requirements.

Rank (Score)	Topic, Description, and Benefits
1. (0.17)	*Topic:* Storage, Retrieval, and Utilization of Utility Data *Description:* The development of dedicated software and hardware that would take advantage of recent advances in GPS and GIS technologies and increase the quality and efficiency of storing, retrieving, and utilizing utility records. *Benefits:* Increasingly comprehensive and accurate utility records, allowing resources to be focused on finding the remaining utilities.
2. (0.16)	*Topic:* Multisensor Platforms *Description:* The development of multisensor platforms that combine two or more existing technologies [e.g., ground-penetrating radar (GPR) and electromagnetic (EM) location or GPR and acoustic approaches]. *Benefits:* More reliable performance for utility locating across a variety of soil conditions.
3. (0.14)	*Topic:* Development of Guidelines *Description:* The development of guidelines and other tools for the conduct of utility investigations for transportation projects. *Benefits:* Allows transportation designers/planners to get the most out of the SUE data they receive so as to maximize the benefit/cost to the agency.
4. (0.12)	*Topic:* Smart Tagging *Description:* Advances in hardware and software that support smart tagging (e.g., ball markers, RFIDs) and documentation of utilities during initial installation and when exposed during excavations for various purposes. *Benefits:* Improved in-field identification of utility location, type, and characteristics.
5. (0.10)	*Topic:* Initiation of Education and Training *Description:* Initiation of educational, training, and dissemination activities aimed at increasing the awareness of transportation engineers and other decision makers to the state of the art and cost-benefit implications of gathering better utility information early in the design process. *Benefits:* Improved allocation and more effective use of utility locating expenditures.
6. (0.10)	*Topic:* Location of Deep Utilities *Description:* The development of locating technologies that target deep utilities that currently cannot be detected by surface-based approaches. These could include direct-path detection methods deployed from inside a utility or cross-bore techniques based on vacuum-excavated boreholes. *Benefits:* Improvement in detection of the most difficult utilities to find from the surface and reduced impact of unlocated or mislocated deep utilities on transportation projects.
7. (0.08)	*Topic:* External Soil Void Detection Technologies *Description:* The development of new technologies or enhancement of existing technologies capable of locating and characterizing external soil voids from within a buried pipe or culvert. *Benefits:* Detection of future ground instability problems that can cause road settlement and sinkholes.
8. (0.07)	*Topic:* Benchmarking of Current Technologies *Description:* The use of existing and/or purpose-constructed test facilities to systematically evaluate and document the capabilities and limitations of current utility locating equipment under controlled conditions of varying complexity. *Benefits:* Independent information on the capabilities of different types of detection equipment.
9. (0.06)	*Topic:* Deformation Characterization Technologies *Description:* The development of new technologies or enhancement of existing technologies capable of characterizing the cross-sectional deformation of buried pipes and culverts over time. *Benefits:* Ability to track gradual deterioration of utilities constructed with ductile utility materials.

Table ES.1. Research Topics as Ranked by National Panel

CHAPTER 1

Introduction

Background to the Report

This report has been prepared as part of a study funded by the second Strategic Highway Research Program (SHRP 2), which is in turn funded by Congress to provide a targeted, short-term research program addressing key issues in highway transportation. The SHRP 2 program addresses four strategic focus areas: the role of human behavior in highway safety (Safety); rapid highway renewal (Renewal); congestion reduction through improved travel time reliability (Reliability); and transportation planning that better integrates community, economic, and environmental considerations into new highway capacity (Capacity). The goal of SHRP 2 renewal research is to develop a consistent, systematic approach to performing highway renewal that is rapid, causes minimal disruption, and produces long-lasting facilities. The renewal scope applies to all road classes.

This report looks at developing technologies and procedures that will help minimize disruption, delay, and risk when transportation projects include underground utility issues. These approaches include improving surface geophysical techniques, using existing techniques more effectively, and integrating these techniques with better recordkeeping practices. This work was divided into two phases. The project's first phase surveyed current and emerging technologies and determined the areas with the most potential for innovation and improvement. From a ranked list of alternatives developed in the first phase, specific project descriptions were developed for funding consideration through the SHRP 2 program.

For the purposes of this report, "locating" is defined more broadly than a contractor, utility owner, or a subsurface utility engineer might understand it to mean. To a contractor or utility owner, this term means the process of getting a mark placed on the ground for damage prevention or any other purpose. To a subsurface utility engineer, this term means the process of exposing a utility to precisely and accurately measure and document its three-dimensional location. Within this document, the broad and multifaceted term "utility locating" indicates the determination of a utility position. In particular, utility locating refers to the following:

- Geophysical technology used to detect and image underground utilities;
- Processes, procedures, and techniques used by field technicians in collecting the geophysical data in the field;
- Means and methods of transferring data from the instrumentation to the data users;
- Other sources of information regarding utility location, such as visual observation, existing records, or both;
- Integration and validation of data sources;
- Formatting and display of data to the data users;
- Retention of and recordkeeping practices for the data; and
- Use of the recorded data for the next locating exercise at this location.

The term "utility characterization" is used to describe characteristics of the utility other than location. These characteristics include size, ownership, material type, utility type (purpose), age, and usage status (inactive, abandoned, out-of-service, active). It may also include the condition of the utility. Condition can be further subdivided by cathodic state (for metallic utilities), pipe-wall thickness, corrosion (inside and outside of the pipe), wrapping and coating integrity, and physical condition (breaks, tears, and gouges). Associated utility buried appurtenances such as vaults and thrust blocks could also have characterization data. Some characterization data may be obtained or inferred through remote sensing means, while others may require direct means (physical observation through exposure). Other data may only be obtainable through existing records.

The term "innovation" can mean introducing completely new methods and ideas. It can also mean changing or increasing the use of existing methods or ideas not pervasively used, or increasing the geographic extent of those methods. It can mean changing the timing of methods to obtain better results.

To meet the project objectives, this report seeks to identify the existing technologies, procedures, challenges, and suitable approaches to encourage improvement in performance through a targeted series of research projects.

A Closer Look at the Problem

The increasing installation, maintenance, rehabilitation, or replacement activities related to underground utilities are matched by the increasing need for urban street and highway projects to extend highway networks, reduce congestion, and carry out maintenance and renovation projects. Public rights-of-way, such as highways and streets, are the natural location for utility services that are critical to city and regional development, and utility providers typically have a legal right for access to this right-of-way. The space within this right-of-way is becoming crowded with utilities, and past practices have not adequately documented the location or character of these utilities—creating project cost, safety, and time issues for renewal projects.

While utility locating technologies continue to improve, knowledge of these technologies and their capabilities may not be in the hands of the appropriate decision makers. Also, integration of these technologies is lacking due to the wide variety and differing missions of the stakeholders that are involved in the process, such as state and city transportation agencies, design consultants, utility companies, and contract utility locating firms.

Each state has a statute—and none identical to that of another state—that addresses utility markings for safety purposes during construction, but there is much less guidance on the responsibilities and procedures for locating utilities for project planning and design purposes. Marking utilities for damage prevention and for design-basis information is different in many ways, but these differences are not always fully appreciated. Although there is an engineering consensus standard (ASCE 38-02) (*1*) to address this problem, this standard is not yet universally used.

When roads in a given area are at or approaching full capacity, the cause of many major traffic delays is utility work, along with traffic accidents and other street work that disrupts normal traffic flow. Damage to street and highway pavement as a result of open-cut utility work and the increased life-cycle cost to maintain road pavement in an acceptable condition are also sources of friction between utility providers and street or highway engineers. Unneccessary pavement damage that results when the location or condition of a utility is unknown is even more vexing to highway owners. These three issues have important connections to how the utility identificaton, relocation, and operational phases of highway renewal projects are conducted.

Improvements in the interactions involved around highway work, utility location activities, and utility repair work are vital to reduce project delays and costs, accidental damage to utility lines, and damage to street pavements through uncoordinated utility work. Utility coordination committees have had some success in planning for near-term utility work on a street to be repaved, but the need to consider all the possibilities and execute the utility work in a timely fashion before the roadwork commences can potentially add significant time pressures for highway projects. This issue is addressed by a companion SHRP 2 study (*2*).

Another obstacle is that of the reliability of information sources. This question is at the heart of the utility problem. Utility information has been collected over the years in many different forms with widely varying standards of accuracy and quality control. It may have been transferred from plan to plan or database to database even as the original locational references themselves have changed. While steps are under way to improve and standardize recordkeeping and to verify utility positions, much of the existing locational information on buried utilities must be considered suspect until proven otherwise. In other words, utility lines may appear on project plans, but there are few guarantees as to the accuracy or reliability of this information unless a quality-controlled process incorporating subsurface utility engineering (SUE) has been employed (see chapters 3 and 4 for a further discussion of SUE).

In summary, there is widespread recognition of both the need to improve the quality and accessibility of information on the location and condition of underground utilities for design purposes and to prevent utility hits during road and utility work. This report focuses in particular on the impacts of utilities on urban transportation project planning and execution, the effectiveness of location and characterization tools already in the marketplace, the potential for improved use of existing tools, and how to accelerate the development of promising new tools and approaches.

Future Challenges

The utility problems introduced in the previous paragraphs are experienced worldwide and are increasingly difficult to manage as urban populations grow and existing utilities need replacing. In 1900, the world population was estimated to be about 1.6 billion with only 13% of this population living in urban areas. By May 2007, the world population was estimated to have risen to 6.6 billion and, in this same month, the crossover point was estimated to have occurred at which more than 50% of the world's population were said to live in urban areas (*3*). In the United States, this transition from a mostly rural population to a mostly urban population occurred much earlier—around 1910—providing a more highly developed problem but also the opportunity to be at the forefront of the development of technological and administrative developments that could be used throughout the rest of the world.

The length of the total utility network (using the assumptions applied in Table 1.1) is estimated at about 11 million miles. This is nearly three times the reported length of U.S. highway miles, which is 3,997,461 miles according to Kane (*4*), and much of which is in rural areas with few or no buried utilities.

To further illustrate that the interaction of utilities and transportation is a growing problem worldwide, Farrimond (*5*) reports that "every year, on average, utilities dig 4 million holes in the U.K.'s highways and footpaths . . . ," "road maintenance is one of the worst regarded services in Britain," and that the costs of utility work in UK streets is in excess of x1.5 billion per annum (~US$2.25 billion at 2008 exchange rates), with consequent indirect costs in excess of x3 billion (~US$4.5 billion) per annum. As urban traffic congestion rises, utility works often provide a trigger for significantly increased congestion and, as the utility networks continue to age, the maintenance and replacement work required on the systems is likely to increase. This is likely to be true regardless of whether a concerted effort is made to improve the poor condition of most underground utilities (see ASCE Infrastructure Report Card http://www.asce.org/reportcard/2005/index2005.cfm), in which case a large volume of planned work will be undertaken, or whether the system is left to deteriorate, in which case an increasing amount of unplanned work to repair breakages and other types of failures will occur.

Future Solutions

A major improvement in current techniques for locating buried utilities is needed—techniques that accurately resolve the position and type of an underground utility in the presence of other underground utilities and structures, as well as techniques that have a reasonable cost relative to the cost of problems avoided. Also, developing and maintaining better records of existing utilities are critical to address those utilities whose material, depth, or surrounding environment make detection and imaging a challenge for existing and future technology. Human resource issues also need attention to ensure adequate education levels of technicians relative to the work undertaken, adequate training in the proper use of equipment, adequate pay scales to retain a qualified work force, and adequate time scheduling for proper operation of the technologies used. Developed technologies also need to be broadly deployed to be effective, that is, all the tools in the toolbox need to be available and used appropriately.

	Transmission (miles)				Distribution/Collection (miles)				Services (miles)			Total (miles)
Gas	Gathering	41,000	(*6*)	*2006*	1,212,688		(*7*)	*2005*	780,392	(*7, 8*)	*2005*	**2,359,080**
	Interstate	250,000										
	Intrastate	75,000										
Hazardous liquid		160,868	(*9*)	*2003*								**160,868**
Oil	Gathering	35,000	(*10*)	*2001*								**177,200**
	Crude	65,942	(*11*)	*2004*								
	Product	76,258										
Water	660,000		(*12*)	*2002*	995,644		(*13*)	*2007*	854,364	(*13, 14*)	*2007*	**2,510,008**
Sewer					Public	724,000	(*15*)	*2006*				**1,224,000**
					Private	500,000						
Electric	167,643		(*16*)	*2006*	600,000		(*17*)	*2007*	400,000	(*18*)	*2007*	**1,167,643**
Telecom	Underground cable		Metallic		382,472		(*19*)	*2006*				**3,194,921**
			Fiber		217,266							
	Buried cable		Metallic		2,178,320							
			Fiber		217,322							
	Conduit system		Trench		199,541							
Grand total												**10,793,719**

Table 1.1. Estimated Lengths of Major Underground Utility Services **(6–19)**

Several advances are evident that can make utilities easier to locate—such as, permanent utility marking systems and field-deployable global positioning system (GPS)-geographical information system (GIS) databases of locations and attributes—but so are technologies that may increase the difficulty of future utility locating, including directionally drilled plastic pipes on curved alignments at greater depths of installation. Recent extreme events, namely, hurricanes and terrorist acts, also have exposed new difficulties and concerns. Trying to find critical buried utilities after a major disaster has obliterated landmarks has highlighted deficiencies in current approaches. The threat of terrorist action against buried utilities is causing new restrictions on the availability of information on buried assets.

The clear problems faced and the size of the potential market both provide strong incentives for improved solutions.

Organization of the Report

Intended Audience

This report is intended to document the existing state of practice and state of the art for utility locating and characterization technologies as a means of providing recommendations for future research and development activities and administrative changes that would mitigate the current utility-related difficulties faced by transportation agencies. The intended audience for the report is, thus, principally the decision makers and research administrators who are responsible for setting funding priorities and approving future research programs. It is hoped that the report also will be useful as a general review of current and emerging utility locating and characterization technologies, but discussion of many of the technical details has been curtailed so that the report can be understandable to readers with a wide range of technical and managerial backgrounds. References for further information and an annotated bibliography are provided for those wishing to pursue greater detail on the various technologies discussed.

Scope of the Report

This report concerns issues affecting the delivery of needed transportation projects—issues that are related to utilities located in or adjacent to the public right-of-way. The report has a particular focus on urban area transportation projects where the utility issues are often the most problematic. While technological development is seen as a critical component in creating better project results, it has been observed by many involved in providing input to this report that administrative, scheduling, and funding allocations should also be improved if greater success over a wide range of projects is to be achieved. Thus, the report addresses both technical issues and administrative issues.

Layout of Report

The report organization follows the data collection and evaluation process used in arriving at the targeted innovation areas and the specific project descriptions prepared for funding consideration. The introduction sets the stage for the magnitude of the problem and the benefits that improved technologies and procedures could bring. Chapter 2 on methodology describes how the information for the project was collected and the process for determining the technologies that would most benefit from targeted research and development support. Chapter 3 provides information on the current interactions between transportation project owners and utility owners and where the practitioners believe that the process could be improved. Chapters 4 and 5 focus on the technologies available to locate and characterize utilities—providing an overview of technological possibilities and assessing the level of maturity and future potential for the various technologies. Chapter 6 discusses the targeted areas for future work and provides listings of those priority actions by different application sectors applicable to the utility-transportation interaction problems—and represents the findings of Phase 1 of the research project. In chapter 7, the Phase 2 effort to develop specific project descriptions is described and the core text of each recommended project is listed. Finally, in chapter 8, a summary of the findings is provided. References are provided at the end of each chapter. Appendix A provides an annotated bibliography organized by sectors of interest. Appendix B lists case histories of successful approaches to mitigating utility-related problems in transportation and other construction projects. Appendix C provides a list of organizations related to utilities, pipelines, and damage prevention issues for buried utilities.

References

1. American Society of Civil Engineers. *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data*. ASCE Standard No. CI/ASCE 38-02, ASCE, Reston, Va., 2002, 20 pp.
2. Ellis, R., M. Venner, C. Paulsen, J. Anspach, G. Adams, and K. Vandenbergh. *SHRP 2 Report S2-R15-RW: Integrating the Priorities of Transportation Agencies and Utility Companies*. TRB, Washington, D.C., 2009.
3. Wimberley, R., and M. Kulikowski. Mayday 23: World Population Becomes More Urban Than Rural. Press Release, North Carolina State University, May 2007, p. 2.
4. Kane, A. *U.S. Highway System Overview*. Presented at the ICAF Meeting, March 2006, 15 slides. http://downloads.transportation.org/Kane-2006-03-10.pdf.
5. Farrimond, M. The ESWRAC Initiative. *Proc., ISTT No-Dig 2004 Conf*. Hamburg, Germany, Nov. 2004, p. 9.
6. U.S. Department of Energy. Transmission, Distribution & Storage. Oct. 2006. http://www.fossil.energy.gov/programs/oilgas/delivery/index.html.
7. Pipeline and Hazardous Materials Safety Administration. Gas Distribution Systems Annual Report Data File Fields, Distribution Annual Report Form RSPA F 7100.1-1, Dec. 2005.

8. The total number of gas services in the United States, according to reference 7, is 63,523,945. This number was then converted to miles by taking an average length of one service line to be 65 ft.
9. Pipeline and Hazardous Materials Safety Administration. Frequently Asked Questions: General Pipeline FAQs. 2003. http://www.phmsa.dot.gov/media/pipeline_qa.html.
10. Pipeline 101. Overview: How Many Pipelines Are There? 2001. http://www.pipeline101.com/Overview/energy-pl.html.
11. Bureau of Transportation Statistics. The Transportation Network: 2004. http://www.bts.gov/publications/pocket_guide_to_transportation/2006/html/table_01.html.
12. Brongers, M. P. H. Appendix K: Drinking Water and Sewer Systems. Cost of Corrosion, March 2002. http://www.corrosioncost.com/pdf/water.pdf.
13. U.S. Environmental Protection Agency. *Distribution System Inventory, Integrity and Water Quality,* Jan. 2007, p. 13. http://www.epa.gov/safewater/disinfection/tcr/pdfs/issuepaper_tcr_ds-inventory.pdf.
14. The total number of water services in the United States, according to reference 13, is about 69,545,307. This number was then converted to miles by taking an average length of one service line to be 65 ft.
15. U.S. Environmental Protection Agency. *Emerging Technologies for Conveyance: New Installations and Rehabilitation Methods.* EPA 832-R-06-004, July 2006.
16. North American Electric Reliability Council. *Long-Term Reliability Assessment: The Reliability of the Bulk of Power Systems in North America.* Oct. 2006. http://www.nerc.com/files/LTRA2006.pdf.
17. Eleven U.S. utilities reported a total of 296,093 miles. However, the length of underground electrical distribution is expected to be much less than for gas or water, which are fully underground. A figure of 600,000 miles is assumed as the U.S. total.
18. This figure is a rough estimate based on underground electric service being less than half the length of underground water services.
19. U.S. Federal Communications Commission. Table I.A: Outside Plant Statistics—Cable and Wire Facilities. *FCC Report 43-08: ARMIS Operating Data Report,* 2006.

CHAPTER 2

Methodology

This chapter outlines the procedures used and the types of data collected that form the basis for the recommendations made. Two formal information-search methodologies were used to (1) determine current issues as perceived by transportation agency personnel and utility-locating or SUE firms, and to (2) search for emerging technologies for utility locating and characterization and for relevant technological developments in other fields.

Identification of Current Issues

Questionnaires to Agencies and Utility Locating Firms

Two questionnaires were developed to collect data on the current issues and perceptions within the industry. The first questionnaire asked public agency transportation designers and their design consultants to identify current issues. This questionnaire was developed with input from SUE consultants and current and former state department of transportation (DOT) utility engineers. Questions were designed for a wide range of anticipated issues such as education, policy, technology, costs, and agency expectations.

This first questionnaire was presented to DOT utility directors at the 2007 AASHTO Right-of-Way and Utility Conference. Thirty-four states and the District of Columbia were represented at this meeting. Representatives from the Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) also participated. The chair of the utility committee requested participation from all attendees; 16 individuals responded. It was also presented to all Washington State DOT design managers and the ASCE branch officers within the states of Washington, Arizona, and Alabama. In total, out of 210 questionnaires, 43 were returned, for a response of 20%. A summary of the responses to the first questionnaire is provided in Table 2.1. In this table, answers are given to the request to "Rank the issues for not mapping utilities accurately and comprehensively during the design stages of a project. Rank from 1 (most important) to 10 (least important)." For each issue, the number of people ranking that issue at each importance level is given. Thus, for the issue "Getting good information takes too long," 10 respondents ranked this issue as most important, and 20 out of the 35 respondents ranked the issue as one of the top three issues listed. On the other hand, for the issue, "I'm willing to gamble on a project-by-project basis that utilities won't be a problem," 12 respondents ranked this as the least important reason for not mapping utilities accurately. Not all respondents answered all questions. Hence, the total number of responses varies from issue to issue.

The results shown in Table 2.1 are generally well distributed. Cost, time, and lack of management support to locate utilities appear to be the largest issues. The response to the issue that current equipment just is not good enough indicates that a majority of the designers responding believe that equipment capability was not among the most important issues. It is not clear, however, whether this results from a high expectation of equipment capabilities or because other issues at present are seen to predominate. From the agency engineers' and transportation designers' points of view, it seems that a multifaceted approach to encouraging innovation is warranted, one that includes education and policy suggestions and technology that may address the time and costs needed to accurately and comprehensively identify and map utilities.

The desire for and relative importance of characterization data were also solicited from the first questionnaire. The summary of responses is shown in Table 2.2.

Owner, size, and type of utility are clearly important to the respondents. The origin of data and encasement status are important issues but are not critical. Type of backfill and material are least important. However, all characterization data are important to some select respondents.

Other relevant comments and suggestions from the first questionnaire, in no particular order, follow:

- Require utility owners to use computer-aided design and drafting (CADD) for relocation as-built drawings, show

Issue	Importance of Issue for Inaccurate Location of Utilities, Ranked Highest (1) to Lowest (8 or Greater)							
	1	2	3	4	5	6	7	≥ 8
	Number of Responses Per Importance Level							
Utility records are usually good enough for design work	5	5	5	3	1	3	1	6
Getting good information costs too much	9	9	5	3	1	2	1	3
Getting good information takes too long	10	5	5	1	3	4	4	3
I tried getting utility information from specialized consultants and had problems	3	3	1	5	4	1	0	9
Utilities are a construction problem	6	2	1	4	2	4	2	8
Current equipment to find utilities just isn't good enough	1	2	2	2	5	1	4	9
The one-call center does a good enough job	5	3	6	1	2	2	3	4
Utilities are the utility owners' problem	3	2	8	1	3	1	1	9
We don't get management support to spend money on utility issues in design	8	4	5	4	2	0	3	4
I'm willing to gamble on a project-by-project basis that utilities won't be a problem	3	3	2	0	0	2	1	12
I don't know enough about the costs or time to relocate utilities to have a good answer	4	2	1	3	1	0	1	7

Note: See discussion in the text for more explanation on the response numbers.

Table 2.1. Summary of Responses from Transportation Owner and Designer Personnel to the First Questionnaire

depth on records, maintain accurate records, and pay for *all* expenses from bad location information.
- Require state DOTs to require SUE.
- Get one-call agencies to do designer tickets.
- Develop public geospatial databases.

Utility Characteristics	Importance of Determining Characteristic, Ranked Highest (1) to Lowest (≥8)							
	1	2	3	4	5	6	7	≥ 8
	Number of Responses per Importance Level							
Owner of utility	20	5	7	4	3	0	0	2
Age of utility	1	2	3	6	8	6	4	5
Size of utility	10	7	11	8	0	1	0	1
Type of utility	22	15	2	3	1	0	0	0
Where utility data came from	4	5	3	5	8	4	2	6
Condition of utility	2	2	4	3	7	7	5	4
Encasement or direct buried	4	0	2	5	11	8	4	3
Type of backfill / paving	2	0	3	0	1	2	5	17
Type of material	3	1	2	3	5	3	5	12

Note: See discussion in the text for more explanation on the response numbers.

Table 2.2. Relative Importance of Utility Characterization Data

- Require professional survey/GPS for as-built information.
- Mandate use of the *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data* (*1*).
- Require utilities to be shown correctly after relocation.
- Get high-quality mapping early.
- Educate all stakeholders.

A second questionnaire was developed to solicit information from firms whose business includes locating and characterizing utilities. An Internet search with key words "subsurface utility engineering" and "locating" was performed. This search netted 128 firms whose Web pages included SUE or utility locating services; the second questionnaire was sent to all of them. Of the 12 respondents, 11 are firms with significant SUE contracts with at least one state DOT. One contract locating firm responded.

Follow-up phone calls were placed to some of the nonresponding firms in an attempt to discover reasons for the low response. Universally, the answers were that (1) the firm was not in business to locate all utilities, or (2) they did not typically work in the design stage of transportation projects.

Responses from the second questionnaire as to which utility type presents the most problems on projects are shown in Table 2.3.

Other Contacts

In addition to the two questionnaires, an effort was made through personal communication to solicit the experiences of

Type of Utility	No. of Responses as Largest Problem
Telecom	19
Electric	13
Water	12
Storm	11
Sanitary	10
Product pipelines	9
Gas	8
Services	7

Table 2.3. Utilities Presenting the Largest Problems for Transportation Projects

individuals with long careers in utility locating, subsurface utility engineering, one-call damage prevention, technology development, and transportation engineering. Some of the responses were verbal and some were written. Individuals and companies in the transportation and utility sectors were contacted at conferences, over the phone, and through e-mail and asked for their thoughts on and experiences in identifying, locating, mapping, and characterizing utilities and encouraging best practices and innovation. Their responses varied, but many of the views on critical aspects of utility locating were consistent.

There was a common view that difficult-to-locate utilities are predominantly those that are nonmetallic, that have no access points to insert a conductor or sonde, or that have long stretches between access points. It was also noted that metallic utilities that are buried beneath or near other sources of metal, such as other utilities, paving reinforcing steel, fences, and guardrails, pose a challenge.

Respondents indicated that with a sufficiently large budget, unlimited time, total access to utility structures, records, and select personnel, there are few situations in which the vast majority of utilities could not be located with existing technology. Exceptions include nonmetallic fiber-optic lines or other small-diameter, nonmetallic utilities (especially those deeper than 2 ft, directionally drilled, and with no associated trench), extremely deep utilities (in excess of 20 ft), and utilities within certain geographic areas in which ambient conditions create a poor signal-to-noise ratio for geophysical survey methods. It was considered more difficult to indirectly obtain utility characterization data than utility location data. Most data could only be inferred through physical access to the utility or through utility records.

Opinions were also solicited on how to mitigate problems and encourage innovation. The discussion of these topics can be found in chapters 4, 5, and 6.

Technology Search

Literature Search Process

A wide-ranging literature search was carried out—building on the existing literature search performed in 1999–2000 for the Federal Laboratory Consortium (FLC) discussed later in this section, the technical reference database of the Trenchless Technology Center, and the reference lists of project participants. The updated literature search was initiated with assistance from the National Agricultural Library, which had been involved in the previous FLC study managed by Kate Hayes. The literature sources were grouped according to the application area—for example, locating or characterizing technologies, product information, problem discussions, case studies, and legislation. Most literature sources were annotated as to content and relevance and the most pertinent findings and technology advances extracted for analysis and discussion by the project team. Specific references cited in the report are provided in the reference sections at the end of each chapter, and a selected broader bibliography of pertinent reports, papers, articles, patents, and companies is provided in Appendix A.

Patent Search Process

The patent search again built on the previous FLC study and was initiated by the National Agricultural Library and continued by the project team members. The list of patents identified is not included in this report, but it was reviewed to identify specific new technological developments and research and development trends.

Statement of Need Process

The FLC has developed several statements of need (SON) for problems affecting U.S. industry or public interests. The process is intended to identify commercially available, emerging, and noncommercialized technologies that are potentially useful in solving the problem identified. Information on potentially applicable technologies or research developments is solicited from researchers in federal laboratories and selected universities. The first step is to develop a SON that contains an adequate definition of the criteria—for example, the most important range of applications and the approximate range of acceptable costs for a commercialized technology—that technological improvements must meet in order to address the problem and to provide a significant advance over current practice. This SON helps to focus attention on the most applicable technologies rather than on any potentially related technologies. The SON is developed with input from the affected industry and other interested parties.

Once completed, the SON is then circulated to researchers in federal laboratories and selected universities to solicit their input on technologies that may have application. These may include technologies that are used in other fields but have not yet been applied to the identified problem, technologies that are currently under development for other purposes that may have application to the current problem, and novel research findings for which applications are not fully understood.

A SON process had previously been used by the authors at the request of the FLC in 1999 (*2*) and a summary report prepared (*3*). This process was repeated during the current study to measure the progress of previously identified technologies and to discover currently developing technologies that could have application to buried utility location and characterization. The major change from the previous SON was to solicit information on field characterization technologies for underground utilities in addition to field locating technologies.

- The SON was distributed directly to a wide range of individuals representing major engineering, utilities, research, and technology transfer organizations, including the ASCE; Common Ground Alliance (CGA); National Utilities Contractor Association (NUCA); FLC; Tech Transfer Society, D.C. Chapter; National Council of Entrepreneurial Tech Transfer and Commercialization; and the Association of University Technology Managers.
- It was distributed to 15 company representatives who participated in the 1999–2000 project. In some cases, announcements were sent to multiple company participants or company e-mail addresses to ensure that the companies received the notification.
- It was distributed to five federal laboratory researchers who participated in the 1999–2000 project, including the U.S. Geological Survey (USGS), Department of Energy (DOE), DOT, Army, and Johns Hopkins Applied Physics Lab, Tech Transfer Office.
- It was distributed to the director of the National Institutes of Health (NIH) Tech Transfer Office, an NIH grantee at the Department of Radiology at the University of Chicago, and to the editor of the *Federal Technology Watch* and the *Technology Commercialization* newsletters.
- The SON was placed on the Trenchless Technology Center Web site, and during the many external contacts made during the project, individuals were made aware of the SON and encouraged to respond. In particular, over 60 related organizations, departments, and associations were contacted by phone and e-mail to determine current activities in relation to underground utility locating and characterization (see below).

No formal response form was required and, hence, it is not possible to identify specifically how many responses to the SON were received. However, an extensive range of individuals and organizations were made aware of the technology search and had the opportunity to respond with potential technological advances.

Organizational Contacts and Special Information Sources

A wide range of organizations were contacted during this study, including contacts at more than 60 organizations identified by the Common Ground Alliance Research and Development Committee as being potentially linked to utility damage-prevention issues. The list of organizations contacted and their response in terms of activities related to underground utilities is provided in Appendix C.

Some organizations that merit identification are briefly introduced below as they are actively pursuing innovation and advances in dealing with underground utility problems. The list is not intended to be comprehensive but rather illustrative in nature, and information from these organizations will be returned to later in the report.

- *Common Ground Alliance:* The alliance grew out of a study of one-call systems and damage-prevention best practices sponsored by the U.S. Department of Transportation, Research and Special Programs Administration, Office of Pipeline Safety, as authorized by the Transportation Equity Act for the 21st Century (TEA 21). It has since become a major organization working to improve practices and technologies related to damage prevention for buried utilities and pipelines. It has a structured membership based on utility sectors and roles and a wide range of subcommittees—including an R&D committee.
- *Gas Technology Institute:* The Gas Technology Institute (GTI) was formed by a merger of the Gas Research Institute and the Gas Technology Center. The group has conducted research related to the gas sector since 1941. GTI has a wide range of research related to utility locating and characterization.
- *United Kingdom Water Industry Research:* The United Kingdom Water Industry Research (UKWIR) organization has been at the heart of many recent U.K. and European initiatives to improve the way in which buried utilities are designed and managed. Some of its initiatives are outlined below and discussed in later chapters of the report.
- *European Street Works Research Advisory Council:* The European Street Works Research Advisory Council (ESWRAC) is led by UKWIR and involves utilities across Europe. It has successfully lobbied for £3.5 million (~US$7 million at 2008 exchange rates) of European Commission research on asset location and condition assessment.
- *GIGA:* Ground-penetrating radar innovative research for highly reliable robustness/accuracy gas pipe detection/location. This project involved six main European partners:

Gaz de France, European Gas Group (GERG), Ingegneria dei Sistemi SpA (IDS), OSYS Technology, Thales Air Defence, and Tracto-Technik. The GIGA project was partly supported by the European Commission's Fifth Framework Program for Community Research, Energy, Environment and Sustainable Development (Contract # ENK6-CT-2001-00506). The main activities of the GIGA project, which lasted from 2001 to 2003, were planned to try to overcome some "intrinsic" limitations of currently available ground-penetrating radar (GPR). A description of some of the technology advances pursued and a discussion of the testing of some IDS equipment configurations are provided in chapter 6.

- *ORFEUS:* This is an EU-supported project being undertaken by a consortium of nine organizations consisting of equipment developers, user organizations, and academic institutions (*4*). It has two aims:
  - To improve the performance of GPR deployed on the surface to provide underground maps; and
  - To develop a new radar to provide a look-ahead capability for horizontal directional drilling equipment.

  The three-year project, which began in late 2006, is valued at x5 million (~US$7.5 million), 50% of which is contributed by the European Commission's 6th R&D Framework Program (http://www.orfeus-project.eu/).
- *Mapping the Underworld:* This is a £1 million (~US$2 million) research project funded by the U.K. Engineering and Physical Sciences Research Council (EPSRC), with cofunding of £200,000 (~US$400,000) from UKWIR for industry liaison, which is being led by the University of Birmingham. It consists of four research subprojects covering location technology (led by the University of Birmingham), mapping (University of Nottingham), data integration (University of Leeds) and asset tagging (University of Oxford), and an Engineering Program Network for academe-industry interaction. Dr. Chris Rogers, one of the team members for this report, is the principal investigator for the *Mapping the Underworld* project. A bid worth £3.3 million (~US$6.6 million) is being submitted to take the location technology program forward beyond its initial feasibility stage.
- Office of Pipeline Safety/Pipeline and Hazardous Materials Safety Administration: The Office of Pipeline Safety (OPS) is the federal safety authority for ensuring the safe, reliable, and environmentally sound operation of the nation's pipeline transportation system. It is part of the Pipeline and Hazardous Materials Safety Administration (PHMSA) which, in turn, is one of 10 agencies within the U.S. DOT. PHMSA works to protect the American public and the environment by ensuring the safe and secure movement of hazardous materials to industry and consumers by all transportation modes, including the nation's pipelines. Through PHMSA, the department develops and enforces regulations for the safe, reliable, and environmentally sound operation of the nation's 2.3 million mile pipeline transportation system. PHMSA has an ongoing research program related to pipeline safety.
- *VISTA:* The VISTA project is a £2.4 million (~US$4.8 million) project funded by the U.K. Department of Trade and Industry (DTI) and managed by UKWIR. The project is being carried out by the University of Leeds and the University of Nottingham and is taking forward the results of the research conducted under the respective *Mapping the Underworld* subprojects. The project will investigate the use of global navigation satellite technology linked to existing asset records to produce 3-D images of utilities' underground assets. More specifically, the objective is to develop methods to integrate the diverse records of assets held by numerous utility service providers into a single common database with common attribute information, and develop protocols for sharing of the data and updating the information as amendments or additions to the buried infrastructure occur. This, like *Mapping the Underworld,* is one element of a £10 million (~US$20 million) assets location research program, of which £7 million (~US$14 million) had already been initiated in April 2007. See also ESWRAC, *Mapping the Underworld,* and UKWIR for associated U.K. initiatives and organizations.
- The Construction Institute of the American Society of Civil Engineers: The Construction Institute of the American Society of Civil Engineers (CI/ASCE) formed a utility committee in 1998 to address issues, to develop and promote standards, and to provide continuing education in the utility issues facing professionals in the broad construction industry. They published CI-ASCE 38-02, *Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data,* in 2002. This national engineering standard is updated every five years to address changes in the practice of subsurface utility engineering as they relate to utility mapping. It looks not at the technology, but rather at the processes used by the project owner and engineer to get utility information on plan documents.

Case History Search

One line of investigation for the literature search was to find case history examples of utility problems on projects and how they were addressed, successfully or otherwise, and to find case history examples of the selection and application of utility locating and characterization technologies. This proved to be a difficult process in terms of finding sufficient information to properly describe a case history for meaningful analysis. There are many reports of utility damage events, and it is possible also in many cases to find the general cause of utility damage events. However, there is much less reported information on utility locating and characterization activities done for planning purposes or problems that did not result in a catastrophic event or physical utility damage. Selected case histories of procedures are included in Appendix B, and a summary of the implications derived from the case histories is provided in chapter 6. An electronic version of the case history information has been prepared and is searchable using selected keywords to find case histories that may be the most closely relevant to a planned project. This database is available by contacting the Trenchless Technology Center.

Synthesis Process

Through the literature search, SON process, attendance at national and international meetings, and various organizational contacts, the research team amassed a considerable amount of data. Identifying the common and critical application and procedural issues and the most promising avenues of technology development was carried out through team discussions and many external discussions of team members with industry colleagues.

In developing the targeted research recommendations, it was decided to first select (see chapter 6) a moderately broad range of avenues of improvement that offered the best potential for technology enhancement and improvements in practical results. This list was too extensive to fit the scale of the planned SHRP 2 research effort and hence a further selection was carried out to identify those activities that provide the strongest potential of short- to medium-term impacts, that would fit with the nature of activities appropriate for SHRP 2 and that would allow reasonable progress to be made within the budget of approximately $5 million expected to be available.

Ranking Process

Using the list composed of the nine main avenues identified for improvement, the draft report and a ranking form was circulated to an external panel, including state DOT personnel, municipal and major infrastructure facility personnel, utility owners, contractors, and one-call center and locating personnel. A total of 14 individuals (9 external and 5 from the project team) completed the ranking procedure using the Analytical Hierarchy Process (*5*), which involves a pairwise comparison of alternatives by individuals within decision-making groups.

The final result of the report's first phase was, thus, a ranked list of technology and process improvements considered to offer the most impact on transportation projects in the near- to mid-term and with the budget and time schedule for funding available within the SHRP 2 program.

Development of Project Descriptions

Phase 2 of this project then developed project descriptions for each of the nine targeted improvements. The development of these recommendations and the resulting project descriptions are described in chapter 7.

References

1. American Society of Civil Engineers. *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data*. ASCE Standard No. CI/ASCE 38-02, ASCE, Reston, Va., 2002, 20 pp.
2. Federal Laboratory Consortium for Technology Transfer. *Statement of Need-Utility Locating Technologies 1999.* FLC, 1999, p. 19. http://www.nal.usda.gov/ttic/utilfnl.htm.
3. Federal Laboratory Consortium for Technology Transfer. *Utility Locating Technologies: A Summary of Responses to a Statement of Need.* Summary Report, FLC, 2000, p. 59. http://www.federallabs.org/utilities/Presentations/Utility_Locating_Technologies_Report.pdf.
4. Manacorda, G., H. Scott, M. Rameil, R. Courseille, M. Farrimond, and D. Pinchbeck. *The ORFEUS Project: A Step Change in Ground Penetrating Radar Technology to Locate Buried Utilities.* Presented at ISTT NoDig 2007, Rome, Italy, Sept. 2007.
5. Saaty, T. L. *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process.* RWS Publ. 2000 (revised), Pittsburgh, Pa., 2000, p. 478.

CHAPTER 3

Utility Issues in Transportation Projects

Subsurface Utility Engineering

Up until the 1980s, a department of transportation (DOT) employee usually worked directly with a utility company representative to address utility issues. In 1989, at the Federal Highway Administration (FHWA)-hosted National Highway Utility Conference, in Cleveland, Ohio, a new branch of civil engineering was introduced. It was called subsurface utility engineering, or SUE. Since its introduction, SUE has evolved to encompass not only utility mapping, but also utility characterization, coordination, design, and relocation design. Since 1989, the FHWA has played a major role in validating and promoting SUE.

The basic premise of SUE is that utility location data, as shown on plans, can come from various sources, including records, surface geophysical imaging, determinations based on visible physical features, and conversations with reliable—or unreliable—parties. Knowing the data's genesis and the processes used to collect and interpret it allows the data to be classified according to its reliability. The evaluation of data reliability is based on four utility quality levels (QL). Quality level A, B, C, and D designations all require adherence to rigorous protocols before the data is assigned a utility quality level. Perhaps most importantly, an appropriately registered professional must take direct, responsible charge of data collection and depiction before the data is associated with a quality level. The American Society of Civil Engineers (ASCE) Guidelines (*1*) standardize these collection and depiction protocols.

Interactions Between the Project Owners and Utilities

Responsibility for determining the ownership, location, and condition of a visible object in the highway right-of-way is generally well defined, and there are clear standards for accuracy and precision of depicted items, including visible utility structures. The transportation project owners invariably produce a topographic survey and take responsibility for that cost and time. This is not the case for the nonvisible space. Challenges in documenting and understanding accuracy for indirectly measured or inferred utilities are part of the problem of resolving utility issues on transportation projects and also relate to interpretations of the "accuracy" language in state one-call statutes. Responsibility for locating and characterizing the nonvisible (that is, buried utility) items occupying space varies widely and is not well delineated in practice. Also, different parties may be responsible for utility depictions for differing phases of the project (for example, planning, design, and construction).

A new transportation project is an opportunity to repair, upgrade, and, in some cases, rationalize existing buried infrastructure within the limits of the project. However, comprehensive utility work prior to a transportation project extends the project timetable and the period of concentrated disruption for residents and businesses. The utility work itself may cause unexpected damage to adjacent utilities or structures—causing further delays and uncertainties. Such decisions need to be taken on a project-by-project basis.

Why Is Knowing the Location and Character of Utilities Important?

The purposes for locating and characterizing utilities are many. They include the broad categories that follow:

- Reducing or eliminating unnecessary utility relocations;
- Obtaining timely information for design, construction, and material inventory for necessary relocations;
- Making sound decisions on betterment or relocation or replacement versus rehabilitation (in situ) of utilities based on their condition, their location, or both during the window of opportunity of the transportation project;
- Making the public and construction worker safe;
- Continuing and maintaining important utility services; and

- Limiting pavement damage during utility expansion or repair.

Utility Relocations

The FHWA issued a report in 2002 on avoiding utility relocations (*2*). It included reasons why utilities are relocated unnecessarily. Some of these reasons have direct application to this study and they are discussed in this section.

Utilities May Be Moved More Than Once per Project

Utilities being relocated more than once per project can occur when initial project utility relocations are not recorded properly or not recorded at all, and a subsequent project design change creates a new utility conflict. The situation occurs because of the following reasons:

- Utility relocations are usually performed before project construction, so that construction can proceed without conflicts.
- Late-stage design changes are a frequent occurrence, sometimes happening after utilities are relocated.
- Projects are halted during some stage of their design or construction, but after some amount of utility relocation, and are reactivated at a later time.
- Initially relocated utilities may not be constructed in accordance with the relocation plans for various reasons. These reasons may include mistakes or intentional changes due to site or ground conditions. Providing accurate as-built records to the project managers may not occur when these changes are made.
- Project designers may be using old plan sets that show the original utility locations, but not the relocated ones, since project owners usually wait until construction plans are issued to incorporate these initial utility relocations.

Utilities Are Not Located in a Timely Fashion

Knowing where utilities are as early as possible during the project development process allows for the efficient use of that location data for planning purposes. These purposes include budgeting utility relocation costs and time; taking into account existing utility plans for new or upgraded service; public outreach for utility structure placements; and permitting for environmental issues, height restrictions, or other reasons. This does not happen on many projects for various reasons, including the following:

- Utility issues are rated low in importance in the overall complexity of a highway planning process.
- Agencies are reluctant to expend resources for utility mapping for a project that may never be designed or for which the project footprint may change.
- Many publications by the SUE industry, FHWA, and others advocate using only utility owner records for the depiction of utility locations in the planning stage of a project (e.g., *Subsurface Utility Engineering: A Proven Solution*) (*3*).

Some state DOTs (Virginia and Washington, for example) are beginning to advocate the use of surface geophysics to map utilities for large projects at the cusp of design (0 to 10% completion stage) in spite of the above reasons for not locating utilities at this early stage. For example, Virginia DOT includes utility designating as a service item (locating through surface geophysics) in their topographic survey contracts, typically performed in the planning or early design stages. Washington DOT has done the same on a specific large project, the Alaska Way Viaduct and Sea Wall Replacement Project, through downtown Seattle.

Utilities Can Be Damaged During Construction

Transportation projects typically require excavation for pavement replacement, vertical or horizontal alignment changes, and drainage system additions, as well as the relocation of any existing utilities affected by the project. This excavation work opens up the possibility of damage to existing utilities and the risk of deaths, injuries, costs, and project delays. Because of the seriousness of many utility and pipeline accidents and the high cost of disruption to some types of utilities (for example, fiber optic cables), much attention has been paid to this issue over the past 10 years. Efforts to mitigate damage have fallen into the following major categories:

- Procedural mitigation: Improved one-call procedures; increased use of one-call (public and contractor) education; tracking damage statistics (national and state utility offices); using damage statistics to prioritize actions; and moving the responsibility of the damage-prevention marking process to contractors or a single entity rather than individual utility owners.
- Technological mitigation: Improved locating and marking technologies; improved mapping; pipeline encroachment monitoring; leakage and mechanical damage detection; and "see ahead" technologies for excavation equipment.

It is important to understand the extent of utility damage and its causes in order to plan how to reduce damage and disruption of projects. On a national level, the Common Ground Alliance has initiated a Damage Information Reporting Tool (DIRT). There is some collection of data at the state level, with one of the best examples being the Utility Notification Center of Colorado (UNCC). Its 2005 report indicated that 9,371 damage incidents occurred in 2005, an 11.4% decrease from 10,573 incidents in 2004. Excavators did request a locate on 55.7% and did not request a locate on 32.3% of the incidents (*4*). The fact that 55.7% of those excavators that damaged a facility had requested a locate within the time specified under the law means that merely gaining compliance with one-call laws is not sufficient to prevent damage. Excavating, locating, or marking practices still need major improvement.

Not all damage to utilities is reported or immediately detected, which makes assigning responsibility for damage costs difficult. It also may cause later service problems that are difficult to trace and that produce unexpected, severe safety consequences.

Utilities May Not Be Where Logic Would Indicate

A mistake frequently made is that the existing features of the land are taken to reflect the location of the utilities beneath it. Utilities are expected to follow the line of the road, be at the edge of it, trend straight between visible structures such as fire hydrants, and cross roads perpendicularly. This was mostly the case for the 20th century, because it was efficient for past construction techniques (for example, hand digging, backhoes). However, underground obstacles encountered during construction, such as rocks or water, may have affected this preferred emplacement from time to time. Also, while utilities may have been originally installed following the trend of the road, the land could have changed over time. Roadways may have been straightened, widened, added to, and removed, and the utilities may have stayed where they were. New construction techniques and materials allow differing utility emplacement procedures and alignments to be easily accomplished. Materials such as fiber optic cables and plastics are easily bendable. Emplacement techniques, such as directional drilling, allow greater freedom from the constraints of above-ground features. Utilities can now exist almost anywhere and in any kind of configuration or pattern.

Pavement Integrity Is Important to Transportation Agencies

The interplay between utilities and transportation projects does not occur only during the planning, design, and construction of the project but must be managed throughout the life of the transportation service. Few occurrences in public works are as frustrating for the public and the public works engineers as a new street or highway pavement being cut for utility work. Efforts to combat this problem have included Utility Coordination Committees—typically on a citywide basis for street work or a regional basis for state highway work. These committees meet on a regular basis, and the transportation project plans are discussed in detail to allow utility companies to plan their work within the affected rights-of-way to be completed in a timely fashion prior to or during the street or highway work. This collaboration is also encouraged or enforced by restrictions on utility cuts (except for emergency operations) for a certain period after completion of the new pavement.

This report is not about managing utilities in the right-of-way during the service life of a transportation project, but this issue cannot be separated from the planning, design, and construction operations if a minimal life-cycle cost and a well-managed coexistence between utilities and transportation is to be achieved.

The primary interactions between life-cycle issues and the planning, design, and construction process include the following:

- Utility coordination should occur at the earliest stages of planning a transportation project.
- Effective utility coordination requires resources and time during the project planning phases.
- Accurate and comprehensive utility maps are needed as early as possible in the project so that the necessary utilities can be targeted.
- Effective characterization of the operating condition, safety and remaining life of the affected utilities needs to be accomplished so that decisions can be made about rehabilitation or replacement prior to placement of the new pavement.
- Utility companies need to understand the permit restrictions and costs that will become effective once the project is constructed.

Who to Contact and What Utilities to Look For

Determining who has underground facilities is an important and necessary first step in order to ask them for information on their buried utilities. Interactions between the transportation agency and the utility owner will be nonexistent if the owner is not identified. Responsibility for documenting whose facilities are underground at a particular location is vague. Recorded sources of information on who owns the utilities in the ground are varied and generally inconsistent from area to area. DOT or municipal permitting departments, past projects, governmental agencies, a state one-call center, Internet/literature searches, and conversation are some information sources. Another method of determining ownership may be possible by detecting the presence of a utility and then tracing it to a visible structure that gives a clue as to ownership.

The list of utility types is extensive. Power, natural gas, telecommunications, sewer, and water top the standard list. Steam, cathodic protection, gasoline, oil, propane, industrial gases, and others exist in certain places. Each utility is typically composed of wires or pipes of different sizes, materials, and protective sheathing. Each utility may have associated structures occupying underground space, such as thrust blocks, vaults, and storage areas. Wires may be encased or individually placed in common trenches. Splices and loops may exist beyond the immediate area of the main pipe or cable. Some utilities may occupy the same space, such as a fiber optic cable inside a sewer pipe.

In any one project location, the list of utility owners also can be extensive. An individual person may own a water well and septic system and run underground wiring for light or heat. An individual may also own the sewer system connection to the main or to the public right-of-way line. Corporations may own fiber optic lines running between buildings. Municipalities may own storm and sanitary sewer systems, and sometimes the town gas, electric, and water systems as well. Apartment complexes may own steam and gas systems. College and industrial campuses may own all or some of the utilities found on their property. Railroads own signal and track switching wiring. DOTs may own storm drainage, sign lighting, and information technology systems. Public and private corporations or authorities may supply water, gas, electric, and telecommunications.

Where Is It Underground?

This is one of the major questions for which this study hopes to find better solutions. Accurate and comprehensive records are a solution. However, existing records of underground site conditions are usually incorrect and incomplete, and the reasons may include the following:

- Records were not accurate in the first place—design drawings are often not "as built," or installations were "field run," and no record was ever made of actual locations.
- On old sites, there have usually been several utility owners, architects, engineers, and contractors installing facilities and burying objects for decades in the area. The records seldom get put in a single file and are often lost—there is almost never a composite map.
- References are frequently lost. The records show something 28 ft from a building that is no longer there, or from the edge of a two-lane road that is now four lanes or part of a parking lot.
- Lines, pipes, and tanks are abandoned but do not get taken off the drawings.

Even so-called as-builts frequently lack the detail and veracity needed for design purposes in a utility congested environment. Furthermore, references on depth are rarely referenced to a recognized elevation datum. The amount of cover over a utility can change without obvious visual indications due to interim construction activity, erosion, and so forth, creating errors on records where "depth of cover" is the sole reference to vertical position (5).

The problem has only grown worse since 1995. The increasing use of GIS systems for utility recordkeeping, coupled with the easy integration of data from CADD systems, has led to a proliferation of utility data. Sometimes original data has been scrapped once it has become digital. Digitizing mistakes are common, as are misinterpretations of the original record data. Without ground-truthing or other verification means, it is impossible to know the accuracy or completeness of these utility location and characterization data.

A reliable image of a utility's position can be accurately transferred to plans through professional survey and mapping services. However, sometimes markings on the ground surface are transferred to paper or CADD without the benefit of professional quality control. Pacing off distances, using a GPS system inadequate for engineering survey accuracies, or other means of measurements are sometimes used. The precision of the surface geophysical methods are defeated when this occurs, and the accuracy and reliability of the final data become unknown despite appearing to be well documented or determined.

Even with all available surface geophysical tools in use and with adequate time and budget, there are still those situations in which the tools are inadequate or the data are ambiguous. Tough locating tasks with improbable or impossible locating success due to the utility circumstances or its environment (for example, nearby structures that interfere with the locating methods used) are listed in Box 3.1.

Another obstacle is the diverse ways in which surface geophysical methods are used and by whom. Reliance on the response of utility owners through one-call systems has not worked well for the design stage of projects because the system was designed for safety during construction only. Indeed, in a majority of states, the legislation or practices preclude permitting or mandating that utility owners respond to "design locates." Regardless of whether utility owners should mark during design, the following are some arguments as to why individual utility companies cannot do as good a job for planning or design purposes as a single entity responsible for marking all the utilities in a project.

The practice of a single entity marking all utilities within the project limits fosters an environment in which this full range of utilities can be marked on the ground surface with greater reliability during design than is likely to be the case if individual markings are made on a utility-by-utility basis. Comparisons of the two approaches are given in Table 3.1.

An additional and significant problem exists when utility owners mark their own utilities. Someone has to transfer that data from the ground to the CADD file. This process begins with the surveyor. However, when the surveyor has no control over the process of the field marks, the surveyor does not know when to actually survey the marks. The surveyor does not know if all the marks have been made in the field and so

Box 3.1. Challenging Conditions for Utility Location

Deep utilities	Inaccurate or missing records
Braided utilities that weave around each other	Gas and oil field gathering lines
Utilities layered on top of others	Railroad communications facilities
Empty nonmetallic conduits	Thrust blocks
Close and parallel utilities	Limits of encasements
Abandoned and discontinuous utilities, and utilities in poor condition	Utilities under salt water
Stubs for future connections	Loops of wires
Anode beds/wires	Slag and highly conductive backfill
Large grounding systems	Utilities beneath reinforcing steel
Under cars and other obstructions	No access to utilities
Septic systems	Wooden water lines
Material and depth variance	Steam lines
	Utilities near guardrails

may need to make multiple trips to the same spot to survey additional marks. All of this results in cost and time inefficiencies and potential quality issues.

Another issue is that of responsibility. For those states allowing utility owners to mark for design, in many cases those utilities are protected from liability by statutes that say the utilities are not responsible for accuracy or completeness of the marks. There is little incentive for doing the job correctly.

Finally, it is necessary to have a wide variety of surface geophysical equipment available to effectively image various utilities under a range of site conditions (see, for example, the appendix to ASCE 38-02) (*1*). The cost of having this equipment available, and technicians trained to use it, is high. A properly outfitted technician may have equipment at his disposal costing more than $100,000, when vehicle, survey equipment, safety equipment, and surface geophysical equipment are considered.

Coordinating Utility Issues with the Project

Effective action in the planning and design stage is a key to reducing the impact of utility problems on transportation projects. This utility coordination process is addressed by a companion SHRP 2 study (*6*), and these two studies, while separate, should be integrated for a more complete understanding of the problems, issues, and potential solutions facing transportation project providers and utilities.

Because of the many utility owners, long timelines of project development, different systems of recordkeeping, different purposes for knowing the locations and character of utilities,

Comprehensive Approach	Utility-by-Utility Approach
Has available or at least has requested all available utility owners' records	Has available only those records for each utility owner
Finds and marks all utilities capable of being found	Only marks some utilities—does not have advantage of seeing all parts of the puzzle. For instance, abandoned utilities, unknown utilities, and multiple nonencased wires cause identification confusion.
Has a realistic time frame for finding and marking utilities	Is under severe time constraints for getting utilities marked
Has many pieces of equipment on-site or readily available	Has limited equipment available
Maps a large area, allowing better familiarization with utilities at a site	Usually only responsible for a small area, making it difficult to see the large picture
Because of the large area to be marked and reasonable time frames, traffic control can be set up, allowing time and security for decision and precision	Usually no time for traffic control. Locator runs between vehicles when clear of traffic.

Table 3.1. Comparison of Comprehensive and Utility-by-Utility Approaches to Utility Identification and Locating

Box 3.2. Roles Related to Utilities in Transportation Projects

State DOT Personnel	*Utility Company Personnel*	*Other Personnel*
Utility engineers	Records	Railroads
Survey section	Engineering	State one-call centers, inspectors, consultants, designers
Property department	Locators	Municipal GIS departments, engineers, consultants
Traffic department	Contract locators	Federal agencies
Maintenance	Construction inspectors	Military
Consultants		Private owners

and different accommodation policies and guidance, the responsibility for collecting and depicting utility information for transportation projects is varied. Transportation agencies typically have a department or person responsible for seeing that this function is carried out in accordance with their own procedures and policies. This department, depending upon the organization, may be contained within the broader divisions of design, survey, construction, or maintenance.

The personnel or organizations that may have a role in the utility issues for a transportation project are listed in Box 3.2. With this many parties involved in the process, there is a need to clearly identify responsibilities, scopes of work, and timing sufficiently to address all the parties and the means to get utility information delineated on plans.

The Virginia DOT Case Study

The Virginia Department of Transportation (VDOT) has perhaps the most extensive use of SUE services and consultants under contract. This reduces the number of parties responsible for utility issues outside the control of VDOT. The list below is illustrative of VDOT's contracted services or benefits.

- VDOT employs several strategies to get horizontal utility mapping on the project plans. In each case, it relies on consultants under its control. This ensures that (1) the mapping scope includes those utilities not typically marked by utility owners or their one-call contractors (such as unknown, abandoned, out-of-service, or privately owned utilities, multiple direct-buried cables, cathodic protection systems, and empty conduits), (2) the timing of data collection is in accordance with project needs, (3) VDOT is protected against errors or omissions in the utility mapping data, and (4) the survey and CADD mapping of the data are efficient.
- VDOT establishes regional subsurface utility mapping contracts directly with providers of this service. Additionally, it has included horizontal utility mapping in statewide and regional topographical survey contracts. This enables VDOT to move collection of comprehensive accurate horizontal utility data into the planning stages of the project and to start using that data early for planning and preliminary design decisions.
- VDOT reimburses all utility owners for their relocation design costs. Utility owners can do this design themselves or get permission to use a consultant.
- VDOT has regional utility relocation design contracts in place. This allows VDOT to directly perform utility relocation designs for municipalities or for other utility owners.
- VDOT negotiates and obtains any required utility easements directly with the land owners in conjunction with the highway project.
- VDOT provides utility owners and consultants with licenses for their project CADD platforms.
- VDOT sometimes includes utility coordination in consultant design contracts; it also employs outside consultants under direct contract with the DOT for these services on an as-needed basis. These consultant services can encompass responsibility for conflict identification.
- VDOT uses its regional SUE contracts for conflict verification through physical exposure (test holes).

All of these services, controlled by VDOT, take burden from the utility owners. Utility owners are still included in correspondence and meetings and can take control of aspects of these services when they desire. VDOT has stated a 20% reduction in time to take a project from planning to construction by using these procedures. It has also reduced institutional wariness and conflict between the agencies. In a 2007 report to the Virginia Transportation Commission, VDOT met every project budget and timetable for every project for the first time since it has been tracking projections (*7*).

VDOT's project constructors still must use the one-call system for damage prevention purposes. This is an important state-mandated process that addresses the utility owners' roles and responsibilities. It is their final chance to protect their facilities and find utility changes and additions within the project location after design is complete but before construction is complete.

Other state DOTs use SUE consultants to varying degrees. Some use them on a project-specific basis or for just a portion of a project, such as for planning purposes only or design only. Some states do not use SUE consultants at all. Some states have a prequalification process for SUE consultants; many do not.

Subsurface utility engineers typically have access to a much wider array of utility surface geophysical devices and techniques than utility owners and contract locators do, and the commensurate training to use it. However, even with this wider array and training, there may be some utilities that cannot be identified or detected. The following chapter discusses available locating technologies.

References

1. American Society of Civil Engineers. *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data*. ASCE Standard No. CI/ASCE 38-02, ASCE, Reston, Va., 2002, 20 pp.
2. *Avoiding Utility Relocations.* DTFH61-01-C-00024, U.S. Department of Transportation, U.S. Federal Highway Administration, Office of Program Administration, July 2002.
3. *Subsurface Utility Engineering: A Proven Solution.* U.S. FHWA Film, 1995.
4. *Perspectives on Facility Damage—2005.* Utility Notification Center of Colorado, Golden, Colo., Sept. 2005, p. 76.
5. Anspach, J. H. ASCE Continuing Education Class: CI/ASCE 38-02. Reston, Va., 1995.
6. Ellis, R., M. Venner, C. Paulsen, J. Anspach, G. Adams, and K. Vandenbergh. *SHRP 2 Report S2-R15-RW: Integrating the Priorities of Transportation Agencies and Utility Companies*. TRB, Washington, D.C., 2009.
7. VDOT Meets or Exceeds All Project Completion and Budget Goals for First Time. *Roads & Bridges News*, Sept. 2007.

CHAPTER 4

Utility Locating Technologies

Introduction

"While it is hard to find a black cat in a dark coal bin by optical means, it is easy to distinguish its furry outline from hard coal by touch" (*1*). In other words, a property contrast is necessary to effectively differentiate an object from its environment, as pointed out in the referenced NRC study. In utilities, property contrasts occur because the utility's material, interior product (such as gas or fluid), or backfill material is somehow different from the surrounding earth. Measuring electrical conductivity, magnetism, heat, mass, electrical capacity, and rigidity can detect property contrasts. Sometimes these contrasts may be altered or enhanced through the use of conductors, magnets, miniature transmitters, fluids, or gases to better differentiate the object from its environment. "Geophysical methods" describes the detection, imaging, and tracing of utilities through property contrasts.

Geophysical methods of identifying property contrasts are not foolproof, and the results often require professional interpretation in much the same way that medical electromagnetic imaging tools, such as CAT scans, MRIs, and X-rays, require a doctor's interpretation. However, unlike medical imaging, where the aim may be to identify an object—or organ—within organic material at a relatively shallow depth, imaging a utility may require looking through many feet of materials that are of varied composition, making the utility-imaging task more difficult than that of medical imaging in some ways.

What follows are descriptions of some terms and methods common to buried utility detection, with indications of how the terms are used and how the methods are applied.

Terminology

The subsurface utility engineering profession has developed its own terminology over the past 25 years to address its particular needs and those of designers. The Federal Highway Administration (FHWA), the American Society of Civil Engineers (ASCE), and others have adopted this terminology, but the utility and damage-prevention communities have not. Thus, some terms differ in usage and meaning between the communities. It is important, therefore, to define how this report applies these terms, as opposed to how others might use them.

Included in the title of this report is the term "locating," which has different meanings to different communities. To a subsurface utility engineer, "locating" is the process of exposing a utility to precisely and accurately measure and document its three-dimensional location. To a contractor, "locating" is the process of getting a utility owner or someone else to place a mark on the ground to prevent damage. For the purpose of this report, "locating" is defined, as stated in chapter 1's *Background to the Report,* as indicating the determination of a utility position. The terminology used in this report is shown in Table 4.1.

Geophysical Methods

Geophysical methods for utility detection fall into one of two broad categories: passive or active. Passive geophysical methods use energies produced by nature, society, utility structures, or their products to detect contrast. Usually, passive detection instrumentation consists only of an energy receiver. For example, the passive method might detect the iron in a pipe, a buried magnet, the 60 Hz electromagnetic (EM) wave from an energized power line, the 87 Hz EM wave of the U.S. Navy's submarine communications, or the noise produced from a leaking pipe as its contents escape through the leak orifice. Active geophysical methods, on the other hand, typically use both a transmitting device and a receiving device. The transmitter produces energy that is broadcast into the ground or directly into the utility or its product through a physical connection. This energy interacts with the utility and the environment. The instrument's receiver detects the subsequent change in the transmitted energy. Examples of active geophysical utility detection methods include introducing

Designating	The process of using a surface geophysical method or methods to interpret the presence of a subsurface utility and to mark its approximate horizontal position (its designation) on the ground surface. (Note: Utility owners and contractors sometimes call this process "locating.")
Locating	The process of exposing and recording the precise vertical and horizontal location of a utility (or, see "designating"). The term is also used in a more general context within this report.
Conflict analysis	The engineering process of using a conflict matrix to evaluate and compare depicted designating information with proposed plans (highway, bridge, drainage, and other) in order to inform all stakeholders of potential conflicts, potential resolutions (including avoidance of utility relocations where possible), and costs to cure.
Data management	The process involving the physical surveying of designating and locating information for project planning and recordkeeping purposes and transferring it into a CAD system, GIS files, or project plans
Minimally intrusive excavation method	A method of excavation that minimizes the potential for damage to the structure being uncovered. Factors such as utility material and condition may influence specific techniques. Typical techniques for utility exposures include air-entrainment/vacuum-extraction systems, water-jet/vacuum-extraction systems, and careful hand tool usage.
One-call notification center	An entity that administers a system through which a person can notify utility owners and operators of proposed excavations. Typically, the one-call center notifies member utility owners that they may send records to the designer or designate and mark on the ground surface the existing indications of some or all of the utilities that may be present.
One-call statute	A local or state requirement that an excavator or designer of excavation call a central number to notify some or all existing utility owners of that planned excavation.
State of the art	The latest and most sophisticated use of equipment and procedures in regular commercial practice by at least one entity.
State of the practice	The most common level of equipment and procedures in regular commercial practice, on average, within the industry.
Subsurface utility engineering (SUE)	A branch of engineering practice that involves managing certain risks associated with utility mapping at appropriate quality levels, utility coordination, utility relocation design and coordination, utility condition assessment, communication of utility data to concerned parties, utility relocation cost estimates, implementation of utility accommodation policies, and utility design.
Subsurface utility engineer	A person who by education and experience is qualified to practice subsurface utility engineering.
Surface geophysical method	Any of a number of methods designed to utilize and interpret ambient or applied energy fields for the purpose of identifying properties of, and structure within, the earth. Such methods typically include variants of electromagnetic, magnetic, elastic wave, gravitational, and chemical energies.
Survey datum	The points of reference used to define a specific geographic location in three-dimensional space.
Test hole	The excavation made to determine, measure, and record the presence of a utility structure. (Contractors may call this a "pothole")
Utility	A privately, publicly, or cooperatively owned line, facility, or system for producing, transmitting, or distributing communications, cable television, power, electricity, light, heat, gas, oil, crude products, water, steam, waste, or any other similar commodity, including any fire or police signal system or street-lighting system.
Utility attribute	A distinctive documented characteristic of a utility that may include but is not limited to elevation, horizontal position, configurations of multiple nonencased pipes or cables, shape, size, material type, condition, age, quality level, and date of documentation.
Utility depiction	A visual image of existing utility information on project plan sheets or other media.
Utility quality level	A professional opinion of the quality and reliability of utility information. Such reliability is determined by the means and methods of the professional. Each of the four existing utility data quality levels is established by different methods of data collection and interpretation.
Utility quality level A	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. Minimally intrusive excavation equipment is typically used to minimize the potential for utility damage. A precise horizontal and vertical location, as well as other utility attributes, is shown on plan documents. Accuracy is typically set to approximately 0.6-in. vertical and to applicable horizontal survey and mapping accuracy as defined or expected by the project owner.
Utility quality level B	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.

Table 4.1. Utility Locating Terminology

(continued on next page)

Utility quality level C	Information obtained by surveying and plotting visible above-ground utility features and by using professional judgment in correlating this information to quality level D information.
Utility quality level D	Information derived from existing records or oral recollections.
Utility relocation policy	A policy (typically of the project owner or utility owner) for the relocation of utility facilities required by the project. This policy includes but is not limited to establishing provisions for compensating utility owners; for removing and reinstalling utility facilities; for acquiring or permitting necessary rights of way at the new location; for moving, rearranging, or changing the type of existing facilities; and for taking necessary protective measures.
Utility search	The search for a specific or unknown utility or utilities using a level of effort in accordance with the specified quality level, within a defined area.
Utility trace	The process of using surface geophysical methods to image and track a particular utility.

Table 4.1. Utility Locating Terminology (continued)

sound into a water system through a fire hydrant, broadcasting a specific EM frequency into the ground, inserting a miniaturized transmitter into a sewer pipe, or introducing radioactive particles into a product line.

Both passive and active geophysical methods allow us to distinguish an underground utility. They allow us to distinguish but not to see; to calculate indirectly but not to measure directly; to infer the existence but not to confirm. These are important distinctions. The presence of a mark on the ground, made using geophysical methods, does not indicate with absolute accuracy the existence of a utility. Likewise, the absence of a mark on the ground is not assurance that there will be no utilities in that area.

Currently, there are many commercially available instruments that use different methods to detect and trace utilities. Detecting a utility (that is, determining a contrast) and tracing that utility (that is, determining its direction and continuity) are sometimes accomplished through different methods. The effectiveness of the instruments employing these techniques varies as a result of the following: site geology, backfill type and homogeneity, utility material type, methods of and materials for joining/splicing utility sections, utility condition, depth, soil moisture, nearby buried objects, type of ground surface and its "smoothness," ambient noise and temperature, surface objects or site conditions, stray/interfering energies, and built-in equipment biases.

In the subsequent sections, the principles and applications of various geophysical methods are described, and through a discussion of these methods, the complexity of the utility-detection tracing problem becomes apparent.

Electromagnetic Methods

The electromagnetic spectrum is broad, and a portion of it can be used for utility detection. Electromagnetic methods fall into four categories, each within a particular frequency range: visible light, radio waves, infrared, and X-rays.

Visual Range

This is the portion of the electromagnetic spectrum between 10^{14} and 10^{15} Hertz (Hz). Utilities that are above ground and not hidden by an opaque object can be positively identified. Evidence that a utility may exist includes a repair patch, natural gas leakage "pinpointing" bore, or vault cover. Utilities that are exposed through excavation can also be positively identified. However, utilities hidden by an opaque surface, such as those below ground, behind a wall, or beneath a floor, cannot be visually identified.

Radio Waves

Radio waves are composed of frequencies ranging between 30 gigahertz (GHz) and 30 hertz (Hz) (see Table 4.2). For utility detection purposes, frequencies for commercially available equipment range from about 50 Hz to 1 GHz. Radio waves are a popular and versatile technology for looking into the ground.

Pipe and Cable Locators (Time-Domain Electromagnetics)

Pipe and cable locators are the most common instruments for detecting and tracing underground utilities. This equipment has many manufacturers and hundreds of separate pieces. It varies in antenna size, shape, and number; in the frequency and threshold of output; in types of attachments; in its depth measurements and current-flow direction indicating; in its signal strength displays; and in the shape, size, and weight of transmitters and receivers. The authors have witnessed firsthand instances in which instruments with identical frequencies, similar-looking antennas, and signal outputs were not equally able to detect a signal from a particular utility. The selection of the appropriate equipment is, thus, not a simple task based on easily defined characteristics.

There are trade-offs with pipe and cable locators. Emissions are limited by Federal Communications Commission (FCC)

Frequency Range	Acronym	Common Name	Type of Instrumentation
30 GHz – 300 GHz	EHF	Extremely high frequency (microwaves)	None yet
3 GHz – 30 GHz	SHF	Super high frequency (microwaves)	None Yet
300 MHz – 3 GHz	UHF	Ultrahigh frequency	Ground-penetrating radar
30 MHz – 300 MHz	VHF	Very high frequency	Ground-penetrating radar
3 MHz – 30 MHz	HF	High frequency	None yet
300 kHz – 3 MHz	MF	Medium frequency	Pipe & cable locator
30 kHz – 300 kHz	LF	Low frequency	Pipe & cable locator
3 kHz – 30 kHz	VLF	Very low frequency	Pipe & cable locator, terrain conductivity meter
300 Hz – 3 kHz	VF	Voice frequency	Pipe & cable locator
30 Hz – 300 Hz	ELF	Extremely low frequency	Pipe & cable locator

Table 4.2. Radio Wave Frequencies and Applications

regulations. Lower-frequency locators can penetrate deeper into the ground, but more power is needed to do so. When the frequency is lower, the less that frequency will tend to excite other conductors nearby, increasing the likelihood of a correct interpretation. Less-conductive utilities need higher frequency to propagate over distance. However, with higher frequency, the signal will travel less distance. A larger homogenous conductor can be more difficult to detect and trace than a smaller one, since the radio waves spread out and travel on the pipe surface. A larger surface means more signal attenuation. A particular point along a utility's path will have a particular, most-efficient frequency. The most difficult conductive (metallic) utility to detect is typically a large and deep one with relatively poor conductivity (for example, a cast iron pipe with lots of nonwelded joints). All pipe and cable locators have one or more receiving antennas, and if the locators are active devices, they will also have one or more transmitting antennas. The size, shape, and type of antenna are directly related to its efficiency in receiving a signal of a certain shape and frequency. Antenna theory will not be discussed in detail here, other than to indicate the following concepts:

- The most efficient antenna for a cylindrical signal (as from a long straight pipe or cable) is a loop, the larger the better.
- Pipe- and cable-locating antennas are most frequently not loops but dipoles.
- Multifrequency instruments may compromise the efficiency of their antennas to receive/transit more than one frequency range.
- An underground pipe or cable network will act as a complex antenna, or group of antennas, in the ground.
- Radiation from one conductor can induce onto a nearby conductor, which will reradiate to another nearby conductor and so forth, until the signal at the ground surface (near the transmitter) is no longer a good indication of the location of the initial conductor. It can be highly distorted, shift location, and dissipate.
- Each transmitter will have a distinctive shape and density of signal from its antenna; orientation of that antenna to a desired conductor is crucial.
- Antennas can be oriented to pick up a maximum signal (peak mode) or a minimum signal (null mode).

When using any particular pipe and cable locator, there are three important performance elements. The first is getting the signal onto a conductor (either a specific one or one as yet undiscovered). The second is propagating the signal along the conductor to some point where the utility location is to be detected. The third is propagating that signal back through the ground and into the receiving antenna. Control over all three variables is initially available, but once a particular frequency and power have been selected, the control over the signal propagation along the conductor (utility) ceases.

Pipe and cable locators work in one or more of four distinct ways, each having strengths as well as weaknesses, and each a potentially useful tool for detecting and tracing a utility, depending on specific conditions. As it relates to conventional pipe-location equipment, a current is introduced onto a pipe or cable, and the current's magnetic field is measured at the surface through two detection methods.

The first detection method uses passive utility detection. An antenna is used to detect a radio-frequency (RF) transmission source emanating from the utility without the use of a matching transmitter. There is no control over the signal strength or frequency. Some instruments detect only a small frequency band near 50 to 60 Hz. This frequency is found in underground power systems, and detection senses the load imposed on the wires by the consumer using the power. As the load changes, so does the signal strength. These changes can be used to advantage by a trained technician to determine the presence of more than one conductor in different but nearby locations. Additional passive power frequencies are used for cathodic protection, and there are some manufacturers with these available frequencies. A third source of passive signals is AM/FM commercial radio stations broadcasting in the medium frequency/high frequency/very high frequency (MF/HF/VHF) ranges. A fourth source is military communications in the extremely low frequency (ELF) range.

The second detection method uses active utility detection, and it comes in three varieties. The first turns the underground utility system into a broadcast antenna through a direct connection to the utility and to a grounding mechanism. This method will generally allow a maximum signal onto a particular utility, at least at that initial contact point. Placement of the grounding mechanism is critical for maximum system isolation. Even with a perfect grounding location, the signal from one underground conductor can generate a secondary signal to other nearby conductors. The lower the frequency, the less signal "bleed-off" will occur. The second uses a toroid clamp to direct a signal onto an exposed pipe or cable. A direct contact between the broadcast antenna and the utility does not occur, but the shape of the clamp isolates and directs the broadcast signal onto the clamped utility at that location. The third, and perhaps the most used, turns the geophysical instrument into a broadcasting station, similar to that of a radio or television station. The antenna in the transmitter broadcasts a radio wave. Signal density and shape is dependent on the antenna; therefore, propagation to underground conductors is highly variable depending on antenna placement, orientation, and the surrounding environment.

The first pipe and cable locator of the transistor age had a single loop antenna in both its transmitting and receiving devices. It used a single frequency, the "tuning" of which was based on finding a long continuous conductor in average soils. That frequency was about 150 kHz. Other instrumentation quickly followed with different single frequencies both higher or lower than 150 kHz.

It then became possible to connect the transmitting source directly to the underground utility at a surface feature, such as at a pipe riser or fire hydrant. This active mode came in two forms. One form used either a direct connection to the utility with a ground stake placed somewhere to complete a circuit or a toroid clamp antenna placed around a pipe or cable, as long as the pipe or cable was grounded from the toroid clamp in both directions. Small waterproof transmitters were developed that could be sent inside sewer pipes or plastic conduits. A passive receiving device was developed to use commercial AM/FM radio station broadcast signals, some of which could be induced into long conductors in the ground.

Antenna shapes became varied, and dipole antennas became popular because of their directionality and size. Eventually, some manufacturers began to use two receiving antennas to indicate to the operator that the signal peak was to the right or left. This was a great development that allowed for the observation of signal symmetry, perhaps one of the most critical interpretation factors. A significant development occurred in the 1980s when multiple frequency transmitters and receivers in a single unit became available. A single piece of equipment could now have the frequency advantages of two or more separate pieces of equipment. Additional features such as signal strength readouts, depth estimates, and current direction followed.

Now there are many instruments available in the general frequency ranges of 60 Hz, 512 Hz, 1 kHz, 8 kHz, 29 kHz, 33 kHz, 80 kHz, 83 kHz, 110 kHz, 250 kHz, 300 kHz, 480 kHz, and so forth. It may be necessary to have equipment in all of these frequency ranges to effectively detect and trace a particular utility, although in some cases, a single frequency might be all that is needed. It depends on factors previously noted.

Pipe and cable locators are suitable instruments for both detecting and tracing utilities, depending on frequency and method of signal generation. This can be effective up to a depth of 20 ft, although, more frequently, the maximum depth for effective detection is somewhat less. High-power sondes (transmitters) that can be placed into and pulled through a utility may increase the effective depth of detection to 50 ft or more, although the chances that the peak surface will be directly over the utility decreases with depth.

Depth estimation with pipe and cable locators is possible, but it is fraught with potential for error due to site conditions. Under ideal conditions, such as a single conductor in homogeneous soil with a recently calibrated instrument, depths can be quite precise and accurate. Some manufacturer specifications state 2.5% to 5% accuracy to a depth of 10 ft. In the congested utility arena of an urban or suburban street, depth estimations are frequently wrong by a significant amount. Depth estimations can also be useful for determining signal symmetry.

To summarize current practice, competent use is made of a wide variety of instruments covering the broadest possible frequency spectrum, types and shapes of antennas, and accessory features such as signal strength meters, depth estimation, and current flow direction. A wide variety of direct coupling methods, with extended grounding wires, multiple grounding systems, and remote pipe attachment devices, including clamps, magnets, and spikes, are in use. Toroid clamps, with nonconductive extension poles are used, as are composite core reels for metallic insertions into nonmetallic pipes or conduits. Sondes of many varieties are available. Confined-space entry equipment, with dewatering pumps, is available. Crews are used for confined-space entry and electromagnetic "sweeping" of the defined area. Procedures are available to maximize utility detection and tracing, and for safe opening of utility appurtenances. Practitioners employ several pieces of equipment with direct connect wire and toroid clamps.

Terrain Conductivity (Frequency-Domain Electromagnetics)

Another utility detection method in the radio wave range is that of terrain conductivity (TC). TC measures the average electrical conductivity of a cone-spaced volume of earth beneath the transmitting and receiving antennas. When less of a utility is within a cone, there will be less of an effect on the average resistivity. Maximum depth penetration of the bottom of the cone can be as deep as 150 ft; however, greater depths require greater antenna spacing and power and decrease resolution. Utility detection thresholds are currently limited by manageable antenna spacing and the resolution required for utility detection to depths of 20 ft. Success is more often limited to the first 10 ft of cover. Factors affecting ground conductivity include earth materials, such as rock and soil, and the water and its solutes in the interstitial pore spaces. Most rocks and soils have high electric resistivity. Most of the water and solutes have low resistivity. Utilities' resistivities can range from extremely low (metallic) to very high (large empty clay pipe). Attempts to look for contrasts between the utility and the earth can vary from highly effective, to somewhat effective, to impossible, depending on the type of utility and the soil.

In the northern United States, road salt placed on the pavement for deicing purposes is absorbed into the soil around the roadway, increasing the ground conductivity. This can make detecting a metallic utility difficult, but conversely it may make detecting a nonmetallic utility easier. In areas that have high moisture or a high water table, it may be impossible to detect any kind of utility, unless it is watertight, empty, large, and relatively shallow. Regardless of the conditions, to be adequately interpreted, there must be sufficient collected data with different antenna orientations or within a tightly spaced grid search pattern to clearly identify an anomaly that a utility might produce.

Some utilities lend themselves to detection by TC methods. Tracing is more difficult than detection and requires massive amounts of data. TC methods may be applied to trace septic systems, especially in dry soil. The moisture and chemical composition from the septic waste might produce a detectable anomaly, as might the gravel bedding or metallic drain pipes. TC methods might also trace buried tanks, well shafts, or vault covers. Since TC instrumentation, which includes the receiver and transmitter, is basically carried by one person, it can be an effective detection or search tool to find metallic utilities in a noncongested, dry environment. However, in general, interpreting TC data is much more complex than interpreting data from pipe and cable locators. Although data interpretation can be performed remotely by others, accurate positional data must be available at all times during the data collection process. Data loggers linked to GPS help reduce this problem. Currently, depth estimation with TC methods is not considered realistic.

Competent practitioners select frequency, search and trace techniques, and survey methods on appropriate projects after review of records and site conditions, but this method is rarely used.

Ground-Penetrating Radar (GPR)

With perhaps the best-funded ongoing research, GPR is another geophysical electromagnetic tool in the radio wave range. Use of GPR research for utility detection began in the 1960s with the advent of plastic gas pipes. Since then, hundreds of millions of dollars have probably been poured into GPR research. Early versions of this tool required a full-time repair technician, expensive "thermal" paper, much power, long cables, and a highly experienced geophysicist to interpret the data. Initial equipment costs were over $50,000. The results of these early GPR efforts were disappointing but showed promise. Now there are many commercially available GPR devices. They are easier to use and interpret than ever before, and they are coming down significantly in price.

GPR works by sending an electromagnetic pulse into the ground. For utilities, the frequency range is typically between about 50 MHz and 500 MHz. Some ratio of this pulse signal is transmitted through boundaries and some ratio is reflected from the boundaries back to the receiving antenna. The boundaries are formed as a function of a particular particle's dielectric properties. Overall propagation into the ground is a factor of power, frequency, and soil resistivity. The FCC limits the power, and for each base GPR unit, the manufacturer selects the frequency and matches it to a particular antenna. Manufacturers offer several antennas, each at an extra cost and possibly requiring additional hardware and software. The operator cannot change the soil resistivity or the dielectric constant of the particle boundaries. In some ways then, GPR seems easier for an untrained technician to use in the field than pipe and cable locators, because GPR introduces fewer variables for the equipment operator to address. However, referencing the machine's location becomes critical, and data interpretation becomes more difficult and time consuming, but attempts are being made to overcome these challenges to using GPR.

With GPR, detection occurs when the utility's dielectric constant differs from that of the surrounding soil. A dielectric constant that differs significantly from the soil around it would produce the best reflection. This occurs, for instance, when the utility is metallic and the ground is dry sand. Although pipe and cable locators might detect the same utility faster and cheaper and the result would be easier to interpret, GPR may perform better in those situations in which the utility is metallic but its joints are not, precluding a good circuit for the pipe and cable locator method. A small clay sewer pipe is not much different in dielectric constant than the surrounding soil. If the pipe is empty, a reflection may occur at the pipe/air interface. If the pipe is filled with water and the surrounding ground is saturated, there will be little or no differentiating reflection.

However, detection of a buried utility is constrained by the signal wavelength-to-pipe cross-sectional size ratio. This means that the smaller the utility, the higher the frequency needed to image it. Therefore, identifying a small utility becomes increasingly difficult the deeper it is placed. The diameter-to-depth ratio of a single fiber optic cable that is surrounded by soil with similar qualities—for instance, if it has no metal, very small air space, or plastic sheathing—makes such a cable virtually undetectable using GPR or anything else. A rule of thumb for the current technology in practice is that, under ideal conditions, a 12 to 1 depth-to-diameter ratio provides reliable utility detection down to the first 6 ft—that is, a 1-in. utility at a 1-ft depth, or a 3-in. utility at a 3-ft depth. Competent methodologies may improve this ratio. However, tightly spaced pavement reinforcing steel will effectively stop the penetration of any signal. Road deicing salt, which increases the conductivity of soil near roadways, may do the same. A very rough surface may create too much signal noise, effectively drowning out any signal. Highly conductive soil, as in areas with high iron content or in prepared roadway base material, will cause depth penetration problems, and utilities under salt water are virtually impossible to image, unless they are so large that a sufficiently low frequency can be used to penetrate the water.

Such interferences preclude the imaging of any utility in certain conditions. In fact, one of this report's authors observed Virginia marine clay preventing several commercially available GPRs from imaging a metallic storm-drain pipe that was 1 ft in diameter and less than 8 in. below ground at one site. At another site, GPRs failed to detect the signals of every buried utility. Some parts of the country have great success with GPR imaging. Florida, with its dry nonconductive sands, is an ideal setting for GPR. In Bellevue, Washington, a recent GPR survey detected about 50% of the utilities known to exist, but in nearby downtown Seattle, the success rate dropped to below 5%.

GPR has been oversold in the past. GPR is expensive ($10,000 to $100,000, including integrated GPS and associated computer programs), and as demonstrated, its value may vary significantly depending on the surrounding conditions. Yet, GPR has several advantages over pipe and cable locators. Its biggest advantage is that it can detect nonmetallic utilities. A second advantage is that, even if the utility itself cannot be imaged, GPR can sometimes detect the sides or the materials of the trench in which the utility was placed. A third advantage is its depth determination. The radar data display is directly proportional to the electromagnetic wave's speed in the soil. Given that the soil's properties are relatively uniform and consistent in relation to wave speed, the depth of the utility can be easily measured. With a few test holes to calibrate wave propagation speed, the depth determination can be quite accurate and precise, as opposed to the variability and unreliability of the pipe and cable locator methods.

Opinions vary widely on how useful GPR is as a utility detection tool because of how disparate the success can be depending on the geological factors at play. Those who have seen GPR work in one place but are not trained in the tool's physics may believe it should work everywhere, but it will not. For others, GPR failed to work once, so they will not try it again.

And while GPR is a good search and a good trace tool, the GPR instrument must be pulled along a grid pattern while data is collected, unlike pipe and cable locators that produce a continuous EM signal output. It is important to keep the grid spacing small to collect enough data to "connect the dots," especially in a utility-congested environment with many linear changes in utility direction. Grid spacing should not exceed the width of the antenna size or else there may be gaps in the data, and gaps in the data invariably result in guesses, which can lead to errors. Such grid spacing issues get insufficient attention from GPR users. Obstacles in the survey area can also present a significant challenge that could result in incomplete data.

Recent research advances in data processing, GPS integration, laser-based referencing, data migration, multiple antenna arrays, stepped frequency capabilities, and image recognition software are in commercial development. These technological advances will help address GPR's challenges, but they will not turn GPR into a total utility-detection and -tracing solution.

The current state of the art has competent practitioners review each project site for adequate soil conditions and employ GPR when it is suitable. They use multiple frequencies and use GPR in conjunction with other techniques. A site-appropriate survey and data referencing methods are selected. Data is collected in closely spaced parallel profiles and combined in a 3-D volume of data for postprocessing and time- or depth-slice interpretation. While GPR is still rarely used for conventional locating, it is becoming more common as equipment costs drop and ease of use improves.

Infrared Electromagnetic Waves (Heat)

Some utilities—including steam pipes and sanitary sewers—have operating temperatures distinguishable from the temperature of the surrounding soil. If the utility is shallow enough or if the temperature difference is large enough, a temperature differential can be detected at the surface using an infrared camera. In fact, after a snowfall, a utility line can sometimes be detected by the difference in the speed with which the snow on the ground above it is melting because of the temperature difference.

Some utilities—including steam lines, energized power cables, sanitary sewer lines, and industrial process lines—give off significantly more heat than others, but the deeper a utility is buried, the less chance there is that the heat signature can be detected at the surface.

Infrared methods are difficult to use and interpret in a congested urban environment with lots of cement paving. Solar gain during the day heats the ground to the point where infrared is mostly useless. Pavement's large thermal mass retains daytime heat, spreads it out, and releases it uniformly at night. Climate, site, geology, and utility conditions must be just right to make this technique work effectively with current technology to locate utilities. Infrared has no depth-estimation capabilities.

The current state of the art employs infrared cameras or thermistors for very specific situations, but the infrared method is rarely used.

Resistivity Measurements

Resistivity measurements are taken by injecting a direct current (DC) into the ground using two or more electrodes, measuring the resultant voltage at other electrodes and calculating the average resistivity. The spacing of electrodes controls measurement depth. The many different types of electrode geometries each produce specific results. The detection is that, if enough data is collected, a utility with a resistivity different from that of the surrounding area will show up as an anomaly. Resistivity may be useful as a search technique but not as a trace technique. Data setup and collection is cumbersome and not easily delegated to a technician.

This method is rarely used. When it is used, it is most often employed for an unrelated reason, with the advantage that it can also detect the presence of a utility.

Magnetic Methods

Iron is a material commonly used in pipes. The magnetic properties of iron or nickel can be used to detect and sometimes trace an iron or steel pipe. There are two general types of magnetic surveys applicable to utility detection: total field and gradient.

A total field survey measures magnetic-field sources at the ground surface. Because the magnetic field of a pipe is typically small and hard to interpret, total field magnetic surveys are rarely used as a utility location method. Other stronger magnetic-field sources include the earth's internal magnetic field (caused by convection fields in the earth's rotating liquid outer core), its external fields (caused by electric currents in the earth's ionosphere), and small magnetized materials in the earth's crust (such as rocks, soil, and man-made, placed objects). In general, total field surveys are usually used for environmental surveys. Occasionally, an anomalous reading is caused by a pipe.

The gradient survey method, which uses gradiometers, has the best application to find buried utility objects. With the gradient method, a single instrument is used to cancel the effects of internal and external magnetic fields through the placement of two total-field sensors within about 20 in. of each other. In the absence of a nearby source of iron, these sensors are in balance. As the detector moves closer to a magnetic object, the shape and intensity of the magnetic field causes an imbalance in the sensors. This imbalance creates a reading that the equipment operator can interpret.

The buried pipe's magnetic field is very weak compared to the total field. The buried pipe's field contribution decreases rapidly as the distance between the sensors and the pipe increases. Pipes that are more than several feet below the surface will be difficult to detect unless they have a very high initial magnetic strength. Initial magnetic strength is related to object shape, internal structure, purity of material, and the object's location on the earth during manufacturing. The field technician has no control over these factors. As a result, some utility-related iron-bearing structures, such as valve boxes, manhole covers, septic systems, magnetic "marker" tanks, wells, Parker-Kalon survey nails, and iron casings, can be found more easily than others. It is generally easier to detect a vertical linear structure than a flat round horizontal one. Depth estimation is not possible with magnetic methods.

The current state of the art for the gradient survey method uses gradiometers extensively in grid searches to discover iron-bearing structures. Total field methods are rarely used as a primary utility detection tool.

Elastic Waves (Acoustics/Sound/Mechanical)

When pipes are nonmetallic and a metallic conductor cannot be inserted into it, elastic waves may be used to detect and trace the pipes. An elastic wave requires the creation of an initial energy input, after which the wave travels through the medium until all the energy has been transferred. The ground, the pipe, or the pipe's product may act as the medium. In general, the more noncompressible (rigid) the material, the less the wave attenuates over distance.

As with EM methods, there are three aspects of the elastic wave propagation and detection. The elastic wave must be introduced into the propagating medium, travel through it, and be detected after its travel, including any reflections or refractions that occur due to buried structures. Several factors can be controlled when the wave is introduced, including the wave's rough frequency range and the method of coupling the wave generator to the surface to be vibrated. Once a frequency is selected, wave propagation through the earth or the utility is beyond the technician's control. Receiving the elastic wave is also largely out of the technician's control, although various types of ground surfaces can enhance or decrease the signal. For instance, detecting the signal over a concrete surface is usually easier than over a soft dirt surface.

There are three basic techniques for using elastic waves to image utilities. They are seismic reflection, seismic refraction, and acoustic emission. Many studies have been performed to assess the applicability of seismic reflection and refraction as utility-imaging techniques. So far, these techniques have only been useful under specialized conditions and with rigorous procedures, because most utilities are too small for detection by the large wavelength of seismic (acoustic) waves. There are no commercial applications of these two techniques for pipe and cable location at this time, although acoustic pipe location equipment developed by the Gas Technology Institute is nearing the commercialization stage, as discussed in chapter 6. The discussion that follows is limited to acoustic emission. This method is fairly standard for tracing nonmetallic water lines, but it is relatively useless as a search technique. Acoustic emission has no depth-estimation capabilities.

Acoustic Emission

A pipe under rapidly varying mechanical stress may deform and generate noise. Various transducers, which are linear accelerometers that translate motion into electrical signals, can monitor this noise, or acoustic emission. The premise is that the noise will be loudest directly over the pipe, because the elastic wave will have traveled the shortest distance at this point and less signal attenuation will have occurred. However, the type of surface (for example, soil or concrete), fill (rock or clay), compaction, ground moisture, and so forth may distort the noise distribution. There are three methods for using acoustic emission techniques, all of which are susceptible to interference from noise, such as that produced by aircraft, automobiles, trains, and electrical transformers. It is a good trace technique, but it is not an effective search technique, and access to the utility system must be available at one point.

Active Sonics

This method involves inducing a sound onto or into a pipe, which can be accomplished by striking the pipe at an exposed point or by introducing a noise source into the pipe. The noise source may be pulled through metallic, nonmetallic, empty, or filled pipes, or it may be carried by a tractor device, thereby getting the sound closer to the detection point. By marking or measuring the loudest points at the ground surface, the utility may be traced. A linear accelerometer, which is basically an amplified stethoscope, may also be used to detect sound at the surface.

Active sonics is employed when a manhole cover is struck with a hammer to introduce sound waves into both the air inside the manhole cover and the pipe itself. If there are multiple manhole covers at a remote location, it may be possible to tell which cover is related—or directly attached via the pipe network or the air inside the pipe—to the one being struck by listening to the sound. Similarly, in an area where there is an exposed pipe and it is desired to know if it is the same pipe entering an adjacent basement, the pipe can be struck with a hammer and the sound that is carried along the pipe can be detected in the basement. Direct access to these utility structures makes the job easy, but detecting the resulting sound through the ground becomes more difficult, so sound amplification devices are used. Most of these devices were developed for the water leak detection industry but are now used by the utility detection business as well.

Passive Sonics

A second sonic method relies on the ability of the pipe's product to escape. This method is sometimes known as passive sonics. For instance, water escaping a pipe at a hydrant or service petcock (or at a leak) will vibrate the pipe. This vibration will carry along the pipe for some distance before attenuation. Factors such as product pressure, shape and size of orifice, and type of pipe material will affect the initial sound generation. Pipe material, surrounding material, compaction, and product will affect the distance the sound travels along the pipe. Factors already mentioned affect the sound detection between the receiver and the pipe. There are several commercial manufacturers for devices using these principles. Detection over the pipe is again made with an amplified device that typically provides a sound and visual reading of signal intensity. In ideal conditions of low ambient noise, shallow pipes, smooth rigid ground surface, and high fluid pressure, detection of the pipe can occur for perhaps a thousand feet, at best. Under normal site conditions, several hundred feet is more typical.

Resonant Sonics

A third sonic method relies on the pipe's product being a noncompressible fluid (water in most cases). Interfacing the fluid surface (at a hydrant, for example) and generating a pressure wave in the fluid will create detectable vibrations in the pipe. It is possible to tune the oscillator's frequency to one (or more) of the resonant frequencies of the pipe, usually resulting in more tracing distance. A disadvantage is the need for many different types of fluid/oscillator interfaces. Utility-joint damage is possible, so wave intensities are generally small, decreasing tracing distance. There is at least one commercial manufacturer of equipment using this technique.

Summary of Elastic Waves

All three methods of elastic waves may be used when necessary, but the methods are rarely used in normal circumstances.

Borehole Geophysics

Bringing the signal generator or signal detection device closer to the utility can enhance the aforementioned methods. One way to do this is to bore holes in the ground that allow for signal generation and detection closer to the utility of interest. Boreholes offer great promise not only for radio waves, magnetics, and elastic waves but also for X-rays. Boreholes make it possible to get a better signal for propagation onto the utility and to use the "shadow" of the utility as a detection method. Radiation is an issue, and X-rays are not viable unless a detector is located on the other side of the structure from the generator. The ground may be used as a natural shield, and the shadow of a utility between two boreholes, or nonmetallic sewer pipes, may provide a point of focus. Remaining issues include damage caused by insects and small animals living in the ground, potential state licensing for X-ray technicians, and safety or regulatory challenges. Nuclear soil-density gauges are commonly used in geotechnical practice, but as regulation of these gauges increases, alternative methods of inferring soil density and compaction are being developed. There is no known commercial X-ray research under way for imaging buried utilities.

There are many commercial applications of borehole geophysics for environmental engineering. Some of these seem to be adaptable for utility detection. This method is a better search technique than a trace technique.

Boreholes raise the issue of potential damage to existing utilities. Obviously, the smaller the hole, the less chance for damage. Air- and water-vacuum devices and microdirectional boring devices may be useful as compared to traditional hole-boring machines. Horizontal boreholes from right-of-way line to right-of-way line might be useful for horizontal imaging. Vertical boreholes might give a better utility-depth estimate.

At a state-of-the-art level, there are occasional uses of air and vacuum devices for creating boreholes to determine the existence and horizontal location of a utility, but these techniques are not used in general practice.

Microgravitational Techniques

In theory, microgravitational techniques may be used to detect extremely large, predominantly empty utilities or tunnels. The concept is that the expected gravitational force at a given point on the earth can be calculated. This gravitational force is directly related to the effects of mass. If a large utility or tunnel is empty, the empty space has much less mass than if it is filled with product. The survey must be precise because of the small values being measured. Nearby sources of above-grade mass must be addressed, as well as regional effects and the movements of celestial bodies. Elevations must be determined to millimeter accuracies. Obviously, this procedure is time-consuming and expensive, but useful results might be obtained in certain favorable cases (*2*). The method is theoretically possible, but there are few practical applications. This is not used except in rare cases.

Isotopic (Radiometric) Techniques

A utility or the area immediately surrounding it may be detected through scintillation or Geiger counters if either is carrying or has been contaminated by uranium, thorium, or other radioactive compounds. Isotopic techniques would be very effective, if not for the health, safety, and permitting issues that preclude its use in generally uncontrolled environments. This could work as a search or trace technique. This method is theoretically possible, but it is not used in practice.

Chemical Techniques

Chemical detection may be employed as a search technique, but it is rarely employed as a trace technique. The concept is that products conveyed in pipes, left near pipes following construction techniques, or outgassed from the plastic pipe product may exhibit a chemical signature that can be detected. For example, natural gas that is leaking through pipe joints or other breaks in the pipe can be detected with flame ionization or photo ionization techniques. Natural gas leaks also affect vegetation and soil in observable ways by displacing oxygen. Trained personnel may be able to use this vegetation damage, as well as detection of an introduced odorant, as an indication of natural gas piping in the area. The state of the art of this approach remains theoretical for general utility detection practice, but the approach is typically only used by natural gas companies as part of their leak detection operations.

Data-Processing Techniques

Many of the methods that have been mentioned can be combined with data-processing techniques and mathematical algorithms to enhance results. Data processing can range from traditional practices, such as manual data graphing, to complex algorithmic formulas linked to graphical outputs. However, caution must be exercised because data interpretation in the office rather than during field investigations does not allow interpretations to be immediately cross-checked through other field measurements.

Geophysical diffraction tomography (GDT) is a specific data-processing technique based on the principles of optical holography. It can be used with sound waves and electromagnetic waves in a variety of data collection geometries and techniques. Surface and borehole methods are used with ground-penetrating radar, seismic reflection, and offset vertical seismic profiling. This technique requires a large amount of data collection and data manipulation with, generally, proprietary algorithms.

In the current state of the art, data is collected from multiple antennas at different frequencies, integrated with GPS locational information, and processed with algorithms to produce 3-D displays of underground utilities. The approach is being used by a few firms on specific projects. Its use is expected to grow.

Marker Methods

The most common type of utility marker is that of a paint or chalk mark on the ground. The mark is usually temporary and serves an immediate damage-prevention, repair, or attachment purpose or else it marks a location for a subsequent survey. In some limited instances these marks are made using more permanent means, but concerns over aesthetics, security, and mark maintenance usually preclude this practice. These temporary marks are well understood and will not be discussed further.

The concept and practice of emplacing permanent visible markers, tracer wires or tape, buried magnets, or other buried detectable devices has been around for decades. As the technology has advanced, so has the sophistication of the marker devices. Currently, a variety of methods are in use. All these methods have a distinct drawback: a marker is not part of the utility structure; therefore, over time, the marker's location may no longer be indicative of the utility's location.

Visual Markers

Utility Signs/Pipeline Markers

Some utility owners place aboveground signs near their facilities. Owners of high-pressure gas transmission lines, major water pipelines, and fiber optic lines have been marking their facilities in this way for years. These methods have the disadvantage of indicating the utility only at a single point. If multiple markers are visible, a general trend of the line may be apparent. Markers are generally installed for warning purposes; therefore, they may be placed in a location most visible to others rather than directly over the utility. Markers may be removed and replaced in another location by vandals, mowing crews, and others. These markers serve as a good detection method but not a trace method. Examples include surface-marking posts and horizontal surface decals or curb markers, marking posts with readily accessible connections to locating wires, permanent magnet markers, and marker panels.

Flush Markers

The traditional means of identifying the location of buried airport facilities by the Federal Aviation Administration has been to place 2-ft × 2-ft × 6-in. concrete markers flush with the ground, immediately above marked features. These heavy markers cost about $100 each and require painting as well as ongoing attention to remove grass and repair soil erosion. Mowing equipment can easily displace the markers, which can compromise facility records and excavation accuracy (*3*).

Surface-to-Structure Markers

Utility owners in the San Antonio District of the Texas DOT use a marker that is embedded in the soil from the ground surface down to the utility. They emplace this marking system on a case-by-case basis, usually when data on the depth of a utility structure is requested by the DOT. Excavation is done by hand to expose the utility, and a 2-in. PVC pipe is then placed in the excavation, and dirt is backfilled around it. This gives future personnel direct access to the utility. They can measure the depth and record an elevation. They typically place a cap over the open end of the PVC pipe. This method does raise issues of future utility integrity and security.

Parker-Kalon Nails/Survey Markers

Since 1981, subsurface utility engineers have been placing PK nails, hubs, and lathes or other semipermanent markers directly over a utility after a test hole has been excavated. These markers' locations are recorded and referenced to the utility beneath it. Some engineers use unique markers that display other information, such as company name, type of utility, test-hole number, and depth. Lately, security issues are being raised over display of this additional information.

Continuous Buried Markers

Tracer tapes and wires are sometimes placed in the backfill near newly constructed nonmetallic water and gas lines. The tapes and markers are generally metallic and exposed at a meter or service riser. They can serve two purposes: warning an excavator during construction that a utility is nearby and providing a means to use a pipe and cable locator to trace the marker, since the utility itself is difficult to detect.

Tracer tapes sometimes are color coded and may have other information written on them, such as the utility owner, utility type, or just a cautionary message. A disadvantage of a tracer tape is that once it is broken, it is difficult to splice the tape back into a continuous conductor, rendering future detection by geophysical means highly improbable.

Tracer wires have the advantage of being easily spliced if broken. In actuality, excavators rarely perform this practice, and its problems are the same as those of tracer tape. Because they are small (usually #12 coated wire), tracer wires do not have other sources of information imprinted on them.

Tracer wires or tapes are not necessarily placed directly over the utility. Utility construction methods often involve a large backhoe-excavated trench. Utilities can be on one side of the trench and the tracer on the other. Also, if the utility is exposed during a future excavation, it is not guaranteed that the tracer will be replaced in its original position. In some cases, the tracer can even end up below the utility it is intended to mark. These are some of many reasons why, despite the value of a tracer wire or tape, the signal received and interpreted at the surface may not be accurate as to its representation of the actual utility location. Initial attempts to solve this problem involved wrapping the wire around the pipe. This was found to cause plastic pipe to melt or to introduce an explosion hazard because of nearby lightning strikes, so this practice is no longer used by the gas industry. Fiber optic conduits may have trace wires emplaced directly within the conduit, along with the fiber optic line.

New methods for implanting magnetic markers into pipelines or warning tapes are being investigated. Although a patent was granted for plastic gas pipes (U.S. Patent 5,173,139), such pipes are not yet in commercial use.

Single-Point Buried Markers

Magnets have long been used to indicate utility structures. Gas distribution companies may place a small magnet in its plastic curb box structures so that maintenance crews can find the curb box if it gets covered with soil or vegetation. For several decades, small magnets have been placed in the roadway material directly over a utility when exposed by subsurface utility engineers, allowing a standard gradiometer to be used in the future to find the magnet. In the 1970s, a high-gauss magnet was developed that could be placed 6 ft into a utility excavation for future detection. Magnetic orientation was crucial to receive a maximum signal at the surface.

Passive Electromagnetic Balls

These 4-in. diameter plastic balls with an embedded sonde were developed in the 1980s. The concept was that these balls would be placed at strategic locations during the installation of new utilities, such as at future sewer line connections and at stubs of gas and water services. The balls required a matching receiver and their battery life was limited, but the intent was for these balls to only last several years until utility service was connected.

These devices were soon replaced by passive markers, which act as passive antennas, reflecting the query signal from the signal source without need for an internal power source. They are not affected by moisture, minerals, chemicals, and temperature extremes. Internal components are self-leveling, ensuring that they will always be in a horizontal orientation for best signal strength, regardless of how the device is placed in the ground. Some manufacturers have developed marker balls with specific frequencies so that a signal reception would indicate a particular utility. This requires different receiving antennas, but it provides utility-owner specificity. These are generally in the high frequency (HF) or ultrahigh frequency (UHF) range.

Radio-Frequency Identification Tag or Balls

New radio-frequency identification (RFID) technology is rapidly developing as a means to both locate utilities at a specific point and characterize utilities. Active markers can be given unique preset identification numbers. The placement crew can also program them with utility information. Color coding the markers also provides visual differentiation. Using this method, it is possible to quickly find a buried marker at a later date using a surface scan, verifying the utility details contained in the RFID tag, and then using a localized excavation process to physically expose the utility, if necessary.

Summary of Marker Methods

Physical utility marking can be an important tool to reduce damage in future excavation activities. Either during construction or in the future when a utility is exposed, a physical marker can be installed. Physical markers can indicate the proximity of a utility line by using stakes or buried marker tapes. Electromagnetic markers or identification systems can employ passive marker balls or RFID markers under development, or they can be conductive wires or tapes that allow electric connections to provide an EM locating signal from the wire or tape. The wire or tape provides an EM signal path for nonconductive pipes or telecommunication fiber-optic cables, and they can be installed either within the conduit or immediately above the pipe.

RFID methods are still in development, although they have been in field use for several years. They show strong potential for application to utility locating and characterization problems.

Summary of Geophysical Methods

Research by United Kingdom Water Industry Research (UKWIR) in 2000 and 2001 concluded that, at best, existing technologies had no better than a 50% success rate in identifying buried assets. The report concluded, “These trials show the need for substantial improvements in equipment performance” (*4*).

The numerous locations where utilities are exposed and where detection signals or aids can be introduced means that a better performance can be achieved when using all the available commercially developed tools that have been mentioned. In other words, with the appropriate time, money, equipment, and training, a majority of existing utilities within our transportation rights-of-way can be detected and traced. The technological challenges are (1) to more cost-effectively locate, characterize, and manage utility information for transportation projects and (2) to improve detection in difficult circumstances.

Ongoing private and public research efforts are incrementally improving our abilities in detection, tracing, and data interpretation, and much of our existing technology can be made more user friendly. Examples of potential improvements may include more variety in pipe and cable locator antennas, such as making them detachable and interchangeable; better and more adaptable direct connection devices for the wide variety of sizes, shapes, and limited space access of today’s utilities; better ways of introducing conductors into nonconductive conduits or pipes; and easier methods of generating sound, such as through internal pipe/conduit travel and advanced sound-pickup devices with better ambient noise filtering. Single-platform multitool devices, better signal processing algorithms, target recognition patterns/artificial intelligence, signal symmetry indicators, and automatic and user-controlled signal gain would also improve abilities, as would better ways to excavate a borehole and development of miniature or shaped transmitting antennas for signal generation and reception in a borehole.

Excavation Methods of Locating Utilities

Individual geophysical methods are insufficient to accurately determine the three-dimensional location of a utility. As has been discussed, some methods can give a depth estimate; when conditions are ideal, those estimations may be somewhat accurate. Although horizontal estimations are generally more reliable because most measurements are in the horizontal plane, they too can be inaccurate due to the congestion of the underground site, as well as other factors. Conduit encasement limits are not detectable through most EM methods. This leads to excavation as the most reliable method to accurately locate an underground structure horizontally and vertically. Once exposed, a utility can be measured and referenced to other features or survey control.

Excavation methods vary, but they all bear some risk of damage to the utility being sought or to an unknown utility. The two best-known methods for limiting the potential for damage are air/vacuum excavation and water/vacuum excavation. Both methods use a powerful vacuum to remove soil from an excavation. The difference lies in the method of loosening the soil before removal. Both methods require pavement or concrete at the ground surface, or deeper if old roadways are submerged, to be removed through traditional means, such as jackhammers, rock drills, or concrete saws. For extremely shallow utilities or utilities embedded in the roadway, there is always a higher risk of damage.

Water excavation methods offer a much greater force to break up the existing soil, and excavation is usually faster than with air. The disadvantage is that a greater force can more readily damage the wrappings and coatings on cathodically protected gas lines. A less-understood disadvantage is that of subsequent soil compaction and paving integrity. Water-saturated soil is typically not suited for backfill. Even if the saturated soil is not used as backfill, the soil surrounding the test hole may be disturbed by the water saturation, which may in turn lead to ground settlement. A third disadvantage is that of cathodic cells in the soil. Introducing moisture around a pipe where moisture may not typically exist can change the cathodic currents in the ground, leading to an increased risk of corrosion. A fourth disadvantage to water excavation is the operational difficulty that arises when the air or ground temperature is below freezing.

Air excavation methods are more labor intensive and time-consuming than water excavation methods, and coatings and wrappings can still be damaged. But one advantage of the air method is that the material removed from the test hole can typically be used to backfill the test hole. Site cleanup is usually easier to accomplish.

All excavation methods are encountering a relatively new problem. Controlled density fill (CDF, or flowable fill) is a material some municipalities and utility owners use as an easier way to backfill trenches and other excavations. CDF serves the secondary purpose of getting rid of select waste material, such as fly ash, that is produced by power and sewage plants. When mixed and applied correctly, it is easily fragmented and removed. When mixed improperly, it can become as hard as concrete. Increasingly, utilities are becoming encased in this CDF. It is unclear how much of this CDF is mixed improperly, but anecdotal evidence indicates that the amount is significant. Exposing utilities encased in improperly mixed CDF is dangerous, since destructive tools are necessary to break the CDF apart. CDF emplacements can be massive, and in the future, exposing significant portions of utility systems may be more difficult and less safe. One advantage of CDF is that it is relatively uniform, making a contrast with a utility more obvious, so long as the utility is not made of concrete. This would imply that surface geophysical methods may work better over utilities encased in CDF than in a less homogeneous backfill. In the future, methods, techniques, and equipment developed to apply CDF's properties to the advantage of surface imaging could be further explored. For the time being, knowing whether the CDF (or concrete) has a utility embedded in it and how deep that utility may be embedded is important to safely identify encasements that lack additional and reliable information about the utility itself.

Data Management

Maintaining accurate and complete records for existing utilities is without question the best way to locate those utilities in the future. In the past, there were many reasons for failing to create and update records, some of which were discussed in chapter 3. However, CADD and GIS databases and GPS survey technology are approaching a point at which record generation, management, and updating can be done inexpensively, easily, and more reliably than ever before.

Transferring location data from the geophysical device to the end data user is just as important a process as using the geophysical device in the first place. Subsurface utility engineers place a premium on this aspect, as does ASCE 38-02 (*5*), and they use licensed professionals to certify the survey process and final mapping deliverables.

Some pieces of surface geophysical equipment are now incorporating GPS equipment directly into the original data-gathering process. Geophysical data and position data are downloaded to the office in a single process and a map of the results is generated. This practice has advantages and disadvantages. The advantages include no markings on the ground and little additional survey time. The disadvantages include the technician's inability to make on-site decisions about the perceived accuracy of the received signal. Quality assurance checks of the survey data correlated to the surface geophysical data are nonexistent, unless other topographic or reference features are included in the data set. This danger is alleviated somewhat when laser theodolites are used in conjunction with camera recorders. Data users must be informed of the process and make their own decisions as to the reliability of the data versus its generation cost. Because this is a relatively new technology, error statistics are not yet available.

Record Generation During Utility Installation

Who Makes the Record

Traditional practice was that utility owners generated records of their own utilities. Survey procedures until recently were expensive and time-consuming, and utility owners frequently did not employ in-house surveyors. As a result, utility owners mostly used existing topographic features as a reference for where their facilities were installed. There were varying standards for how to measure distances from these features, depending on the utility company and sometimes even the construction supervisor. Records were made for the general purpose of knowing on what side of the street the backhoe should start excavating for maintenance activities or new service hookups. Vertical data was rarely recorded. Although general depths were mostly desired and adhered to, variations due to discovered obstacles during excavation may have changed the depth of installations. Even now, it is rare to generate reliable, accurate, and recoverable utility-location data during installation.

In some cases, developers or design-build project constructors may construct utilities as part of their development efforts, and they can then deed them back to the utility owners. Record generation in this instance may be the responsibility of the developer.

Discussion is under way in certain states on whether utility owners should be the entities to generate and maintain the records of their facilities in the public right-of-way. Many states have statutes requiring utilities to do so and to furnish this information to other public entities when requested. Some state DOTs and municipalities are beginning to keep or generate utility records themselves, as a right-of-way management tool.

Records from an Exposed Utility

When a utility is constructed in an open-cut trench, traditional survey methods are available to record its location in three dimensions. Referencing this survey data to a recoverable survey control is crucial to retrieving this location in the future. Topographic references or nonpermanent markers are insufficient. State plane coordinates, latitude/longitude based on GPS techniques, or county or municipal controls can be used. Survey accuracy could be specified and standardized for utility data surveys that are intended for record generation. Many state DOTs require third-order accuracy equivalents; this is probably sufficient for most record purposes.

A common misconception is that surveying exposed utilities automatically results in utility quality level A data. However, in order for data to be referenced as such, it must be certified by a registered professional. The proliferation of handheld GPS devices for survey and the ease of their use have resulted in a lot of data that appears definitive but whose accuracy depends on the type of GPS and collection method used.

Records from Trenchless-Emplaced Utilities

When a utility is constructed through trenchless means, record generation becomes more complex. There are three methods available. None is accomplished through direct measurement; therefore, any mapping data resulting from indirect location measurements should not be portrayed as quality level A data.

Tracking Heads (Sondes) During Installation

One system for controlling an underground boring tool involves the use of gyroscopes, accelerometers, magnetometers, or all of these to track the movements of the boring tool. The location of the boring tool is essentially in real time. Gyroscopes and accelerometers track the motion of the boring head with respect to a reference starting point and the earth's gravitational field. The instruments are subject to error drift with time, and their absolute position needs to be regularly calibrated to provide an accurate output. Magnetometers track the motion of the boring head with respect to the earth's magnetic field. Measurements with magnetometers can suffer from magnetic interference, so sometimes an auxiliary system is used to create a localized magnetic field in the area of the bore that overrides the natural magnetic and electrical fields in areas where interference is suspected. For the borehole mapping to have a global reference, GPS or other survey methods must be used to provide the actual location of the boring head at the start and end of the bore. Some inference about the accuracy of measurements along the bore can be made from the error between the surveyed location at the end of the bore and the location provided by the bore-tracking device.

A second method, which is also the more popular method when conditions allow and surface access above the bore is possible, uses a walkover system that requires a crewmember to walk along the drill path with a receiver that detects the signal from a radio sonde mounted on the drill head. Magnets may also be used as a confirming location source. The principles that apply to this method of tracing the drill head are the same as those discussed in the "Geophysical Methods" section. Depths and locations are subject to the same sources of interference. Some tracking instruments are linked to a GPS system. Some systems automatically create a drawing of the installation based on the GPS location of the tracking head and the EM signals received from the sonde at the tracking device.

Surface Geophysical Tracing After Installation

This method is no different than that of using a surface geophysical method for tracing an older utility. Once the trench is backfilled, traditional surface geophysical means can be used at any time to designate the utility. If this action is performed under the direction of a registered professional, the data may be depicted as quality level B data, assuming all other necessary actions are followed, as per the ASCE guidelines (*5*).

Gyroscopic Referencing

Gyroscopic-based pipeline or conduit mapping systems are designed to determine the XYZ location of utilities, but to use a gyroscopic referencing system, there must be an entrance and exit point. In general, these systems are capable of mapping pipes with internal diameters of 2 in. to 48 in. Systems can be tethered to a control unit that stores the data or else the logging data can be stored inside the system with no power or data cable tether (such as required for a robotic camera).

One advantage of such a system is that it is independent of the pipe material. EM sondes may not be effective in metal pipe because a signal may not be broadcast beyond the metal pipe barrier. Depth of pipe emplacement can also be a detectability issue with sondes.

The most common way to move the gyroscope through the pipe is a pulling wire. A winch is typically used on runs up to 4,000 ft. On runs over 4,000 ft, other methods of propulsion are often used, such as robots, compressed air, or pumping. The quantity and radii of bends in the pipe or conduit may preclude the gyroscope passing through the pipe.

There is no definitive run length. The achievable length is largely dependent on the shape of the pipe (for example, sharp bends reduce the achievable length) and the mode of propulsion. It is necessary to have available intermediate coordinates for very long runs (similar to the requirements of intelligent pigging applications). Such coordinates might be available at a utility structure to correlate the horizontal positioning. The elevation may be more difficult to access at an intermediate point.

Standard tolerances in X, Y, and Z of 0.25% of distance between known waypoints can be observed. (For example, the tolerance for a 400-ft run is 1 ft, for a 2,000-ft run it is 5 ft, and so forth). Most pipelines can be mapped with a high degree of accuracy by establishing reference points with known geographic coordinates at the start and end of the run and on very long runs at known intervals between the two (http://www.geospatialcorporation.com/technical.html). Performing this work under the direction of a licensed professional may lead to depiction of this data at quality level A at the end points and quality level B for all points between. The judgment of the professional is needed to decide when the X and Y data should not be certified at quality level B but dropped to quality level C due to differences in precision and accuracy values between the beginning and end of the run.

Summary of Record Generation

The state of the art of record generation during utility installation uses a registered professional to survey and certify open-trenched utilities as quality level A data at actual instrument-reading points and described as to accuracy and precision for all interpolated points. Geophysical tracing of a trenchless-emplaced utility and subsequent survey is certified by a registered professional at quality level B. Gyroscopically surveyed data is certified at its end points as quality level A data and described as to accuracy and precision for all interpolated points. However, constructed utilities are rarely referenced to recoverable survey control, described as to accuracy and precision parameters, or certified by a registered professional.

Record Updates

Utilities are exposed for reasons other than initial installation. Typical reasons may include ongoing maintenance activities such as repairs, new service connections, and anode emplacement. Other construction activities in the area (by parties other than the utility owner) may also expose the utilities. Ongoing highway construction and paving repair are two such reasons. Exposed utilities can be surveyed and documented in the same fashion as those undergoing installation.

The current state of the art has a registered professional survey and certify exposed utilities as quality level A data at actual instrument-reading points and described as to accuracy and precision for all interpolated points. However, exposed utilities are rarely documented at all, let alone referenced to recoverable survey control, described as to accuracy and precision parameters, or certified by a registered professional.

Record Maintenance

The maintenance of records is an area of diverse utility and agency practices. Utility owners are usually thought of as the entities required to develop and keep records, but there is no clear mandate on the generation, accuracy, or completeness of those records except in the case of select owners, such as interstate pipeline companies. Other issues include record format, scale, standardization, and centralization.

GIS systems are beginning to address these issues. While early GIS systems had poor positional reference data, an increasing number of systems have positional control that is first- or second-order survey accuracy. Airports, municipalities, and industrial complexes were early proponents of GIS systems that include utility data. Some of these systems are quite robust, with many utility information attributes. Although utility quality levels in accordance with CI/ASCE 38-02 are lacking in most of these systems, notable exceptions include the levels at the Port of Seattle, Raleigh-Durham Airport, and some districts within the Texas DOT.

Permitting systems are one way in which those that control the land can gather and maintain utility information, but permit systems rarely require accurate location information for the utilities. For instance, some state DOTs reference utility permits for new installations by highway mile-marker posts. While this may give an indication that there is a utility in the general area, it does not serve adequately for design purposes. Another problem is that of blanket permits, whereby utility owners are given flexibility in adding, changing, or maintaining their facilities as far as required specific documentation. Other problems include permit retrieval.

Several states are combining GIS and utility-permitting applications. Texas DOT, in conjunction with the Texas Transportation Institute, has developed a GIS-based system to automate the utility-permitting process. This permitting system enables engineering drawings and other supporting documentation, which can include utility-quality-level depiction data, to be uploaded, and the uploaded documents to be converted into PDF files. GIS-based visualization of permitted sites, such as a map, a system to track permits through the approval process, and notification and reporting capabilities are also enabled.

The system's goal is to eventually provide a comprehensive inventory of utilities within the Texas DOT right-of-way. Controlling data on new utilities is the first step. Adding data on existing utilities can occur on a project-by-project basis.

The Pennsylvania one-call system has begun collecting utility data in addition to providing excavation notices to utility owners. The intent is to provide a secure repository for, and a point of access to, subsurface utility engineering data, received from project owners, to the affected facility owner. The system requires that each owner of a project valued at more than $400,000 provide to the one-call system utility information at the appropriate quality level. It is yet to be determined how utility relocations and new utilities constructed during or after the project are to be added to this repository. To date, no data has been furnished while data compatibility, formatting, and other issues are under discussion.

State DOTs generally control the utilities in their rights-of-way. This control could include requiring utility owners to furnish accurate and comprehensive information regarding the location and character of their utilities to the DOT in exchange for the privilege of occupying that right-of-way. The permit process must include standardized data attributes and formatting.

The state of the art allows public agencies use of GIS to inventory utilities within the right-of-way. Project maps are appended or utility reference files are directly added to GIS layers. Permits require utility owners to provide record drawings in specific formats. In practice, however, there is typically no centralized utility records database, and existing utility information from project plans is not readily retrievable.

References

1. National Research Council. *Seeing into the Earth: Noninvasive Characterization of the Shallow Subsurface for Environmental and Engineering Applications*. National Research Council, Washington, D.C., 2000, 148 pp.
2. Butler, D. K. Potential Fields Methods for Location of Unexploded Ordnance. *The Leading Edge*, Vol. 20, No. 8, Aug. 2001, pp. 890–895.
3. *Airport Business Magazine*, June 2006.
4. Ashdown, C. Mains Location Equipment: A State of the Art Review and Future Research Needs—Final Report. UKWIR 01/WM/06/1. United Kingdom Water Industry Research, 2001, p. 39.
5. American Society of Civil Engineers. *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data*. ASCE Standard No. CI/ASCE 38-02, ASCE, Reston, Va., 2002, 20 pp.

CHAPTER 5

Utility Characterization Technologies

Introduction

"Utility characterization" is the determination of a utility's characteristics other than its location. These characteristics include the type of utility, the type of material it is made of, owner, size, age, pressure, voltage, capacity, condition, and usage status, which is to say whether it is inactive, abandoned, out of service, or active. A utility's condition can be further subdivided into its cathodic state for metallic utilities, its pipe-wall thickness, its internal and external corrosion, its wrapping and coating integrity, and its physical condition, including breaks, tears, and gouges. Within the locating industry there is no standard governing the collection of this type of data, nor is there a standard among, or within, various utility agencies. For transportation agencies trying to identify existing and potential utility problems for routine management purposes or for new-project planning, this means that the characterization data that is sought should be clearly detailed in any scope of work to ensure that the appropriate data is, in fact, collected. Currently, the greatest advances in characterization technology and analysis probably have to do with oil and gas pipelines, which must be regularly inspected, and for which the Pipeline and Hazardous Materials Safety Administration (PHMSA) or related agencies have established reporting standards to avoid pipeline failures and to implement effective life-cycle management practices.

Existing records are the easiest and probably the most accurate way to determine much of the basic information about a utility. With the exception of information on a utility's current condition and use, most of its characteristics may be included in the original utility record. The record may then be amended as utility sections are replaced, moved, repaired, or abandoned. Even the utility's current condition could potentially be inferred from repair, maintenance, age, or material-type records. Existing records may reveal a utility's age, although forensic techniques that analyze manufacturing variations and property data may also establish a utility's origin and age. In short, because records may be lost, unavailable, or translated to a different medium or may exclude appropriate characterization data, other methods must be available to augment records in determining the characteristics for utilities. A description of some of these methods follows.

An exposed utility offers direct access to determine many of the utility's characteristics. The utility type, material type, encasement type, size, condition, voltage, pipe-wall thickness, and number of wires or conduits can all be directly observed, inferred, or measured with appropriate instruments. Instrumentation may be used to infer whether the utility is inactive, abandoned, or out of service, but usually the utility owner must definitively confirm this through a physical inspection, such as by tapping on the pipe.

Internal inspections, such as in-line inspection, can also be useful for determining some pipeline characteristics, such as pipe material, pipe geometry, pipe wall condition, leakage areas, and obstructions to flow. Inside the utility, cameras can be used for visual observation, lasers for interior pipe-wall surface distance measurements, and a variety of internal geophysical methods for determining pipe-wall thickness, corrosion, and exterior surface condition. Although external inspection of an exposed utility allows these determinations to be made, internal inspection allows for a continuous, less-intrusive means of characterizing many aspects of the utility. Internal inspection requires access from one or both ends of a utility section. The pipe's size and condition, the presence of bends, a lack of access, and health issues may preclude internal inspection using some or all of the available methods. However, an internal inspection's most important feature is that it can be part of an unobtrusive and ongoing utility asset management practice that tracks utility performance and condition data. Such data, when effectively used, minimizes unexpected failures and allows for the most cost-effective life-cycle management decisions to be made about the timing and extent of utility repair and replacement. Effective decisions about whether to repair or replace utilities can be made during the planning and design process for new transportation projects when such data is available and being used.

Surface geophysical methods, many similar to or the same as those described in chapter 4, may be effective for some characterizations. In some cases, utility type, material, and some aspects of condition can be inferred using these methods, although the conditions under which such inferences can be made from surface-based surveys are limited and specific.

What follows are details on some surface geophysical characterization methods that may be used, either through the utility's direct exposure or through internal inspection.

Determining Characteristics from Physical Inspection

General Characteristics

Ownership

Ownership cannot generally be inferred directly from a physical inspection unless an ownership tagging or identification system was used during construction or repair. Examples of such systems include colored pipes or colored markers for different utility systems (a standard color scheme is now in widespread use) or physically imprinted markings along the pipe system at selected intervals or at various appurtenances. Older piping systems often are less easily identifiable. There is also the possibility that ownership or some other aspect of the system has changed since a physical marker was installed. Ownership of a site-identified utility is typically determined through a comparison with utility map records or through detective work to identify the utility and contact potential utility companies for a positive identification. From a surface survey, only the newer types of utility-marking systems, such as marker balls and radio frequency identification (RFID) tagging, offer the desired information quality.

Type of Utility

When a previously undetected pipe or cable is discovered on site, it is important to determine its purpose to help identify its owner and the potential risks of working around it. For some pipes or cables, the pipe's color coding, markings, or material will help in identifying its purpose. For example, a clay pipe is principally for sanitary sewer or drainage purposes. For pipes made from steel, cast iron, or other material, or for unmarked cables or cable ducts, additional investigation may be required to determine whether the pipe carries water, gas, or oil or whether the cable carries electricity, data signals, or optical fiber transmissions. Some determinations are fairly easily made in the field once the pipe or cable is exposed. For instance, a live electric conductor can be identified by its electromagnetic (EM) field; the absence of metal in a cable would indicate a fiber optic cable with no metal sheathing. A gas pipe may have detectable leakage from pipe joints or other defects. If a pipe can be traced to an identifiable appurtenance, such as a valve or hydrant, then the nature of the pipe can be established. There is no consistent means to identify the utility type from a surface survey without the use of utility-marking systems, except in the case of electric cables. If it is urgent that a previously unknown pipe be identified, then a small hole may be drilled into the pipe to determine the type of fluid or gas carried. It is more difficult to identify abandoned or temporarily unused utilities.

Usage Status

Determining whether a utility is in use, inactive, out of service, or abandoned follows steps similar to those used to determine the utility type or owner, as previously discussed. An active EM field created by a live conductor or the presence of noise or vibrations caused by a flowing liquid within a pipe may indicate that the utility is live. Determining whether a utility is abandoned, out of service, or simply inactive, however, may be impossible. Thus, to ensure safety, utilities should be considered live until proven otherwise. In most cases, it is necessary to identify the utility owner to confirm a utility's usage status because surface surveys may give incorrect usage status information. For instance, a field marker may not have been updated to reflect a change in the utility's status.

Physical Characteristics

Utility Size and Material

A utility's size and materials may be readily determined once the pipe or cable has been physically exposed. In some cases, inferences about pipe size and material may be made using some of the utility locating approaches described in the previous chapter. However, precise size measurements and differences between relatively similar materials, such as steel and cast iron or clay and unreinforced concrete, are not possible using the locating equipment currently available. Remember that many utilities are not consistent in the types of material used along its length, that sections may be replaced with different materials, and that repairs may alter the utility's local diameter and other characteristics.

Flow Characteristics

It is generally important to ascertain the flow characteristics of a buried utility to assess construction risk or design for any planned relocation. Flow characteristics for electrical conductors mean the cable's voltage, whether there is alternating or direct current, and the number of phases used. For piping systems, this means the pipe's operating pressure, any expected pressure fluctuations, and the pipe's flow capacity and velocity. For gravity systems, the pipe gradient is critical, and it is important to know whether the system is likely to be surcharged at intervals (that is, operate temporarily under pressure). Among the pipe characteristics, it is important to know the pipe's maximum allowable operating pressure (MAOP) adjusted to the pipe's current structural condition. The characteristics of electrical conductors are more easily measured in the field than those of other utility types, especially if the electrical conductor can be encircled. If the pipe is fully exposed, water flow can be measured nondestructively using special equipment. For instance, to determine fluid or gas pressure, pipe tapping can be used. In general, however, external inspection or surface survey cannot determine a utility's actual-flow and design-flow characteristics. The utility owner must be contacted for this information. The availability of utility failure statistics, such as water-line breaks, and past-condition survey information may be important to establish the adequacy of a line that is to be buried beneath a new roadway. Such information could also be incorporated into updatable electronic-marking systems, such as the RFID tagging discussed earlier.

Age and Condition

Although a pipe's or cable's approximate age may be established by looking at the particular characteristics of its materials or the method of its installation, in general, utility records must be used to establish age. Some aspects of a utility's condition may be established visually through an external inspection of an exposed pipe section. For instance, a visual inspection may detect a utility's cathodic state, any damage to the cable jackets or pipe coatings, any pipe breaks, splits, or gouges, any external corrosion and pitting, or any delamination. However, hidden damage or deterioration, such as corrosion within a pipe or a fault within a cable, may be impossible to visually determine. Technologies for determining some aspects of a pipe or cable condition remotely or without involving destruction are described in the next section. For cables, most techniques involve fault-tracing techniques that isolate sections of cable for integrity testing. For buried pipes, most techniques involve internal inspection systems, with confirmation through localized excavation and inspection. When a pipe is exposed, some of the same techniques used to examine a pipe from within can be used to examine it from the outside, looking inward through the pipe wall. A particular disadvantage of the external inspection process is that it is either localized to the test-pit points at which the pipe is exposed, or else entire pipeline sections must be exposed to gain complete coverage. Because deterioration is often not uniform along a pipe's length, localized observation provides only part of the picture of a pipe's condition.

Some aspects of pipe continuity (for example, deteriorated joints in conductive pipes) may be able to be determined using EM tracing surveys, as discussed in chapter 4. However, surface-based surveys in general can provide very little information that is helpful in determining the age and condition of buried utilities.

Inspection of Oil and Gas Pipelines

Increasingly, public-safety concerns regarding oil and gas pipelines have encouraged or required the development of improved integrity management programs. These programs aim to prevent structural integrity problems, especially those that damage public safety, business operations, or the environment. To operate such a program, the physical condition of a pipeline must be evaluated using various combinations of internal inspection, hydrostatic pressure testing, and direct assessment. Because of the risk to the public and the cost of the pipelines, inspection techniques for oil and gas pipelines are well advanced and are the subject of continuing research. For the most part, the techniques apply to larger diameter steel pipelines with a minimum of bends, but they present a good starting point for the review of general pipeline inspection technologies.

Internal Inspection

In an in-line inspection, a high-tech device known as a smart or intelligent pig is inserted into the pipeline and is propelled by the flowing medium. This smart pig records certain physical data about the pipeline, such as locations of reduced pipe wall thickness, dents, and so forth, as it moves through the pipeline. The ability of smart pigs to find corrosion flaws larger than a certain size makes them extremely valuable for finding flaws before they become critical and cause pipeline failure, either through leak or rupture. Baseline surveys, which are run immediately after pipeline installation, not only identify problems associated with the installation but also serve as reference points for comparison with later surveys to project the pipeline's deterioration over time as a result of factors such as corrosion.

Since their invention in 1964, smart pigs have undergone several generations of technological advancement. There are now four types of specialized pigs that focus on metal loss inspection, crack inspection, geometry inspection, and mapping, respectively.

Metal Loss Inspections

Metal loss in a pipe wall is generally caused by internal or external corrosion, which can be detected through magnetic flux leakage and ultrasonic techniques.

Magnetic Flux Leakage. The magnetic flux leakage (MFL) tool induces a magnetic field in the pipe and records magnetic flux anomalies as it travels along the pipeline. The recorded magnetic flux anomalies are converted to information concerning metal loss, including its length and maximum pit depth, which allows for subsequent calculations, using American Society of Mechanical Engineers (ASME) guidelines (*1*), to determine the pipe's remaining strength. The technique is popular because it is relatively inexpensive and is well understood.

There are two types of these tools, high-resolution MFL and standard-resolution MFL. The main difference between the two is in the number of sensors and the level of resolution. The high-resolution MFL tool is typically capable of readily detecting corrosion pits with a diameter greater than three times the wall thickness. Once pits are detected, these tools can typically assess the depth of the corrosion within ±10% of the wall thickness with an 80% level of confidence.

Transverse magnetic flux leakage tools have been developed to detect longitudinally long and narrow flaws, such as selective seam corrosions and axial gouges. This kind of tool is similar to the longitudinal MFL tool mentioned earlier; however, the induced magnetic field is in a transverse direction, perpendicular to the longitudinal axis of the pipeline.

Ultrasonic Tools. Ultrasonic transducers, also called "UT tools," use large arrays of ultrasonic transducers to send and receive sound waves that travel through the wall thickness, permitting a detailed mapping of the pipe wall. UT tools can indicate whether the wall loss is internal or external. The typical resolution of a UT tool is ±10% of the pipe wall thickness with an 80% level of confidence.

UT tools are typically used in liquid pipelines, such as those carrying crude oil or gasoline, because the liquid in the pipeline acts as the required coupling medium for the ultrasonic sensors. In gas lines, the tool can be run within a batch of liquid sent through the pipeline.

Crack Detection Tools

Crack detection is the most challenging task among internal inspection technologies. In the past, no tools were available for this task; hence, the available tools are fairly new and represent still-developing technologies.

Ultrasonic Crack Detection Tools. In contrast to the ultrasonic metal loss inspection, in which compression waves propagate straight through the wall, the ultrasonic crack detection tool is based on a 45° shear wave generated by the angular incidence of ultrasonic pulses through the liquid coupling medium (such as crude oil). A dense array of sensors is the key to providing high resolution with good discrimination during inspection.

The tool's limitation for gas pipelines is the coupling medium required for the ultrasonic sensors. To improve the performance and cost-effectiveness of the ultrasonic tool, the Gas Technology Institute is developing gas-coupled ultrasonics as an accurate, commercially available gas-pipeline inspection method.

Elastic Wave Tools. The elastic wave tool uses a liquid-filled wheel to inject ultrasound in a circumferential direction to detect and measure cracks and stress corrosion cracking (SCC) in the gas pipeline. It can detect cracks deeper than 25% of the wall thickness and more than 2-in. long. It has also proven useful in detecting coating disbondment. Although the elastic wave vehicle finds SCC occurrences, it also presents too many false positives.

Electromagnetic Acoustic Transducer Tools. Electromagnetic acoustic transducer (EMAT) tools generate ultrasonic waves within the pipe wall but do not need to contact the pipe wall to do so. EMAT pigs send the ultrasonic waves around the circumference of the pipe to detect and size cracks. False positives may also be a problem with EMAT inspections.

Geometry Inspection

Geometric inspections gather information about the physical shape, or geometry, of a pipeline. These tools identify any possible obstructions in the pipe and confirm a free passage for any other tool. They are primarily used to find "outside force damage," or dents, in the pipeline. Dents or other geometric compromises of the pipeline shape may be due to physical contact, stress, or deformation induced by improper installation, erosion, or shifting of the substrate. Dents can affect the strength and performance of the pipeline and may result in damage to critical interior or exterior protective coatings.

The two main types of geometry tools available use the same principle. The simplest geometry inspection tool, called a caliper tool, uses a set of mechanical fingers or arms that ride against the internal surface of the pipe or that use electromagnetic methods to detect variations in pipe diameter. Advanced deformation tools operate in the same manner as a caliper tool, but they also use gyroscopes to provide the o'clock position of the pipe's dent or deformation. These tools can also generally provide a detailed 3-D geometric survey of the pipeline alignment, which allows the interior curvature to be mapped to help analyze stress.

Mapping Tools

A mapping tool incorporates an inertial navigation system, similar to that used to guide missiles, to determine horizontal position and altitude of the tool along its trajectory. Actual geographic coordinates of pipeline's route are calculated by establishing GPS control points along the pipeline and then tying the inertial data to these points.

This tool can be used in conjunction with the other tools described earlier to more accurately find anomalies in metal loss, cracks, and geometry inspection. Without an inertial navigation system, inspection pigs rely on an odometer mounted on them, which is usually accurate to within 2.64 ft/mile of pipe traveled. Some location systems use simple electromagnetic transmissions sent to handheld receivers aboveground.

While specialized inspection technologies for metal loss, crack detection, cross-section geometry, and pipeline mapping are individually well developed, using some or all of them together can compensate for the weaknesses of any one method. Such combinations offer the greatest potential when inspecting pipelines for anomalies, which can be identified and sized using more than one method. Using tools in combination is also a better solution for pipeline operators because it provides complete pipeline integrity data at optimum cost.

Hydrostatic Testing

The hydrostatic test establishes the pressure-carrying capacity of a pipeline, and it may help identify significant defects that could approach critical size at operational pressures. The pipeline must be pressured to at least 125% of the MAOP to provide an adequate margin between the test pressure and the operating pressure. If there is a near-critical defect at or below MAOP, that defect will cause a pipeline failure when pressurized above the MAOP.

Hydrostatic testing is used to commission a pipeline for initial service and as a criterion for qualifying a pipeline for return to service. Hydrostatic tests are also the preferred integrity assessment method when the pipeline is not capable of being internally inspected, or if defects are suspected that may not be detectable by internal inspections. Axial flaws such as stress corrosion cracking, longitudinal seam cracking, selective seam corrosion, long narrow axial (channel) corrosion, and axial gouges are difficult to detect with internal inspection and are better detected with a hydrostatic test.

If hydrostatic testing is used as the primary defense against pipeline failure, it is essential to establish a proper hydrostatic test interval. The interval must be equal to the time required for a defect to grow from a size that just passes the hydrostatic test (125% of MAOP) to a size that is critical at operating pressure.

However, hydrostatic testing cannot provide information about the extent or severity of the remaining damage. Furthermore, hydrostatic testing requires the acquisition of large quantities of test water, which in some areas may be difficult. Once used, the test water may contain trace quantities of petroleum products, requiring that the water be treated before it is disposed of or discharged. Finally, hydrostatic testing requires that the pipeline be out of service for a period of time, thus potentially curtailing the availability of gasoline, jet fuel, diesel fuel, crude oil, or home-heating oil at the delivery point.

Direct Assessment (External)

Current internal inspection technologies or hydrostatic testing may not be suitable, or cost-effective, on certain transmission systems. For example, some pipelines cannot be inspected by smart pigs or cannot be removed from service for hydrostatic testing. Direct assessment techniques can be used for such pipelines because the techniques do not impede pipeline operation.

Direct assessment is a structured process. It uses various aboveground surveys and prior experience to predict where corrosion will or may occur, and then field measurements and monitoring are undertaken to determine the condition of the pipe at these sites. Often, a dig program is used for verifying the condition of the coating and the pipe. Based on the field verifications, additional feedback is received to tune various assessment approaches for the pipeline, to further predict where similar conditions may exist that are conducive to such corrosion, and to perform additional field verification.

Direct assessment has been developed for oil and gas transmission pipelines to deal with certain types of general external corrosion direct assessment (ECDA), internal corrosion direct assessment (ICDA), and a very specialized external corrosion called stress corrosion cracking direct assessment (SCCDA).

External Corrosion Direct Assessment

External corrosion direct assessment (ECDA) addresses general external corrosion caused by a lack of protective coating, usually from certain types of holes in the external coating of pipelines. These holes are normally associated with coating penetrations from rocks, poor pipe installation quality, coating deterioration with time, and many types of third-party damage, such as excavations.

Coating disbonding, resulting from loss of adhesion between the external coating and the outer pipe wall surface, is rarely detected through ECDA, because the nonconductive coating shields the passing current. Coating disbonding creates gaps where the cathodic protective current cannot reach the pipe surface, and reactants may accumulate and foster corrosion.

Internal Corrosion Direct Assessment

Internal corrosion direct assessment (ICDA) attempts to address internal corrosion on gas transmission pipelines that normally operate as a dry-gas service, and it assumes that the presence of an electrolyte (water) serves as the driving mechanism for this general internal corrosion. ICDA rests on the principle that the electrolyte settles out, or drains, on the inner lower surface of a pipe whenever a certain critical angle of inclination is exceeded for a specific gas flow velocity. In determining the critical angle of inclination, the model defined in GRI Report 02-0057, "Internal Corrosion Direct Assessment of Gas Transmission Pipelines—Methodology," or a demonstrated equivalent model could be used (*2*).

However, the use of ICDA does not exclude wet-gas operations that can generate higher risks of failure from internal corrosion (especially for pipelines that don't use an effective cleaning pig/analysis program).

Stress Corrosion Cracking Direct Assessment

Stress corrosion cracking (SCC) is a selective external corrosion attack resulting from a combination of disbonded coating, tensile stress, and certain environmental factors. There are two types of SCC on the outer surface of a pipeline, "high pH" and "near neutral." Industry-recommended practices for stress corrosion cracking direct assessment (SCCDA) are under development as the current B31.8S largely focuses on high pH SCC factors and recommends hydrostatic testing if SCC has gone to failure.

The aboveground tools used in direct assessment are introduced in the paragraphs that follow. These tools are expected to have functions such as measurement of the insulation characteristics of coatings, survey of the level of cathodic potential (CP), location of a coating defect, and evaluation of the area of a coating defect (typically referred to as a "holiday"). The following are types of SCCDA surveys:

- *Close-Interval Surveys:* Close-interval surveys are typically used to determine CP levels along a pipeline, shorts to other structures, and stray current areas. However, they are limited in detecting small coating holidays.
- *AC Current Attenuation Surveys:* These surveys are typically used to assess coating quality and to detect and compare discrete coating anomalies. This technique does not require electrical contact with the soil and can often be used to gather information through magnetically transparent covers, such as soil, ice, water, and concrete.
- *Direct Current or Alternating Current Voltage Gradient Surveys:* Direct current or alternating current voltage gradient (DCVG or ACVG) surveys are typically used to detect small to large holidays. They are sometimes used to determine whether a region is anodic or cathodic, but they cannot determine CP levels. Small, isolated coating holidays associated with corrosion or third-party damage can sometimes be found when survey crews are specifically asked to investigate small indications that ordinarily are considered inconsequential.
- *Pearson Surveys:* These surveys are typically used to detect various coating holidays, but they cannot differentiate the size of each holiday. The technique employs an AC signal injected onto the pipeline and compares the potential gradient along the pipeline between two mobile earth contacts. At coating defects, voltage-gradient increases occur, which are noted and recorded on record sheets as the survey progresses.

Generally, two or more tools are recommended in implementing a direct assessment program. In a dig program, metal loss or cracks in the pipe can be found by such ordinary nondestructive evaluation techniques as ultrasonic, magnetic powders, and so forth. The guided wave method is also a choice to inspect defects in the pipe over a limited length.

Summary for Oil and Gas Pipelines

The current state of the art in oil- and gas-pipeline inspection technology has provided much of the information and data necessary to develop a rational, cost-effective strategy for pipeline integrity management. Currently, a wide range of tools have been designed and are well developed for internal inspection, direct assessment, and hydrostatic testing. The features of each method should be considered in conducting an assessment program, depending on the condition of the actual pipeline in question. The selection of appropriate yet cost-effective methods is still widely considered more art than science.

Nondestructive Inspection Tools for Utility Piping

As discussed in the introduction to this chapter, nondestructive inspection tools for buried pipes are principally deployed within the buried pipes, since only localized excavations are practical to allow for external inspection. Many of the techniques described, however, can be adapted for use on an exposed pipe's exterior. Cable inspection systems are only briefly described because fault location and condition assessment are carried out by the utility owner, who taps into the conductor at various points and propagates signals along individual cables or fibers. The discussions that follow on nondestructive pipe inspection tools are not applicable to all types of underground piping systems. As also mentioned in the introduction to this chapter, pipe material, access limitations, pipe bends, and pipe internal diameter limit the techniques that may be used. An overarching issue is matching the level and frequency of inspection to the risk posed by the utility type and the value derived from regularly knowing the utility's condition. In more direct terms, the techniques appropriate for determining the condition of a long, relatively straight, large-diameter steel pipeline carrying high-pressure natural gas may have little in common with the techniques and equipment appropriate for monitoring small-diameter water distribution piping or sewer collection piping. The available financial resources, the risks posed by potential failure, and the pipe materials or configurations make each application quite distinct.

Visual Inspection

Closed-Circuit Television

There is a wide variety of camera systems for the visual inspection of the interior of pipes or pipelines—ranging from very small-diameter pipes in a boiler heat exchanger to person-entry-size pipes in areas inaccessible for direct inspection. These systems have been in use for many years and can gather data on pipe integrity, size changes, and material changes. The main improvements and innovations in recent years have been in the quality of the images that can be produced through better lighting and high-resolution, digital color imaging; the use of digital video files rather than cumbersome videotapes; and the ability to combine TV inspections with other types of data collection.

Photographic or Laser-Based Scanning Devices

Several manufacturers offer devices that will produce high-resolution images of a pipe wall that can be unwrapped to present the full internal surface of the pipe as a flat surface. From these images, defects can be identified, crack lengths and widths measured, and statistics created about the proportion of defects. From these statistics, or from a simple glance at the visual image, a rapid understanding of the condition of a length of pipe can be gathered. Systems may use a side-scanning laser, or they may simply scan the photographic image collected by a fish-eye lens. A drawback is that the still image does not give as much information about water leakage in a pipe, for example, as a video image, such as closed-circuit television (CCTV), would give. For this reason, in recent systems, still images and CCTV are often combined.

Zoom Cameras

To avoid the time and expense of inserting a CCTV camera system into a drainage pipe, it is sometimes adequate to use a camera that is lowered into the manhole and oriented along the pipe to be inspected. Focused lighting and a high-powered zoom lens provide a quick visual survey of straight sections of pipe that are accessible from the manhole. Debris within the pipe, collapsed sections, protruding lateral taps, and so forth are the types of problems that can be quickly determined.

Pipe Usage Status

Acoustic emission may determine active versus empty water pipes by a nearby means of direct access to the system, such as a fire hydrant. This technique almost always employs resonant sonics and is used mostly to differentiate water systems when more than one water system may be present in an area. This is a very specific application without broad applicability. For the use of acoustic emission in locating water pipes, see the discussion in chapter 4. For acoustic and ultrasonic leak detection, see the section later in this chapter.

Internal Pipe Geometric Measurements

For pipes principally under internal pressure, cross-section changes are usually undetectable from pipe-scanning measurements prior to the pipe's failure. For gravity pipes such as brick sewers that fail principally from external soil loads, visible signs of failure can often be seen as sharp distortions, or major cracks occur, bricks fall out, and so forth. For flexible pipes that are resisting external soil loads, however, the failure generally occurs through a progressive deformation or the "ovaling" of the pipe. When this reaches a critical level, the pipe may suddenly buckle and fail. The extent of ovaling is important to determine the design of pipe-lining systems to rehabilitate the pipe.

Laser-Based Geometric Measurements

Visual inspection is poor at determining such gradual deflections or determining the quantitative amount of ovality in the pipe. For this reason, a number of techniques for assessing the geometry of the pipe's internal surface have been developed. These include rotating laser systems, ring laser systems, and laser point cloud systems.

Such systems are typically mounted on the same types of pipe tractor robots as a CCTV system and may be operated on a sequential basis with a CCTV pipe inspection. Despite some potential difficulties with these systems, they do provide the ability to track the gradual deformation of a pipe over time. In this regard, a major difficulty is ensuring that subsequent passes with the measurement system, perhaps one or two years later, can be accurately registered to the same cross section so that changes over time at that cross section can be determined.

Sonar Inspection

Sonar inspection devices can be used in water-filled pipes in a manner similar to the sonar soundings in lakes and rivers and the ultrasonic inspection methods for a pipe wall. The instrument is immersed in the water, providing it with a good coupling for the sonar signal. The internal shape of the water-filled pipe or the presence of internal debris below the water level may be measured from the reflected signal's time of travel. When the pipe is partially filled, the instrument is typically floated on the water surface, and only the portion of the pipe that is under water can be inspected.

External Pipe Bedding Conditions

Once pipes have been installed in the soil, they are typically constrained to move and settle with the soil or to deform. Ground-induced bending in a pipe may amplify stresses caused by internal pressure or external ground pressure. Likewise, both flexible pipes and rigid pipes can be affected by poor bedding conditions outside of the pipe or by the presence of soil voids over a portion of the perimeter of the pipe. In the case of a flexible pipe, a void or soft bedding on one side of the pipe will cause uneven stress and deformation of the pipe wall. In the case of a rigid pipe, if the pipe fractures, fine soil may wash away or wash into the pipe, creating soil voids. Over time these voids allow sections of fractured pipe to move relative to each other, causing collapse. The voids get larger until a sinkhole occurs when the road surface above the pipe collapses. Such sinkholes are, in fact, a frequent occurrence across the United States.

Thus, an important part of determining the condition of a buried pipe is often also determining the condition of the soil surrounding it and detecting any voids that may have developed.

Some of the surface geophysical techniques discussed in chapter 4 may potentially find reasonably sized soil voids adjacent to pipes. They also have the potential to differentiate pipe backfill in trenches from the natural soil surrounding the trench. When using surface techniques, it is difficult to find small soil voids or weak zones of backfill that are likely to lead to progressive deterioration but that are not distinct enough to be imaged from the surface.

Internal pipe scanning systems, such as ground-penetrating radar (GPR) and ultra-wideband (UWB) pulsed radar systems, can make such determinations, but they are not yet in regular commercial use.

Mechanical Damage to Pipelines

A significant proportion of damage to buried pipelines comes from external mechanical damage caused by inadvertent and often unauthorized excavation in the vicinity of a pipeline. Because of the safety implications of immediate or delayed failures of oil or gas pipelines from this cause, this has been an active area of research funding by the Office of Pipeline Safety (OPS)/PHMSA, both in terms of detecting real-time encroachment and detecting mechanical damage in pipeline surveys. Encroachment detection is not directly of interest to the current report, but the detection of existing mechanical damage can be an important part of utility characterization. Techniques used for the mechanical-damage detection of pipelines were discussed in the previous section on oil and gas pipeline inspection. Some of the techniques discussed in the next section can also be applied to pipe-wall measurements to determine loss of wall thickness due to corrosion.

Pipe-Wall Measurements

Pipe-wall measurement techniques can typically be divided into EM methods that must be applied differently in metallic and nonmetallic pipelines and ultrasonic methods that can be applied to either. Only the techniques that were not discussed for oil and gas pipelines are highlighted here.

Nonlinear Harmonics

The nonlinear harmonics (NLH) method consists of impressing an alternating magnetic field onto magnetic material, such as steel, and sensing the amount of magnetism produced. To do this, a transformer is used to cause a magnetic field to pass through two electrical coils and into the pipe wall. One of the coils is connected to a source of electric current that oscillates thousands of times per second. Because of the nature of the pipe-wall material, the magnetism in the pipe wall does not oscillate with the same pure waveform provided by the electrical source. Instead, its oscillation pattern is distorted so that it contains frequencies that are several times higher than the frequency of the electrical source. The NLH method takes advantage of these higher frequency oscillations, sometimes called the "harmonics of the excitation frequency." A secondary electrical winding on the transformer core responds to the oscillating magnetism and produces an electrical signal that can be filtered to remove the source frequency and retain the harmonics. The amplitudes of these remaining harmonics are considered to be related to the level of stress and strain in the steel pipe wall (*3*).

Magnetic Inductance

Pipe-wall thickness can be measured by pulsing a magnetic inductance coil that is positioned close to the wall and measuring the inductance of the pulsed coil. The distance of the coil from the wall is accurately determined so that the inductance is a measure of the wall thickness. The apparatus may include the combination of an ultrasonic transducer mounted in a fixed position relative to the magnetic pulse coil and arranged so that ultrasonic energy pulses are directed toward the wall. In this manner, reflected ultrasonic pulses will provide a measure of the distance (U.S. Patent 4,418,574).

X-Ray Inspection

Where direct access is limited, X-ray techniques have been applied to measure pipe-wall thickness for pipes covered with insulation. The pipe is exposed to radiation from an X-ray or gamma-ray source. The transmitted radiation is detected by film, or more recently, an imaging plate (*4*). This technique could conceivably be applied internally to a larger diameter pipe, but normally the technique would be applied to an exposed section of pipe.

Ultrasonic Inspection

Ultrasonic thickness gauges use sound waves to measure wall thickness. Different types of materials have different inherent acoustic velocities. For example, the acoustic velocity of steel is 0.2330 in./microsecond and that of aluminum is 0.2500 in./microsecond. Typically, a sample of the material to be tested is required for high-accuracy measurements, although tables exist for common materials. Good coupling of the transmitted and reflected acoustic signal into the measurement device is necessary for good quality measurements. This is difficult to achieve for remote internal pipe inspections in an empty pipe—especially in pipes that are in poor condition or that have internal buildup or debris.

Other Pipe-Scanning Techniques

Ground-Penetrating Radar

Some use has been made of GPR systems in internal pipe inspections. This is only applicable to nonconductive pipes that will allow the signal to propagate through the pipe wall into the surrounding soil. As for the surface-based GPR surveys discussed in chapter 4, differences in materials or the presence of voids will reflect an emitted signal back to a receiver. Continuous wave signals or pulsed signals may be used. The drawback to continuous wave signals is that pipe geometry and other pipe or backfill features can produce signals that are difficult to interpret. Pulsed wave signals tend to produce more easily interpreted signals. However, for both continuous wave and pulsed wave signals, high frequencies or very short wavelength pulses are required to resolve variations in pipe-wall thickness. Fortunately, the necessary high-frequency signals can be used from within a pipe, because the area of interest is within the pipe wall or immediately outside the pipe wall, and signal attenuation is less of a problem. In 2002, the limitations on the power levels versus the frequency spectrum permitted by the FCC for GPR and UWB applications were eased; hence, methods based on the new spectrum limitations are evolving. There are examples of field studies that use within-pipe GPR (*5*, *6*), and a UWB-based pulsed-signal approach is in laboratory testing at Louisiana Tech University (*7*). More methods are generally available for examining steel- or other conductive-walled pipes; thus, GPR approaches for nonconductive pipes are an important area of development.

Surface-based surveys that use GPR may provide generic information about a pipe's or conduit's relative size or shape—depending, of course, on depth and surrounding conditions. Determining material type and other characteristics is usually not possible.

Infrared Measurements

Infrared techniques can be effective for some aspects of utility characterization. The uneven heating or cooling of a pipe wall or a pipe liner can indicate variations in pipe-wall thickness, the bonding of a liner to the pipe wall, the presence of soil voids outside the pipe, and so forth. For differences to be visible, it is necessary have a temperature difference between the inside of the pipe and the surrounding ground. For thick-walled pipe inspection, it may be necessary to first heat or cool the pipes over an extended period of time to get measurable results. However, for thin pipe liners in relatively small pipes, differences in liner bonding can be noted almost immediately using a light bulb as a heat source. The approach can also be applied to steam systems. Steam pipes are almost always insulated, and one aspect of operational efficiency is to gauge the effectiveness of that insulation. External inspection can be done during operation by looking for hot spots along the external surface of the insulation. Internal scans would require draining the system and would look for thermal differences between intact areas of insulation and damaged areas.

Pipe Leakage and Integrity Testing

Smoke Testing

Smoke testing is applied to sections of storm- or sanitary-drainage systems to find leakage points. Sections of the drainage pipe network are isolated and smoke is introduced into the pipe system using fans and a smoke generator. The smoke will exit the pipe network through faulty joints and other leaking or damaged areas and, in many cases, can be observed at the ground surface, indicating the presence and approximate location of a leak. The technique is relatively inexpensive, but it can have a poor success rate, even under good application conditions. The method cannot be used when the water table is above the pipe level. Typically, it is used as a preliminary survey technique to determine major leakage areas in sewers.

Dye and Tracer Testing

Dyes or other tracer elements can be used in pipe networks to trace the connectivity of different pipe sections. Such tracer elements can also be used, under the right conditions, to track leakage out of or into a pipe network. The use of tracers is typically more labor intensive than smoke testing but gives better and more verifiable results. The ability to inject the tracer element at one point or several and observe or measure its arrival at another point or many points in the system is needed.

Pressure Testing

A key aspect of the acceptance process for most pressure pipe systems is some form of pressure testing of the overall system or a segment-by-segment testing protocol. Such pressure testing is also used to gauge the integrity of nonpressure pipe systems, such as storm and sanitary sewer pipe networks. At low pressures and for small-diameter pipes, air pressure can be used for testing, but for large-diameter pipes and for high pressures, a nearly incompressible fluid such as water is used for safety reasons. To find leaks more effectively, the pipe network is typically tested section by section by isolating the section under test from the rest of the pipe network and subjecting it to internal pressure. Depending on the pipe's use, the acceptability criterion may be that it resists pressure at a certain level higher than the maximum allowable operating pressure, or that it has less than a specified pressure drop over a specified period of time. The drawbacks to pressure testing are the length of time required for testing and the need to trace and find leaks if they are present within the section tested. For large-diameter pipes, the volume of water needed for pressure testing also may present challenges. In some cases, localized testing and sealing operations can be carried out from within a pipeline, such as in grouting operations for gravity sanitary sewer lines. In this case, inflatable packers seal off a small section of a pipe, the pressure integrity is checked, and, if it is found lacking, a grout is pumped into the sealed section so that it exits the pipe through the leaking zones and forms a seal around the exterior of the pipe.

Acoustic and Ultrasonic Leak Detection

Both nonaudible and audible methods can be used for leak detection. The methods involve listening for the noise or vibrations that are emitted when a fluid inside a pipe leaks through the pipe wall. Detection can be as simple as using a receiver on the surface to find the maximum amplitude of the signal, which is assumed to be directly over the leak. When two or more measurements are made for a section of pipe, in-pipe methods can estimate the approximate location of the leak. When a traveling receiver is used, in-pipe methods can pinpoint the source of the leak. Systems are also available that use an ultrasonic transmitter inside the pipe and a detector outside.

Pipe-Wall Conductivity Scanning

A relatively new inspection approach known as the focused electrode leak location (FELL) method (*8, 9*) can be used to look for leakage areas in nonconductive pipes. The principle of the technique is that a water leakage path through the pipe wall will greatly increase the conductance between an electrode inside the pipe and a buried electrode outside the pipe. The internal pipe electrode is shielded so that it only responds to leakage points directly opposite the internal electrode position. In a gravity pipe system, the pipe is temporarily filled during passage of the inspection system so that any potential leaks are made active.

Gas Detection

Leaks in gas pipelines can be detected by chemical sensors traversed across the ground surface or, for significant leaks, simply by the odor introduced into the gas. The precise location of such leaks is difficult to determine, however, and more than 500,000 leaks on buried gas distribution piping are incorrectly pinpointed each year, according to the American Water Works Association Research Foundation (AWWARF) (*10*). In 2006, a digital leak-detection research project was funded by AWWARF (Project #4041). A pre-prototype detection unit has been developed and tested by natural-gas and steam-utility crews. Initial trials indicate that detection has improved within a 4-ft excavation window from 66% using existing technology to 100% using the new equipment.

Cable Fault Detection Systems

It is important to know the condition of buried electrical and communication cables and to be able to precisely locate faults in the cable. A number of techniques are available, including those for electrical cables (*11*): Murray loop test, fall of potential test, DC charge and discharge test, induction test, impulse wave echo test, and time domain reflectometry test.

For optical cables, the quality of fiber-optic cable performance depends on attenuation or optical loss and on defects (including faults) that cause reflections or scattering and for which the location can be measured using optical time domain reflectometry.

Combined Inspection Systems

During the passage of an inspection device through a pipe, it can be attractive to make multiple measurements for pipe characterization and condition assessment. The advantages include making the most of the same site mobilization, gaining more information on pipe condition than a single method usually allows, and providing redundant measurements to increase the confidence of the condition assessment. The drawbacks include the increasing complexity and cost of the equipment, which limit the range of contractors available to bid on the work and which require larger-scale jobs to be cost-effective, and whether the range of information that can be collected will in fact be used or needed for effective condition assessment. These issues must be determined on a case-by-case basis, but it is expected that multiplatform inspection systems will become more common as the sensor integration becomes more effective and the costs of such systems drop. Examples of multisensor systems currently available include the following:

- "Smart pigs" used by oil and gas pipeline operators. These may include a variety of sensing devices, depending on the purpose of the survey. The high risks and costs from leaks, government regulation, and the geometry conditions related to many pipelines make smart pigs an attractive inspection option.
- CCTV visual inspection combined with sonar below-water inspection in partially filled pipes can be used when pipes cannot be emptied during inspection.
- CCTV visual inspection combined with laser-based internal pipe geometry measurements make it easier to gauge the continued deformation of pipes under external soil load that is a precursor of collapse problems.
- Multisensor systems that encompass a wide variety of sensors and measurement systems, of which only a few commercial examples exist.

Data- and Asset-Management Systems

Important advances in recent years have been made in the management of utility system data. These advances have been made possible by improvements in computer technology, database and operations management software, GIS software, precise GPS equipment, and wireless cellular or satellite data acquisition systems.

These advances have important implications for the interaction of utility systems with transportation projects because of improvements in utility mapping, recordkeeping, condition assessment, and life-cycle asset management.

Some key areas related to condition assessment are mentioned in the following paragraphs.

Data Management and Display

Most cities and utilities have introduced GISs within their organizations for the management of a wide range of physical and management data. These systems interface with supervisory control and data acquisition (SCADA) systems and wireless monitoring systems, with generalized asset management and maintenance management systems, and with specialized pipeline-inspection data collection software and condition assessment software. When fully implemented, the integration of the systems means that complete maps of a utility system are available in the office or in the field coupled with a full history of maintenance work on a section of a utility and the currently assigned condition of the utility segment. Work orders for repair or maintenance can also be generated directly from the software.

The problems with fully employing the software to define utility locations and conditions are twofold: the pedigree of the data entered into the system is often unknown and it may be inaccurate or incomplete; and there is often a lack of consistency in how physical data is recorded and physical conditions are assessed across work crews from one agency to another.

Nevertheless, these changes represent huge advances in technological capability, and they also provide a platform whereby the accuracy of location and pedigree of information can be readily updated in the future. Guidelines for inspection training and consistent condition assessment also have been developed by several agencies (for example, NASSCO) (*12*).

Prediction of Risk of Failure and Need for Rehabilitation or Replacement

When good records of a utility's characteristics and performance over time are available, it is possible to effectively plan for proactive maintenance, rehabilitation, and replacement that will lower life-cycle costs for the utility. This same information and analysis can guide the decisions that need to be made when a utility is to be left in place beneath a transportation renewal project. Typical factors involved in such decisions include the utility's

- Age;
- Failure history;
- Correlation to location or soil type;
- Correlation among pipes with similar characteristics;
- Condition assessment ratings over time;
- Specific pipe condition attributes over time;
- Cathodic protection level for metal pipelines;
- Risk assessment rating using predictive models; and
- Periodic hydrostatic testing to failure of pipe sections.

Guidelines, Standards, and Regulations for Pipe Inspection and Condition Assessment

Outside the pipeline industry, there are surprisingly few comprehensive guidelines and standards for the inspection, data management, and condition assessment for buried utilities.

Testing and inspection of buried pipelines is discussed in *Piping Systems and Pipeline ASME Code Simplified* (*13*). Procedures and acceptance criteria for various inspection methods can be found in the Boiler and Pressure Vessel Code. Codes are also available for other aspects of piping design, analysis, and management, including the following:

- B31.1 Power piping
- B31.3 Process piping
- B31.4 Pipeline transportation systems for liquid hydrocarbons and other liquids
- B31.5 Refrigeration piping and heat transfer components
- B31.8 Gas transmission and distribution piping systems
- B31.8S Managing system integrity of gas pipelines
- B31.9 Building services piping
- B31.11 Slurry transportation piping systems
- B31G Manual for determining the remaining strength of corroded pipelines

In the municipal sewer sector, there has been a concerted effort over the past several years to standardize the way in which sewer defects are catalogued in condition databases (*14*), and similar efforts have been developed in other utility sectors. Without consistent data collection and interpretation, much of the potential value of condition data in managing maintenance and rehabilitation and making comparisons among systems is lost.

Government regulations also have had some impact outside the pipeline industry. For example, in the sewer sector, the U.S. Environmental Protection Agency developed guidelines for municipalities on how to manage their sewer systems' capacity, management, operations, and maintenance, and the Government Accounting Standards Board developed financial guidelines for updating the asset value of buried infrastructure based on the condition of that infrastructure (*15*).

Summary

There are currently very few aspects of utility characterization data that can be reliably determined from a surface-based utility location or characterization survey. This could change substantially, however, with the introduction of smart marking and tagging systems for utilities. Over time, new utilities would be identified with programmable and updatable electronic markers, and existing utilities could be marked as they are exposed for maintenance or during other excavation activities.

Without the use of smart tags, most characterization data must be obtained from utility records or by physically exposing the utility through access pits or test holes. Utility records may be of variable quality in terms of the accuracy of original information and consistent updating of changes. Even the information that can be attained in a nondestructive manner when the utility is physically exposed is quite limited both in type of data and in extent of the data applicability along the pipeline from a limited exposure.

The most active area of utility-characterization data advances has been in the internal inspection techniques available for pipelines, the development of consistent terminology for pipe defects and pipe condition assessment, and the use of asset management approaches to manage the buried utilities effectively over their life cycles. There has been an equivalent improvement of technology and procedures for the management of electrical and communication cables. Many utilities have readily embraced asset-management approaches and are in a better position to answer questions about utility condition today than they were a decade ago.

One could argue that it is incumbent on utility providers who have been given the right to use the space beneath the public right-of-way to know where their utilities are and to know the characteristics and condition of their utilities so that intelligent decisions can be made about replacement or rehabilitation during transportation renewal projects. While gaps will continue to exist for out-of-service or abandoned utilities, the combination of smart tagging systems and the ongoing asset-management approaches by utilities offer the prospect for a substantial improvement in utility management beneath rights-of-way in the future.

References

1. Manual for Determining the Remaining Strength of Corroded Pipelines, a Supplement to ASME B31 Code for Pressure Piping. American Society Mechanical Engineers Standards, B31G, New York, N.Y., June 1991.
2. Moghissi, O., L. Norris, P. Dusek, B. Cookingham, and N. Sridhar. *Internal Corrosion Direct Assessment of Gas Transmission Pipelines—Methodology.* GRI-02/0057, Gas Research Institute, Des Plaines, Ill., 2002, p. 39.
3. Crouch, A., and G. Chell. Making the "Smart Pig" Smarter. *Technology Today,* Southwest Research Institute, San Antonio, Tex., Fall 2002.
4. Vengrinovich, V. L., Y. Denkevich, S. Zolotarev, A. Kuntsevich, and S. Emelyanenkov. New Technique for Pipes Wall Thickness Assessment Considering Scattering Effect. *Proc., Presented at the 8th ECNDT (European Conference on Nondestructive Testing),* Barcelona, Spain, June 2002.
5. Guy, E. D., J. J. Daniels, and Z. Daniels. Cross-Hole Radar Effectiveness for Coal Mine-Related Subsidence Investigations: Studies Near Discontinuities Imaged Using High-Resolution Seismic Reflection. *Proc., NASTT NO-DIG 2003 Conference,* Las Vegas, Nev., March–April 2003, p. 15.
6. Ariaratnam, S. T., and N. Guercio. In-Pipe Ground Penetrating Radar for Non-Destructive Evaluation of PVC Lined Concrete Pipe. *Solid Mechanics and Its Applications: Advances in Engineering Structures, Mechanics & Construction,* Vol. 140, 2006, pp. 763–772.

7. Jaganathan, A., E. N. Allouche, and N. Simicevic. Pipeline Scanning: Novel Technology for Detection of Voids and Internal Defects in Non-Conductive Buried Pipes. *Proc., ISTT 2006 No-Dig Conference,* Oct. 29–Nov. 11, 2006, Brisbane, Australia.
8. Harris, R. J., and J. Tasello. Sewer Leak Detection—Electro-Scan Adds a New Dimension. Case Study: City of Redding, CA. *Proc., Pipelines 2004 International Conference,* San Diego, Calif., Aug. 2004.
9. Dayananda, D., C. G. Wilmut, and B. J. Dsouza, Effective Identification of Service Line Defects with Electro-Scan Technology. *Proc., Water 2007 Conference,* San Antonio, Tex., March 2007.
10. *Development of a Digital Leak Detector.* Project #4041, until June 2008. American Water Works Association Research Foundation, 2007. http://www.awwarf.org/research.
11. Pabla, A. S. *Electric Power Distribution.* McGraw-Hill Professional, 2005, p. 878.
12. *Pipeline Assessment & Certification Program (PACP) Reference Manual.* National Association of Sewer Service Companies, Owings Mills, Md., 2001, p. 257.
13. Ellenberger, J. P. Piping Systems and Pipeline. *ASME Code Simplified,* McGraw-Hill, 2005, p. 268.
14. *Pipeline Assessment and Certification Program (PACP) Standard Database.* National Association of Sewer Service Companies, Owings Mills, Md., 2004.
15. Government Accounting Standards Board. Statement 34 Resource Center at http://1172.3.167.244/repmodel/other_pubs&resources.html.

CHAPTER 6

Targeting Improvements

Introduction

Thus far, the report has described the administrative and technical landscape within which utility locating and characterization efforts must operate. The focus of this chapter is on identifying how SHRP 2 could best encourage and accelerate actions related to improving technological performance and developing systems, procedures, and funding or time allowances that permit the technology to make a significant difference in the planning, design, and construction of highway renewal projects.

Recommendations must necessarily take into consideration the expected time frame within which the investment's effect will be realized. For example, some administrative and procedural changes could be rapidly implemented, particularly when they are backed by administrative order or legislation. The adoption of some market-ready technologies could also be accelerated to within a few years' time, whereas other longer-term technical developments and recordkeeping or mapping-technology changes could take decades for a full, nationwide implementation. This report takes into consideration the relatively short-term, targeted research mandate imposed by Congress on SHRP 2. Thus, this report's recommendations target those areas for improvement that could potentially demonstrate a change in practice within 5 to 10 years. This does not mean, for instance, that the tagging and mapping of all underground utilities will have migrated to a new technology within 10 years, but rather that, for the foreseeable future, expectations are optimistic that a working system could be operational within 10 years. It could serve as a model for extension to other areas and provide a commercially available system that DOTs and other agencies across the nation could adopt. Another stated SHRP 2 research program goal is to avoid duplication of similar efforts. Hence, research efforts in progress in North America and worldwide influence the selection of which research avenues to pursue.

Utility issues are not just an afterthought to transportation project plans that need proper management. They are an increasingly important cost and schedule determinant. Despite present-day application difficulties and physical limitations, utility locating and characterization technologies may, in the mid to long term, improve in performance and in their ability to integrate into practice.

Revisiting an analogy made in chapter 4, billions of dollars have been invested in medical imaging technologies to diagnose problems and guide invasive surgery, and the results have been spectacular. Yet, the equivalent utility-imaging R&D efforts, which tackle challenges that are arguably even more difficult than those faced by medical imaging, currently encounter less funding and a narrower body of research than those for medical imaging.

This report's recommendations are grouped in four categories, although there is some overlap. These categories, which encompass technological and practical improvements, follow: utility locating through geophysical means, utility characterization, mapping and recordkeeping, and education and training.

Implications from Case History Reviews

As part of the current research-planning effort, case histories were collected and reviewed for utility-damage incidents and for utility-detection procedures that were adopted for various projects. The case histories were compiled into an electronic database, but only the case histories for utility detection and location processes and their outcomes are included in Appendix B. They come from a University of Toronto report (*1*), information compiled by SUE providers (*2*), a Penn State University report for PennDOT (*3*), and numerous individual cases published in literature, such as conference papers, project reports, and vendor-provided technical materials. In many cases, information was combined from several sources to form a single case-history description. This section discusses the implications of the case histories on utility locating technologies and procedures that were examined.

A utility strike occurs nearly every minute somewhere in the U.S. (*4, 5*). Although most utility strikes result in minimal local damage, many others result in fatalities, injuries, significant collateral damage, or all of these. The cost of repairing the damaged utility is often overshadowed by costs associated with a) disruption of services, traffic, and normal life patterns; b) project delays; c) contractor claims; and d) litigation. The latter three are associated not only with utility strikes but also with near-miss events when utilities that are poorly marked or that were previously unknown are discovered during construction. The circumstances of the strike and the adequacy of the response could play as great a role as that of the utility type in determining the extent of the damage and loss incurred as a result of the accident. Observations also include the following: a) some contractors appear to place productivity ahead of regard for existing utilities, and such projects are often characterized by multiple utility strikes; b) fading or erased paint marks more than once appear to be a cause in the cases reviewed, suggesting a need for improved marking technologies or procedures; and c) in some countries, utility companies and municipalities are compensating users for indirect damage and loss.

Subsurface utility engineering (SUE) mapping surveys consistently seem to positively affect the outcome when performed ahead of construction projects. It is not uncommon that agencies are driven to begin using SUE following one or more projects that went poorly because of multiple utility conflicts, serious utility-related accidents, or a combination thereof. From a review of the case studies compiled in Appendix B, it appears that conducting a quality level B mapping effort when design is about 30% completed has been effective, achieving a balance between design-detail availability and the redesign effort that, according to the updated utility location data, is needed. Current risk-management thought, such as is found in the policies of Virginia and Washington DOTs, is that SUE mapping surveys should be advanced to the 0% to 10% stage for even greater benefits. The benefit-to-cost ratio to project owners in the cases described in Appendix B ranged between 2 to 1 and 60 to 1, while the cost of the study ranged between 0.125% and 2% of the total project budget. These values are in line with a report published by Purdue University (*6*), in which a study of 71 projects suggested an average benefit-to-cost ratio of 4.6 to 1. The additional costs associated with quality level B and quality level A SUE investigation were reported to be about 0.5% of the total construction costs. Other published studies indicate even higher rates of return, including the Virginia DOT study (7 to 1), Maryland DOT study (18 to 1), and the Society of American Value Engineers study (10 to 1). A recently published study by Penn State University for PENNDOT found a 22-to-1 cost ratio when it looked at 10 randomly selected PENNDOT projects (www.fhwa.dot.gov/programadmin/pus.cfm).

It is important to note that in all cases only construction-cost and schedule-delay savings were considered. Costs associated with possible utility strikes and other qualitative measures—that is to say, the cost to road users—were not considered due to uncertainty associated with the parameters involved. The older and more developed the area where construction is scheduled to take place, the greater the benefit-to-cost potential; also, the larger the scope of the project, the greater the benefit-to-cost ratio and the smaller the SUE investment as a percentage of the total budget. The cost of a SUE investigation increases with the quality level. Thus, all four investigation stages are usually employed systematically to maximize the benefit-to-cost ratio for this effort; for instance, eliminating utility designation from a SUE study could significantly reduce the effectiveness of the test-hole program.

In summary, SUE is a viable engineering practice that reduces risk-related project costs that are associated with subsurface utilities. SUE is most effective when adopted by an agency in a systematic manner and introduced early in the design stage. The greater a designer's familiarity with valuable SUE data and with the ways in which this data can support the optimization of the design, the higher the agency's monetary return. What becomes of SUE data at the conclusion of a project is a matter that remains to be addressed. In most cases, after its intended use, much of the SUE data that has been collected is effectively lost. The benefit-cost ratio of quality level B and quality level A SUE data could increase if such data were transferred into one or more common databases and archived by the sponsoring agency to support future planning and design activities.

Recent Study Recommendations

Safety-, disruption-, and cost-related concerns surrounding damage to buried utilities and pipelines have escalated in recent years, leading to initiatives and studies addressing utility damage prevention and utility locating technologies. In the local utilities sector, the relationship of utility characterization technologies to condition assessment and asset management has received the most attention recently. In the pipeline sector, the emphasis has been on inspection methodologies for pipeline condition and on the safety and monitoring of unauthorized pipeline intrusion. Some of the more authoritative reports and their recommendations are summarized in the following paragraphs to offer background and further support for the recommendations made in this report.

National Research Council Report: *Seeing into the Earth*

A National Research Council (NRC) Committee of the Board on Earth Sciences and Resources was formed in 1995 with the specific tasks of (1) assessing current capabilities for characterizing the near-surface environment using noninvasive technologies, (2) identifying weak links in current capabilities, and (3) recommending research and development to fill these gaps. NRC committees are carefully assembled on the basis of individual expertise and a collective balance of viewpoints; hence, their recommendations carry significant weight. In the committee's examination of R&D efforts, it looked at recommendations to address why available and adequate methods for undertaking many tasks are not being practiced more widely. The committee's research recommendations are as follows (*7*):

- Scientists and engineers should improve the integration of multidisciplinary data for modeling, visualizing, and understanding the subsurface.
- Government agencies should be encouraged to increase their investments in near-surface characterization R&D in areas appropriate to the mission of each agency.
- Government and industry should cooperatively investigate coordination mechanisms and support site-characterization research and development.
- R&D efforts applied to automation of data acquisition, data processing, and decision making should be given a high priority for research funding because they could produce rapid improvement in all aspects of near-surface characterization.
- Where monitoring is required, noninvasive measurements taken over a prolonged time period should be investigated as a possible monitoring method for site characterization, underground construction, and remediation projects.
- A basic research program should include a significant effort directed toward quantifying physical and chemical realities of what is sensed and toward possible interactions between in situ properties and processes.
- Long-term research to develop new noninvasive tools and techniques should be given a high priority, with emphasis on research done by multidisciplinary teams.

Many of these recommendations focus on near-surface geotechnical or geoenvironmental investigations rather than specifically on utility locating. However, the importance of this topic, the need for expanded R&D, the need to involve mission agencies, and the committee's recommendation to emphasize multidisciplinary teams mirror this report's conclusions. The strongest R&D-specific recommendation that could produce rapid improvement is in data acquisition, data processing, and decision making.

The committee's practice-related recommendations are as follows:

- Government agencies, environmental and engineering contractors, and university researchers should work to analyze and document the potential costs and benefits of the use of noninvasive characterization methods in a wide variety of applications.
- Government agencies (federal, state, and local) need to develop approaches to site characterization that focus on flexible program design procedures and decision-making processes that account for the unique character of each site.
- Scientists and engineers have to place greater emphasis on communicating information about noninvasive tools and techniques and their recent advances to practitioners.
- Government agencies and professional societies are encouraged to form partnerships in long-term efforts to distribute and share information on the capabilities and recent developments of noninvasive characterization methods.

Again, these recommendations are intended to cover the broad needs of all near-surface characterization, but they echo familiar themes in other reports on utility locating—namely, the need to show the cost-benefit of improved techniques and better investigations, the need for flexibility in funding according to risks associated with a site or a utility, and the need to communicate current capabilities.

Another committee recommendation, that of integrating multidisciplinary functions, is in fact the model for the subsurface utility engineering field, in which professional engineers, surveyors, and geophysicists work together to find, portray, and analyze existing utility information.

The NRC report has specific recommendations concerning potential advances for various characterization methodologies, such as field electrical methods, seismic methods, and ground-penetrating radar. These recommendations have been incorporated into this report as appropriate.

Initiatives of the Office of Pipeline Safety, Pipeline Hazardous Materials and Safety Administration

Since the early 1990s, the Office of Pipeline Safety of the Pipeline Hazardous Materials and Safety Administration (OPS/PHMSA) has increased programming both to require safe operations by pipeline operators and to fund targeted research aimed at improving the technology related to pipeline damage prevention and detection technology. The programs restrict their focus to pipelines rather than cables, and important tasks include detection of pipeline encroachment and mechanical damage by third parties and pipeline locating and condition assessment. Areas of research that are currently being funded can be found at http://primis.phmsa.dot.gov; typically, a request for white papers is issued each year from which projects are chosen for full proposal preparation and potential funding.

While OPS/PHMSA has a specific mission relative to pipeline safety, many of the utility detection and encroachment technologies, condition assessment technologies, and mapping and recordkeeping technologies are relevant across the range of buried utilities. Although differences in the pipe size and layout, available funding, and safety implications of hazardous material pipelines mean there are some problems in technology crossover, there is also significant overlap in the core problems to be researched across the utilities.

Gas Technology Institute

In March 2006, the Gas Technology Institute/Geosynthetic Research Institute (GTI/GRI) released a final report by Process Performance Improvement Consultants, LLC, titled *A Compendium of Practices and Current and Emerging Technologies to Prevent Mechanical Damage to Natural Gas and Hazardous Liquids Transmission Pipelines* (*8*). According to the report, while the technologies used to prevent mechanical damage differ in many regards from conventional utility detection technologies, there are many overlaps in practice and similarities in research needs. The report provides recommendations in four areas: recommendations derived from historical safety-performance analyses, improving one-call effectiveness, the role of work practices in preventing mechanical damage, and the role of technology in preventing mechanical damage. The description of locating technologies for the most part refers to the CGA reports (*9, 10*), which in turn cite the *1999 Statement of Need* and *2000 Summary of Responses* (*11, 12*) in regard to potential technologies and desired performance. The findings and recommendations of the GTI/GRI report most relevant to the current study are as follows:

- Additional strengthening of the one-call system is needed.
- Fewer accidents are being caused by previously damaged pipe. (That is to say, partial mechanical damage is being detected before a major incident occurs.)
- Better data on the causes of incidents is providing greater insight on how to prevent them. Some states do not measure damage-prevention performance.
- Exempt entities account for about one-quarter of the third-party-related pipeline incidents.
- Effective programs supported by strong regulation and enforcement can yield a dramatic decrease in damage to underground facilities.
- Options to reduce miscommunication include "positive response" and expansion of the role played by one-call centers to include collecting responses from utilities and providing a single set of responses to excavators.

The report presents 116 practices to enhance damage-prevention programs and develop integrity-management programs. They include the following:

- Practices and technology need to be considered in concert.
- There is a need for an ongoing commitment to study and evaluate pertinent technological developments in other fields.
- There is a need for periodic industry forums.
- Map integration would put all utilities on a unified, compatible base map.
- Lack of precision in one-call requests results in unproductive locating work, which diverts resources away from more productive prevention work.

Initiatives of the United Kingdom Water Industry Research/American Water Works Association Research Foundation

As indicated elsewhere in this report, the United Kingdom has initiated several major R&D programs to deal with streets/highways and utilities. Problems addressed by the programs include the major effect of street work on traffic congestion, and the risks and costs associated with not knowing the location of underground facilities and not having the technology to effectively carry out buried-utility location. A major program entitled Mapping the Underworld emerged from this concern, as did a series of issue-identification and R&D-planning activities. The UKWIR has been driving this work with support provided by AWWARF. The results of the major activities and the conclusions about innovation in locating and characterizing utilities that were reached are briefly reviewed here with references to the source documents.

By way of background, in May 2002, a three-day workshop on multi-utility buried pipes and appurtenances location was held in London. The workshop included 27 delegates from the United Kingdom, the United States, and the Netherlands with varied disciplinary backgrounds and job functions. The workshop discussed the industry's needs, the current technologies that are available, and the gaps that exist between the needs and the current technologies. Discussions resulted in 28 high-level proposals for future innovation, which were then prioritized by potential benefits and rationalized into 16 proposals for further development after the workshop. The estimated cost of the research identified in all proposals totaled $13.3 million. The 16 proposals for further development were as follows:

- Methodology and standards for utility asset-location data collection and exchange;
- Smart-pipe technology;
- Methodology for determining total costs for construction, operations, and maintenance of buried infrastructure, and use of total costs of mislocating buried infrastructure to justify—or not—investment in improving locating techniques, equipment, and GIS-based mapping;
- Asset tagging;
- Develop a multisystem location system—three-phase project;
- Improve GPR performance;
- Employ smart pigs for location of adjacent buried infrastructure;
- Determine feasibility of using horizontal sensing to determine depth of buried infrastructure;
- Develop "see ahead" technology;
- Develop novel approaches to traditional underground infrastructure;
- Develop new technologies for underground asset location—capability review;
- Provide quality training;
- Conduct requirement analysis of user needs;
- Progress toward a better regulatory framework for buried infrastructure management;
- Develop techniques to detect existing small nonferrous buried assets; and
- Categorize the utility environment.

Again, these recommendations closely mirror the findings and assessments made by the current study participants.

Utility Locating Improvements

This section identifies the most promising technological developments relative to utility location and assesses their potential and appropriateness for further acceleration using SHRP 2 funds.

Active Technology Developments

Chapter 4 reviewed the range of potential methods for buried-utility locating and the current state of practice. This section seeks only to identify those methods that either are undergoing significant enhancement or that have the potential to be significantly enhanced through further R&D investments. The focus of this discussion is on the R&D activities under way through publicly funded research projects or through consortia that report on their activities in general terms, if not in specific details about the intellectual property achieved through such research. A brief review of research items that are of particular interest to this report follows. This discussion is not meant to reference every effort. Advanced research for particular technologies may be under way at private companies or research laboratories not mentioned here. However, based on the literature that has been reviewed, patents that have been searched, and discussions held over the course of this project, it is believed that the items reviewed are representative of the ongoing research efforts.

AWWARF/OTD/GTI Partnership Program

The partnership among AWWARF, Operations Technology Development (OTD), and GTI is explained by its name: Underground Facility Pinpointing—Finding a Precise Locating System for Buried Underground Facilities. The second phase of this program was under way as of this writing. This phase includes further investigation of emerging technologies such as capacitive tomography, radio frequency vibration, acoustic pipeline locating, and visualization technologies. However, the key elements of the program are to conduct field demonstrations of locating technologies to find nonmetallic pipe, especially polyethylene pipe. The demonstrations will be conducted in different parts of the country to better establish the conditions where GPR is effective. The report is to contain analysis of the performance data of the various devices, together with specific strengths and weaknesses and possible future research and development.

Acoustic Pipe Locator

The acoustic locator has been developed by GTI and was due to be released in 2008. About 300,000 mi of plastic pipe have been installed without tracer wire in the United States alone and between 500,000 and 1 million mi of it have been installed across the world. The technology was patented in February 2004. A field test indicated the method could detect a 1.25-in. plastic pipe at depths of 3 ft to 4 ft. At a depth of 4 ft, this is about a 36-to-1 depth-to-diameter ratio. Complexities that may affect the efficiency of the method include soil density variations, utility trenches, and side reflections (*13*).

Locatable Plastic Pipe

Developed by GTI, the pipe is composed of magnetized strontium ferrite particles that were incorporated into the pipe during manufacture. The particles are 12% to 24% by weight, but only 3% to 4% by volume. Locating is effective for pipes of 4 in. in diameter and larger. GTI has been working to increase the signal strength for locating purposes. The pipe has been approved by ASTM but needs federal code approval (*14*).

Witten Technologies

Witten Technologies, Inc., has been involved in developing and commercializing arrayed remote sensing technologies since the late 1990s. It has developed GPR sensor arrays (in collaboration with Mala Geoscience as the GPR supplier) that provide sufficient data for the tomographic reconstruction of buried objects found beneath the ground surface. This data is then exported to 3-D CAD or GIS software for database storage and 3-D visualization. The technology built on earlier tomography algorithms developed over several decades by Schlumberger for the oil exploration industry. Since 2000, Witten reports that, in addition to its investments, nearly $2 million in third-party research has gone into the development of the system. Funding contributors have included the Electric Power Research Institute (EPRI) and GTI for the development of computer-assisted radar tomography (CART), which has been fully commercialized since the turn of the century. More recently, USDOT/OPS/PHMSA and Consolidated Edison participated in a project to merge the CART array with an inductive array to introduce a digital mapping of buried pipelines with a dual array system (http://primis.rspa.dot.gov/matrix/PrjHome.rdm?&prj=109). The arrays were not commercially available in 2005 but were considered close to commercialization. Witten has also collaborated with NASA's Jet Propulsion Laboratory (JPL) to use JPL's expertise in advanced radar image analysis to sharpen the tomographic images and identify linear features, such as utility lines near the limit of resolution of the radar (*15*).

Underground Imaging Technologies, Inc.

Underground Imaging Technologies, Inc., (UIT) has been in business since 2002. The company formation was initiated when the Arizona Public Service (APS) Company issued a request for proposals to develop a hardware and software system to map utilities of any material type in any soil. APS entered into a joint venture with Vermeer Manufacturing for development and commercialization of such a system. Based on R&D expenditures in the multimillion-dollar range, and funded entirely as equity capital, UIT entered the marketplace with a GPR unit known as TerraVision. This GPR unit was developed in partnership with Geophysical Survey Systems. The integrated UIT system includes a multisensor time domain electromagnetic system based on the Geonics EM-61 instrument. Deploying these two systems separately or together, UIT has completed numerous projects with customers such as Consolidated Edison, Shaw Group, and New York State DOT. The UIT system includes proprietary software products called DAS and SPADE that support the acquisition, processing, visualization, and interpretation of multiple sensor data and of supporting data in a 3-D workspace. UIT remains committed to ultimately meeting the original goal of working in any soil type, and it has self-funded the development of a prototype multiple-source receiver seismic tomographic system. R&D efforts to attain the needs of commercial applications are still under way.

Forced Resonance Radar

Bakhtar Associates is adapting underground-sensing technologies developed for landmine and unexploded ordinance detection to pipe-locating systems. The system uses a proprietary forced resonance radar and associated signal processing to detect buried objects and to provide an improved signal-to-noise ratio. The claimed advantages for the system are the abilities to resolve images in conductive soils, to detect small-diameter plastic pipes, to differentiate between materials, and to determine the diameter and depth of pipes (*16*). The BakhtarRadar system also uses a high-accuracy GPS unit (horizontal-position accuracy under 0.4 in.) to record the location of detected anomalies, and it is capable of 3-D image reconstruction with dimensional details.

The BakhtarRadar system was tested in two of the Gas Technology Institute's test beds, the clay test bed and the silty-sand test bed, reportedly with positive identification results. The report indicates that the system was "able to locate small diameter plastic pipes in a highly conductive soil. Additionally, accurate depth and diameter information was acquired." The report also characterizes the stage of development of the utility detection system as follows: "The EarthRadar system is not currently in a format compatible with the utility industry's needs. The system is large and awkward and the software requires interpretation and processing. Further development is needed to transform the existing system into a rugged and user-friendly device that utilities can use to locate underground facilities. To gain the performance indicated, the current system needs to be calibrated or tuned for particular soil conditions." Information from Bakhtar (*17*) provides 3-D image reconstruction of the pipes placed in the clay test bed. These pipes were a 2-in. diameter plastic pipe buried at a depth of 2.6 ft and a 4-in. diameter plastic pipe buried at a depth of 7.4 ft. A 2-in. pipe at 2.6 ft represents a depth-to-diameter ratio of 15.5 and a 4-in. pipe at 7.4 ft represents a depth-to-diameter ratio of 22.

NYSEARCH

This commercial collaboration is focused on detecting buried utilities through a technique that has been termed "Hyper-Radar." This approach uses a low frequency to gain depth penetration for GPR even in problem soils while using signal-processing techniques and stepped frequencies to enhance signal-to-noise ratios and increase the resolution with which utilities and other buried targets can be identified. Several independently documented field trials have been carried out using this technology, which has shown improved success in identifying buried utilities with high depth-to-diameter ratios or in problem soils such as conductive clays. At the time of the writing of this report, the first commercial systems were reported to be soon available to the marketplace.

Ingegneria dei Sistemi SpA

Ingegneria dei Sistemi SpA (IDS) has been involved in the development of tomographic GPR arrays for utility designation since 1990. One of its key attributes was the use of a "double threshold detection" radar approach in which detection of an object against background noise, particularly a pipe against localized objects or noise, could be significantly improved on by noting the same level of echo in the same position in multiple scans. Recently, IDS has been a key partner in the GIGA project (see chapter 2 for description). The GIGA approach has been to focus on three main research axes related to the basic performance of the radar detection: (1) radar technology improvements; (2) multiparameter/multiconfiguration data fusion and data processing, based on flexible GPR measurements in close relationship with modeling and simulations; and (3) specific radar and signal-processing algorithms to improve the discrimination between the object to be detected and interfering signals.

At the end of 2003, the GIGA project, which is valued at €3 million (~US$4.5 million), was completed. A new project is now under way to design, develop, and test a new, specific GPR demonstration prototype. Testing of IDS equipment was carried out in autumn 2002 at the Gaz de France test site in Saint Denis, Paris, France. The goals of the test were to measure the probability of detection and false alarm rate, accuracy of location in the horizontal plane, accuracy of location in the vertical plane, range of depth, and resolution of multiple objects in the horizontal plane.

Five equipment configurations from IDS were selected for testing. The results from the testing were reported by Manacorda et al. (*18*). Some limitations in detection rate and range depth were encountered in the presence of highly conductive soils; however, in these areas, tested configurations detected more than 70% of the existing pipes, mainly as a result of the combined use of high- and low-frequency antennas. In pits with lower signal attenuation and where traditional buried pipe layouts were simulated, 100% detection performance was possible. The data analysis provided good accuracy in determining horizontal and vertical position with an averaged error in determining the utilities' depths of less than 1 in. This matches the relevant end-user requirements as determined by a survey of 170 European utilities. Promising results were also noted when using innovative processing techniques such as 3-D migration and polarimetric processing.

Simulation work by IDS in connection with equipment development is adapted from the transmission line matrix modeling (TLM) approach and from another GIGA partner (Thales Air Defense) that uses optical propagation laws and the Descartes and Huygens laws. Both approaches avoid the computational load of solving the full Maxwell equations and are reported to provide good results with greatly reduced computational time. The simulation work is intended to fix the real physical limit of the pipe detection under different site conditions and to select the antenna and radar characteristics to match the operational requirements set by the end user. In the conclusions of their paper, Manacorda et al. assert that an enhancement of the state of the art of underground mapping tools is possible and that in the near term it will be possible to some extent and in the medium to long term it will be entirely possible to match the demanding requirements of the survey, as carried out at the beginning of the GIGA project. The specific requirements being targeted, however, are not defined in the paper.

Mine Detection

Considerable work in buried-object detection is being carried out in the area of mine detection. It has been estimated that, at the current clearance speed, it will take more than 100 years to remove all the landmines that remain in the world (*19*). Mine detection is based on differences between the mine and the surrounding ground, as in buried utility detection, but it may also be based on the detection of either outgassing from the plastic used to construct the mines or outgassing or nuclear resonance from the explosive material itself. A research program has been under way for several years in Japan to construct a combination of either stepped-frequency GPR or impulse GPR with metal detection (MD) and to deploy the detection system in rugged terrain (*20*). While significant work is being done in this area, the range of depth for mine detection is typically up to about 1 ft; hence, successful mine detection approaches may need adaptation or verification for deeper applications or may simply not be applicable. Results from field test comparisons of developed systems to metal detection only indicated that GPR+MD could improve the probability of detecting targets at a depth of around 8 in., where MD detection only becomes difficult. It was also found that the positioning control of the sensor head needed to be improved.

Mapping the Underworld

This major U.K. initiative was discussed in chapter 2, and its research goals were outlined earlier in this chapter. Because the goals of the research initiative closely mirror those of SHRP 2, it is possible to build complementary rather than duplicative research activities.

The aim of the MTU Location Project is to investigate the feasibility of several novel approaches, alongside greatly enhanced approaches, to be combined in a single multimodal approach to locate, identify, and possibly assess the condition of buried assets, whether deployed from the surface or subsurface from within an existing utility conduit. The objectives of the research are as follows:

- To determine the capabilities of existing technologies and the potential of novel technologies to locate and identify buried utilities under three broad headings: GPR, acoustics, and low-frequency electromagnetics.
- To explore in detail the most promising technologies for integration into a single multi-utility device.
- To produce a fundamental understanding of the limitations of signal propagation through and reflection from the underground media encountered in the above operations (that is, bound and unbound pavement structures, soils, pipes, and the materials that they carry).
- To explore the feasibility of combining the techniques to create an integrated, multisensor device.
- To explore the feasibility of deploying the multisensor device both from the surface and from a pig that travels through an existing buried conduit.
- To conduct a survey of relevant industrial stakeholders to determine the accuracy requirements of such a technology.

This project is nearing completion and has achieved its goals.

Other Commercial R&D Activities

As mentioned earlier, the preceding identification of specific research activities is not intended to indicate that this review comprises the only innovative research under way in the field of utility locating. The identified activities were collected through the literature search, the statement of need process described in chapter 2, and contacts by project team members with companies and organizations related to utility locating issues.

Although extensive information-collection activities were conducted as a part of this research, this report has not attempted to categorize the R&D activities of all the companies in the field. Current methods in use are reviewed in chapter 4, and a database of methods and selection software is presented in electronic form in an accompanying product. Appendixes A and C also provide contact information for many companies and organizations related to utility location and characterization.

Many commercial development activities are following similar avenues of development to the approaches outlined above even if the signals used or the specific approaches vary.

Technological Areas of Improvement

This section summarizes the most promising avenues for technological improvement with respect to utility locating. Mapping and marking issues, procedural and funding issues, and education and training needs are dealt with in separate sections. Descriptions of the technology and the current state of the art have been introduced in earlier chapters. This section lays out the key areas that have been identified, including a brief justification for this selection. Many technologies come with a best range of applications—either in terms of target utilities or site conditions. Hence, for many issues, it is not practical or justifiable for the authors to select one particular technology over another, given the wide range of needs, the limited availability of performance data, and the natural reluctance on the part of the companies to release intellectual property. However, the authors believe that it is possible to establish the most promising technological directions and to establish guidelines for targeted research funding that will have the greatest short- to medium-term impact on technological development.

The avenues for improvement are discussed under several key headings that are not necessarily comprehensive but that do cover the most critical needs for locating improvement and the approaches being developed.

Deep Utilities

Finding undocumented utilities, without ancillary detective work, at depth-to-diameter ratios greater than 20 to 1 (that is, a 3-in. utility at a depth of 5 ft, or a 1-ft utility at a depth of 20 ft) has reached the limit of theoretical expectations for surface-based surveys, even under soil conditions considered reasonably fair for most surface geophysical methods. Radio-frequency methods, where the target is a significantly better conductor than the surrounding environment, can increase depth-detection capabilities. Practical expectations for detection are closer to a 12 to 1 depth-to-diameter ratio. Also, when a utility is deeper, there is a greater chance that soil variations and other utilities or objects at shallower depths will mask the presence of the deep utility. Multisensor approaches can compensate for some soil environment difficulties (for example, acoustic techniques will work in conductive soils where GPR is effective only at very shallow depths), but for the foreseeable future there are optimistic expectations for finding unknown utilities of various sizes at depths exceeding 15 ft to 20 ft through surface investigations. Passive surveys use natural random vibrations and can image the zonation of deeper materials through statistical analysis and inversion techniques. However, low-frequency signals are not useful for detecting small and moderate-sized utilities. One key utility-detection component involves introducing an energy source through the ground to the utility. Energy dissipates both when it travels through the ground and when the reflected signal returns to the detector. Both direct connections to the deep utility and the introduction of an energy source closer to the deep utility, such as through a borehole, can be effective in some cases.

Locating deep utilities has received attention in the context of deep tunnel detection, for example in regard to finding tunnels across the demilitarized zone in Korea or across the Mexico-U.S. border. Detection of tunnels at depths of 80 ft and more has been achieved (*21*), but most trials have been in open country and many involved additional items within the tunnel for detection (such as electric lighting circuits). Such tunnel detection often occurs in favorable soil conditions and in a "less noisy" detection environment.

Tunnel detection is currently receiving significant attention from the Departments of Defense (*22*) and Homeland Security, which have issued RFPs that will initiate or continue research funded in the range of several million dollars (*23*). The work being done to address tunnel-detection problems should be tracked closely for results that will aid in the detection of deep utilities in urban areas.

The most promising avenues for addressing the problem of deep utilities in urban environments are as follows:

- Multisensor approaches to increase the reliability of recognition and performance over a range of soil conditions;
- Stepped-frequency and signal-to-noise ratio improvements to increase the depth-to-diameter performance;
- Soil-characteristic surveys to optimize the detection-method parameters for deep utilities;
- Sewers, which are typically below most other utilities, or drilled or vacuum-excavated boreholes employed for direct path scans or reflection scans from a deeper horizon;
- Cross-bore tomography use of boreholes to identify deep utilities—for example, using conductivity surveys, direct-path electromagnetic, or seismic signals;
- Test-hole use to provide a direct access connection to the pipe, eliminating half of the total ground attenuation;
- Extensive records research to identify potential deep utilities in an area;
- Statistical or pattern recognition techniques to improve recognition of specific types of targets;
- Identification of a feature within a deep utility or tunnel that can be more effectively traced than the structure itself;
- Continuous mapping and database development for utilities (see separate discussion);
- Rigorous as-built documentation requirements (see separate discussion); and
- Last opportunity see-ahead approaches to help prevent actual utility strikes (but this does not help in terms of locating for planning and design purposes).

Nonconducting Utilities

Nonconducting utilities, such as those made from plastic or clay or those that do not provide a potential continuous current path, are inherently difficult to locate unless they have been clearly marked using locating tape or wire, marker balls, or other marking techniques, as discussed in the section on utility marking. If the interior of the utility is accessible, then acoustic signals, a conductive trace cable, or an electromagnetic sonde can be introduced into the pipe to aid in locating. However, unrecorded, nonconducting utilities do exist and will only be found if the locating technology can detect the presence of the utility within its ground environment. "Cast-in-stone" project limits may preclude a surface investigation that would identify a remote access point where a conductor or sonde could be introduced. With the large increase in the amount of plastic pipe being installed, the small diameters often used, and the unrestricted depths offered by installation techniques such as horizontal directional drilling, detection of nonconducting utilities at high depth-to-diameter ratios is high on the list of technological needs. Unfortunately, there are significant theoretical limitations, such as depth-to-diameter ratios, and practical limitations, such as congested utilities, layered utilities, and pavement structures, to what can be detected using currently identified approaches.

The most promising avenues for addressing the location of nonconducting utilities are the following:

- Further development of GPR and acoustic technologies for surface-based utility locating (shallower utilities and larger diameter utilities at depth);
- Longer and more efficient cable insertion equipment and improved techniques;
- Major improvements in marking and mapping approaches (see separate discussion); and
- Last opportunity see-ahead approaches to help prevent actual utility strikes (but this does not help in terms of locating for planning and design purposes).

Congested Utilities

Congested utilities and other interference-producing conditions mask the individual signals from various utility-detection approaches and provide a low signal-to-noise ratio. The close horizontal separation of utilities can be addressed to a certain extent using narrowly focused signals, but the identification of vertically stacked utilities is more difficult. Surface-based tomographic approaches can provide some advantages, particularly with multisensor arrays. Surface tomography extensions can include surface-borehole or cross-hole approaches that allow direct-path methods of assessing utility targets. Direct-path methods that transmit or receive signals between a deep horizontal pipe and the surface could provide additional resolution of multiple utilities. This also was discussed in the previous section on deep utilities. The cost of nonsurface-based technologies and the potential that a borehole may cause utility damage are significant limitations to the broad use of these approaches—particularly in the planning stage of a transportation project when the alignment of or funding for the project is uncertain. Vacuum excavation may be explored as one way to eliminate damage related to boreholes.

The most promising avenues for addressing the problem of congested utility areas follow:

- Surface-based, multisensor, tomography approaches;
- Enhancements to existing equipment that would make direct connections to utility systems easier and more efficient;
- Stepped-frequency and signal-to-noise ratio improvements;
- Sewers, typically below most other utilities, or purpose-drilled horizontal boreholes for direct-path tomography;
- Continuous mapping and database development for utilities (see separate discussion); and
- Further definition of the ability of various techniques to discriminate closely spaced utilities (this may not matter for damage prevention but may be very important for design).

Unfavorable Site Conditions

Unfavorable site conditions include the presence of highly conductive soils that limit GPR application and the presence of objects that distort the electromagnetic fields used in conventional locating. Such conditions also include extensive utility congestion and access conditions that prevent adequate surface surveys, such as physical or traffic restrictions. Ground surface and subsurface rigidity may affect acoustic methods.

Utility-detection techniques can often be tuned to optimal frequencies, antennas can be designed for specific site conditions, and error-producing conditions can be identified to allow a locator to compensate for such difficulties. Site conditions may also change with time; for instance, there is a need to deal with changing soil conductivity caused by salt use on roadways.

The most promising avenues to address the problem of unfavorable site conditions are as follows:

- Surface-based, multisensor, tomography approaches;
- Stepped-frequency and signal-to-noise ratio improvements;
- Site condition and soil characteristic surveys that help to establish the most effective locating methods and parameters on a local or regional basis—for example, soil conductivity maps related to GPR applicability;
- Improved recognition of error-producing conditions;
- Sewer use (typically below most other utilities) or purpose-drilled horizontal borehole use for direct-path tomography;
- Continuous mapping and database development for utilities (see separate discussion); and
- Seasonal imaging and documentation (in cold climates) of certain utilities when the ground is rigid (frozen).

Mitigation of Practical Limitations on Theoretical Performance

This approach looks at the fundamental physics that govern the operation of various locating methodologies, and it seeks to optimize each aspect to more closely approach detection-capability theoretical limits. It is necessary to simulate the performance of the detection method in a geometrically complex environment to ensure applicability over a wide range of soil conditions and target utilities.

The practical limitation on the performance of tuning methods in specific conditions is that they are unlikely to function as well as a general purpose technique. To achieve a benefit of tuned performance over a wide range of applications, it is necessary to adjust the detection method in a simple and cost-effective manner as it is used in the field. However, as a result, equipment costs will increase and more high-level site input to the detection process may be necessary.

The most promising avenues to address the mitigation of practical limitations on theoretical performance are the following:

- Multisensor approaches to increase the reliability of recognition and the performance over a range of soil conditions;
- Stepped-frequency and signal-to-noise ratio improvements to increase the depth-to-diameter performance;
- Soil-characteristic surveys to optimize the detection method parameters;
- Statistical or pattern-recognition techniques to improve recognition of specific types of targets; and
- See-ahead approaches that reduce the need to see large distances through the ground.

Multisensor Approaches

Multisensor approaches have been identified as potential solutions to all of the issues raised thus far. The commercial application of such approaches, however, requires that the increase in performance justifies the increase in equipment and operating cost. This, in turn, requires that an increase in performance is properly valued against the risk-based cost of poor detection that may result in project delays, cost overruns, and personal injury.

The most promising avenues to address improvements to multisensor approaches are the following:

- Combinations of electromagnetic induction sensors (conventional locating instruments) with GPR approaches to enhance conventional locating practices with the ability to image nonconducting or unidentified utilities;
- Combinations of acoustic and GPR approaches to provide acceptable performance across ranges in soil conductivity and rigidity;
- Spatially varied sensor arrays and stepped-frequency approaches to provide improved target recognition and signal-to-noise ratio improvements;
- Adoption and extension of available research on sensor fusion and recognition of targets (for example, mine-detection research and other military-related applications); and
- Development of methods to combine information from different approaches (for example, hard and soft data), taking account of different reliabilities (*24*).

Target Recognition, 3-D Location, and Transfer to GIS/CAD

There is still significant room for improvement in approaches to target recognition and reconstruction, estimation, and confirmation of the depth and horizontal position of a utility and in how this information is transferred to computer databases and visualization software. Currently, the only way to gain real confidence in an accurate position and the type of utility is to expose it via test holes. This approach is likely to remain the preferred way for a long time, but it is time-consuming and costly. It would be of great benefit to be confident of gaining positional accuracy without excavation.

The most promising avenues of improvement in regard to this issue are the following:

- Continued research on inverse approaches to target reconstruction;
- Continued research on signal-processing enhancements and statistical and expert system/neural network approaches to identification of unknown targets and known targets with specific characteristics;
- Automated and rapid means of transferring belowground positional information into GIS coordinates (see mapping discussion);
- Improved sensor fusion in combination with other soft or hard data as outlined above; and
- Statistical reliability analysis through correlation of test-hole data with surface geophysical data.

Developing Additional Approaches

Conductivity mapping remains under development for near-surface investigation applications. Multichannel analysis of surface waves is reported to offer great promise for determining the engineering properties and zonation of near-surface materials (*25*), but it is probably less effective in terms of utility location. Various other approaches, such as the use of random earth vibrations mentioned earlier, may find application to certain investigation problems, but the bulk of utility-locating practice is likely to remain with electromagnetic pipe and cable locators, GPR, terrain conductivity, magnetic detection, and acoustic detection. Various combinations of these approaches may also be adopted. It is worth remembering, however, that changes in electronics and computing power can lead to significant changes in what is possible for each technology in terms of speed and cost, manpower requirements, attainable resolution, and so forth. Thus, the technical landscape does not remain static over time and periodic reassessment is needed.

The recommended actions in regard to additional approaches are as follows:

- Regular technology reviews to assess changes in the technical landscape and emerging methods. This would also serve to keep the issues and the latest technologies in front of DOT decision makers and other transportation project designers.
- Use of existing and newly constructed test facilities to document the capabilities of utility locating equipment under controlled conditions of varying complexity.
- Creating a grand technology challenge with regard to locating deep utilities in a poor soil environment. Such a challenge could serve to publicize the technology needs to the general public, to those who make decisions about the funding of utility investigations, and to the broader research community that is not currently involved in utility-location technology research.
- One cross-cutting need in the utility-locating arena is making the equipment usable by people other than highly specialized engineers and scientists to ensure broad acceptance and cost-effectiveness. This does not necessarily reduce the need for an expert to direct SUE-style utility locating and mapping activities, but it would lessen the costs of deploying advanced technologies at a site.
- Improvements in direct-connection devices, such as signal coupling methods, for pipe and cable locators are necessary.

Such devices will tend to be used if available and will enhance the detection of deep utilities and assist in discriminating between braided and stacked utilities.
- Technological advances in locating are an ongoing process, but advances are useless in practice until the client considers them to be cost-effective. Methods and documentation of true utility costs on projects need to be developed.

Utility Characterization Improvements

Improved methods of utility characterization are desired so that, with an ideal set of technologies, the same survey that would pinpoint utility location would also provide the key operational and condition characteristics of the utility. This information, in turn, would allow timely decisions to be made when working in proximity to the utility concerning safety issues, the utility's operating condition, its expected longevity, and the potential for future interference with the renewed highway pavement. To be most effective, this characterization information cannot be left until the construction phase. It is needed during the planning and design phase of the highway project. In the construction phase, characterization information is primarily used for previously undiscovered or inaccessible utilities. Any problems identified at this stage are almost certain to cause project delays and cost increases.

As discussed earlier in the report, the primary characteristics of the utility include its size, material, purpose, ownership, age, and usage status, which is to say whether it is inactive, abandoned, out of service, or active. Some of these attributes could potentially be found from surface investigation methods or from nondestructive or minimally destructive external evaluations of an identified utility service. But most would normally be found from utility records once the utility has been identified. This attributing process from records is standard procedure within the quality assurance process, such as that used by the SUE professional, but it rarely occurs when utility mapping responsibility is fragmented. The additional desired information is primarily related to the utility's structural details (wall thickness, joints, splices, encasement, coating, cathodic protection) and condition (corrosion, physical damage, signal fault, and so forth). It should also be noted that internal inspection of pipes can be used to provide accurate 3-D location information.

The wide variety of information types, the detailed procedures used to gather different data when a utility is physically accessed, and the limited number of technologies available to gather the data in a remote fashion make it difficult to discuss advances related to each characterization need. Instead, the potential advances are discussed below under broader headings that relate to the timing of the information collection and accessibility to the utility.

Active Technology Developments

Chapter 5 reviewed the state of the art for a variety of utility-characterization activities. As discussed in chapter 5, most of the research activities seem to be in the areas of pipeline condition monitoring, mechanical damage prevention for pipelines, and internal inspection technologies coupled to general asset management for buried utilities.

Examples of cutting-edge technologies that continue to be refined include the following:

- Multisensor inspection platforms (smart pigs);
- Multisensor dimensional and condition assessment information;
- Laser point cloud internal pipe dimension analysis, which when correctly registered can provide information on progressive deformation of pipe systems;
- Ultra-wideband (UWB) scanning for pipe wall defects and external voids;
- Passive marking and RFID tagging of utilities;
- Integrated CCTV, condition assessment, and asset management databases; and
- Integrated systems used by municipalities and other utilities.

Technological Areas of Improvement

Characterization Information for Planning and Design

The most promising avenues of improvement in regard to characterization for planning and design are the following:

- More reliance on asset management databases held by the utility. Many utilities are conducting more regular inspections of their assets, and condition-assessment tools, particularly those than can be deployed within a pipe, are improving rapidly. Advanced fault-detection tools for electrical and fiber optic cables are also available that can detect the presence of faults and also provide their locations.
- To integrate the above recommendation into a project-planning process requires identification and coordination of all the relevant utilities in terms of receiving condition information. It also introduces the question of whether utility companies, in return for use of the public right-of-way, will willingly cooperate (or will have a responsibility to cooperate) to assess utility condition before a new or renewal transportation project is constructed. Such issues are explored in more detail in the companion to this SHRP 2 report (*26*).
- The recommended advances to be pursued in asset tagging and advance mapping and recordkeeping will also have a strong impact on the ability to retrieve important utility-characterization information when it is needed during project planning, design, and construction.
- Acceleration of ongoing technical advances in condition-assessment technologies that can be deployed within pipes.

Of particular interest for development are the technologies that track progressive deformation of pipe cross-sections with time, change in pipe-wall thickness, and the development of soil voids outside a pipe. For cables, fault identification and location are also important.

Available Access to the Utility

If SUE approaches are being used for planning and design purposes, then exposure of a utility to confirm its type and to record its 3-D position provides the opportunity to identify as many characteristics about the utility as possible externally. This considerably extends the range of utility characteristics that can be recorded.

The two most promising avenues of improvement in regard to external characterization for planning and design are (1) techniques that can be used when a utility is exposed and that do not require tapping into the utility to gain useful information; and (2) preparation of a guidance or best-practices document that describes the procedures to be followed to investigate pipes or cables when they are uncovered. Some safety guidance exists, but a comprehensive treatment of possibilities for practitioners seems to be lacking.

Recordkeeping, Mapping, and Marking

Many utilities that once had a known location often have to be found again. One-call systems and current locating practices are clearly much needed and have provided significant reductions in utility strikes and significant improvements in worker and public safety. One-call systems will remain critical to damage prevention efforts at least for the foreseeable future, but it is possible to complement locating practices with increasingly reliable database information on utility locations and characteristics. Fortunately, this is one area where there has been a radical change in technology and practice in recent years and this, in turn, provides a reasonable path whereby the circumstances of utility mapping and recordkeeping can be radically changed. Marking technologies also have improved in recent years with potential for greater improvement through RFID tagging that is inexpensive and that allows significant information about a utility to be recorded and retrieved directly on site. The most promising aspects of mapping and database approaches and marking improvements, as well as the most significant barriers to be overcome, are discussed below.

Active Technology Developments

This is a very active area of individual technological advancement and system integration. Three examples are provided below to indicate the commercial research and development activity under way.

ProStar Predator Software

This is used for data collection and damage prevention. It uses the ProStar Grid—a precision land base that includes all available information, such as raster files of scanned topographic maps, aerial photography, paper drawings, digital imagery, survey plats, metes and bounds, CAD files, and any vector graphic files. Existing data is aligned, molded, and shaped to fit key precision points that have been established for a project. It is a transaction-based system that allows changes to data to be recorded, and undone if necessary, and data "pedigree" to be noted in the system. It can operate in real time in the field and simultaneously in a remote office. It can also operate in a damage-prevention mode. The database can be centrally hosted, providing a variety of levels of secure access to different mapping and retrieval functions.

TransLore

This is a GIS-based system designed to automate many management functions for one-call locates. The application may be hosted on the user's server or on a TransLore server. Screening functions identify if a physical locate is needed for particular facility lines.

3M Dynatel 2200MiD Series Locating and Marking System

This type of development system was mentioned in chapter 4. It is a system for field mapping and facilities maintenance that makes it possible to find a location and to confirm details of the buried feature before excavation begins so that workers know in advance what to expect (that is, where a utility has been repaired, as well as when it was placed and who did the work).

Mapping and Database Technologies

Currently, utility records are considered unreliable in terms of documenting accurate information on utility positions. Yet, the existence of technology to provide accurate geo-referenced positional information (high-accuracy GPS) and the widespread use of GIS platforms among utilities and cities provide the opportunity for change. Currently, operating systems that provide accurate, comprehensive utility mapping do exist. For example, in some areas of Japan all utility locations are plotted on a single utility-mapping system that allows for spatially correct 3-D information on buried utilities. The utilities are members of a consortium that shares utility information and commits to keep records up to date (*27*). Changes in approach are also being studied in the United Kingdom—for example, the Mapping the Underworld initiative—and in certain provinces of Canada.

With fragmented utility ownership, concerns about competition, particularly among telecom utilities, and security concerns related to unauthorized access to utilities or terrorist activities, there are many problems to be overcome. The authors of this report, however, believe that the further development of mapping and database approaches tailored to utility needs has a great potential to provide improvements in the design and construction of highway renewal projects and to assist in damage prevention.

The recommended actions to address the aforementioned issues are as follows:

- Continue to promote and teach the ASCE guidelines (*28*) as a means to standardize the collection and depiction of existing underground utilities on planning and design documents.
- Select a number of transportation projects as demonstration projects for advanced mapping and utility management approaches. Closely document the benefits and problems encountered. This will serve to reinforce industry investments in technology development and speed adoption in the marketplace.
- Highlight the benefits of an accurate 3-D GIS database in terms of rapid response and recovery from natural and man-made disasters when physical landmarks are often hidden or obliterated.
- Develop GIS applications to provide XYZ coordinates with a reliability and accuracy estimate for both horizontal position and depth. In the long term, this will lead to location probability that can be upgraded whenever new information about the utility is obtained.
- Develop best practices for utility information databases, including the required positional accuracy for the proposed database developments (for example, New Jersey requires utility providers to map to a certain degree of accuracy, and Georgia DOT has received awards for its utility mapping program). The Common Ground Alliance has an active best-practices program.
- Explore appropriate legislation, policies, funding restrictions, and enforcement to provide a consistent landscape in which improved systems can flourish. Encouragement is probably not sufficient given the complexity of utility providers, issues, and needs.

Utility Marking Technologies

Utility marking presents important needs and new opportunities. However, in practice, market forces alone are unlikely to result in uniform application of marking and pipe-locating aids. To reiterate, conductive pipes and cables carrying electric currents are relatively easy to locate; nonconducting pipes and fiber optic cables are not. Locating can be enhanced by using cable sheathing or separate locating tapes or marker balls to identify the utility's position. The principal drawbacks to separate tapes or markers are that they may become displaced during later excavation and over time the continuity of the tapes is lost. For plastic pipe, research has been under way for several years to enhance the ability to locate the pipe itself by incorporating magnetic filings into the plastic material from which the pipe is made. A key problem in the adoption of such a pipe appears to be that owners and contractors are unwilling to pay additional initial costs to put in place a pipe that is easier to locate in the future. RFID technology is rapidly gaining broad acceptance in industrial and commercial inventory systems. The sensors are inexpensive and can hold a significant amount of information for retrieval by scanners. The key application issue for buried utility systems is that of the signal transmission through the ground medium. As in the mapping and database area, this is a topic with significant potential for change in the near to medium term.

The recommended actions in regard to this topic are as follows:

- Support the adoption of improved marking technologies through cost-benefit studies of improved practices.
- Focus attention on the migration of RFID technologies to buried utilities, although technologies are most likely to be commercially developed with private intellectual property.
- Develop standard practices for RFID data sets.
- Include locatable plastic pipe and RFID prototype applications in the recommended DOT demonstration projects.

Liability and Security Management

Several key issues are always raised when common databases, data sharing, 3-D positional information for utilities, or all of these issues are discussed:

- If a common database is used, who inputs the data, who verifies it, who pays for it, and who has access (commercial-secret protection and hacker or terrorist protection)?
- If discrete databases are used, who sets the standards, who has access, and who controls security?
- In either case, there is the issue of how to handle liability for erroneous information or how to protect against claims when data is misused.

Similar problems affect military and other government databases with distributed updating and various levels of access security. What is needed is a realization that the current approach to utility recordkeeping leaves many undesirable problems and few paths for major improvement. Resistance to utility information-sharing is expected to be very strong based on realistic concerns about the use of the data. It will need to be shown that a utility company's concerns can be properly addressed before such collaborations can effectively move forward.

The recommended actions in regard to this topic are the following:

- The demonstration projects mentioned elsewhere should include a demonstration of data sharing (with appropriate protections in place) so that problems can be identified and resolved.
- Technology partners must demonstrate the capability to manage security, access control, and data-pedigree information.
- Once these projects have been successfully demonstrated and evaluated, broader implementation approaches need to be addressed, including data standards and liability relief for best-faith information provision.

Funding, Procedural, and Contractual Issues

It was asserted earlier in this report that, given adequate time and budget, a team with the appropriate education and experience could find most, if not all, of the utilities on a site—except perhaps for deep, unrecorded utilities. Naturally, improved technologies will speed and improve identification and will potentially lower costs. This means that it is also critical to deploy and more effectively use the technologies that are already available.

Several key issues were raised in chapters 3 and 4, and some of these issues are highlighted here. One issue is the tendency of project owners to gamble that utility problems will not arise. While this will save money on specific projects in the short term, it may eventually lead to large cost overruns if the information on which an owner relies is wrong. Guidance on typical costs and schedules for the relocation of various types of utilities would be helpful for use in preliminary project-planning estimates and in allocating adequate resources for early utility data collection. Also, guidance on what utility data is to be collected, when it is to be collected, and what accuracy is needed should be provided in the form of a scope of work or manual of practice. It would also be helpful if the funding and contractual framework required the right equipment to be brought to the site in accordance with the operational requirements related to detection rate, depth range, and resolution. Furthermore, the engineering and design consultants must bear some responsibility for the correctness of utility location information as well as for design. There is little information about liability issues, relevant case law, standards of care, and guidance to improve performance and avoid problems. If design and construction contracts anticipate utility-related change orders in a manner similar to how uncertain geotechnical data is handled, then contractual disputes will be minimized when utility information is updated. In addition, flexible utility location and characterization funding is needed in the early stages of a transportation project. Fixing budgets at an average cost per mile for utility surveys and coordination does not allow for a response to complex or high-risk conditions in the early stages of a project. The goals of better utility location at the various stages of a project are as follows:

- Planning: Select alignment to avoid problems and lower total costs.
- Design: Avoid redesign, delays, and cost increases.
- Construction: Avoid utility hits, injuries, change orders, delays, and cost increases.

The recommended actions in regard to this topic are as follows:

- Address funding, procedural, and contractual issues to improve the situation regarding the interaction of transportation projects and utility plants. There are many potential avenues for such improvement, but it is recommended that a guidance document concerning the funding, procedural, and contractual issues be prepared and provided for transportation project designers, DOT staff, and management personnel. This should include information on typical costs and schedules for utility relocations and repairs and cost-risk scenarios, allowing some comparison of utility-location costs versus incurred risk later in the project.
- Support the development and adoption of utility damage-prevention efforts. Many best practices are available through the Common Ground Alliance.
- Support the development and adoption of technologies aimed at damage prevention when construction is under way. Specific promising technologies include the following:
  - See-ahead utility detection systems that work with excavation, drilling, or tunneling equipment. They do not address the planning and design issues but do avoid the signal penetration issues for GPR utility detection because the distances being scanned are short.
  - Automatic checking of the GPS coordinates of a working excavator against previous one-call ticket locations. This addresses the issue of non-one-call compliance and pipeline encroachment—both of which have been shown to cause utility damage and public safety issues.

Demonstration Project Development

Demonstration projects have frequently been mentioned as a step toward encouraging innovation and, more importantly, encouraging the adoption of innovation. One possible example of funding and managing demonstration projects related to the mapping of underground utilities within highway rights-of-way is the Off-System Bridge Rehabilitation Program (OSBR). This program is managed by the state DOT that oversees the design and construction of bridge replacements on highways that are not state or federal roads. This is a joint effort among FHWA, state DOT, and county officials. Funding for design and construction is 80% FHWA and 20% state. Counties have the responsibility of acquiring rights-of-way, relocating utilities, and providing traffic control devices, to name a few.

Funding incentives from SHRP 2, matching funds from FHWA, and state and local matching funds could be used to develop specific demonstration projects. It is recommended that mapping and database management should be under state DOT jurisdiction. This would allow or mandate that underground utilities be managed within major highways that already fall under state DOT control. Also, state DOTs would ensure that the data or database is in a file format or computer program that is common, compatible, and easy for transportation engineers to use.

By requiring local matching funds, local urban municipalities might have the opportunity to participate in the program, as well to include their local streets. It would be in the best interest of urban municipalities to know where the utilities are actually located under their streets. Rural counties could choose not to map utilities on their more rural roadways, which are not as likely to undergo a major widening or improvement project.

Education and Training

Despite the extensive network of underground utilities and pipelines across the United States, very few formal education and training resources specifically address design, operation, and maintenance of these assets. Limited efforts have been made to introduce pipeline-related courses and utility asset management instruction into engineering curricula, but this introduction is difficult because of the numerous educational and training needs for each branch of engineering. Utility locating and characterization is, practically speaking, not addressed at all in the majority of engineering curricula in which transportation design project personnel are educated. The topic is most closely related to the study of geophysics in scientific or engineering curricula. Geophysicists are most likely to be involved in new locating and characterization equipment development. Use of general-purpose locating equipment is likely to fall to general construction personnel who have varying levels of training on how to use the equipment and on the physical phenomena affecting the output of the equipment.

This situation is not conducive to the effective management, location, and characterization of underground utilities. On a positive note, the issue of site investigation and mapping of buried assets is starting to make its way into texts dealing with buried utilities, such as in Read (*29*), which has a chapter titled "Site Investigation and Mapping of Buried Assets."

Potential actions in education and training related specifically to the technology of utility locating and characterization include the following:

- Educational materials could be prepared that provide an understanding of the physical principles behind technologies used in utility locating and characterization and that are aimed at formal engineering and construction curricula in universities. This could include short modules suitable for adoption in transportation-related classes or other sectors of engineering curricula. It could also include a more extensive module suitable as a stand-alone short course or for incorporation in undergraduate or graduate courses covering infrastructure management, pipeline design, underground construction, and so forth. (See Table 6.1 for a curriculum proposed by Lew and Anspach (*30*).)
- Educational materials could also be prepared for use by designers, policy makers, and other stakeholders that address the capabilities of existing and novel technologies, the importance of utility issues in transportation projects, and guidelines for best practices in terms of procedures to be followed to allow agencies to get the most out of the technologies and SUE processes that they adopt.

Proposed Project Alternatives

The avenues of improvement described in previous sections were evaluated with respect to the expected duration and funding constraints of SHRP 2, the desire for short- to mid-term results, and minimal duplication of activities under way by

1. Utility system design and construction practices
2. Surface geophysical techniques for imaging utilities
3. Survey practices/engineering surveys/control surveys
4. CADD platforms/GIS and data management/mapping
5. Economic issues for utility relocations
6. Right-of-way issues/national accommodation policies
7. Utility damage prevention laws, construction site safety
8. Traffic control, management, scheduling
9. Contract law, indemnification/insurance/liability issues
10. Communication skills, existing standards/best practices
11. Utility condition assessment, repair vs. replacement economics
12. Highway design/structure design/hydraulic design

Table 6.1. SUE-Related Educational Needs (30)

other organizations. As a result, nine target research and development activities were identified (including related educational components). As described in chapter 2, these nine alternatives were ranked by importance to SHRP 2 by a panel of 14 experts representing a range of participants in the transportation and utility sectors and including the key research team members. While there was significant variation in importance assigned to specific topics, a fairly clear ranking of preferred alternatives emerged from the group as a whole.

The result of the ranking process is shown in Table 6.2 with a score reflecting the degree of consensus and the relative importance of the topic. The final scores are relative to each other and, thus, can best be interpreted by considering the groups of target activities with similar scores. Storage, retrieval, and use of utility data and the development of multisensor platforms were given the greatest importance, followed closely by the development of guidelines. It is interesting to note that the top three investment alternatives focus on legacy problems with respect to dealing with existing underground infrastructure conditions. The second-highest priorities are smart tagging, education and training, and location of deep utilities, which either plan for the future or

Rank (Score)	Topic, Description, and Benefits
1. (0.17)	*Topic:* Storage, Retrieval, and Utilization of Utility Data *Description:* The development of dedicated software and hardware that would take advantage of recent advances in GPS and GIS technologies and increase the quality and efficiency of storing, retrieving, and utilizing utility records. *Benefits:* Increasingly comprehensive and accurate utility records, allowing resources to be focused on finding the remaining utilities.
2. (0.16)	*Topic:* Multisensor Platforms *Description:* The development of multisensor platforms that combine two or more existing technologies [e.g., ground-penetrating radar (GPR) and electromagnetic (EM) location or GPR and acoustic approaches]. *Benefits:* More reliable performance for utility locating across a variety of soil conditions.
3. (0.14)	*Topic:* Development of Guidelines *Description:* The development of guidelines and other tools for the conduct of utility investigations for transportation projects. *Benefits:* Allows transportation designers/planners to get the most out of the SUE data they receive so as to maximize the benefit/cost to the agency.
4. (0.12)	*Topic:* Smart Tagging *Description:* Advances in hardware and software that support smart tagging (e.g., ball markers, RFIDs) and documentation of utilities during initial installation and when exposed during excavations for various purposes. *Benefits:* Improved in-field identification of utility location, type, and characteristics.
5. (0.10)	*Topic:* Initiation of Education and Training *Description:* Initiation of educational, training, and dissemination activities aimed at increasing the awareness of transportation engineers and other decision makers to the state of the art and cost-benefit implications of gathering better utility information early in the design process. *Benefits:* Improved allocation and more effective use of utility locating expenditures.
6. (0.10)	*Topic:* Location of Deep Utilities *Description:* The development of locating technologies that target deep utilities that currently cannot be detected by surface-based approaches. These could include direct-path detection methods deployed from inside a utility or cross-bore techniques based on vacuum-excavated boreholes. *Benefits:* Improvement in detection of the most difficult utilities to find from the surface and reduced impact of unlocated or mislocated deep utilities on transportation projects.
7. (0.08)	*Topic:* External Soil Void Detection Technologies *Description:* The development of new technologies or enhancement of existing technologies capable of locating and characterizing external soil voids from within a buried pipe or culvert. *Benefits:* Detection of future ground instability problems that can cause road settlement and sinkholes.
8. (0.07)	*Topic:* Benchmarking of Current Technologies *Description:* The use of existing and/or purpose-constructed test facilities to systematically evaluate and document the capabilities and limitations of current utility locating equipment under controlled conditions of varying complexity. *Benefits:* Independent information on the capabilities of different types of detection equipment.
9. (0.06)	*Topic:* Deformation Characterization Technologies *Description:* The development of new technologies or enhancement of existing technologies capable of characterizing the cross-sectional deformation of buried pipes and culverts over time. *Benefits:* More reliable performance for utility locating across a variety of soil conditions.

Table 6.2. Ranked Priorities for SHRP 2 Funding Related to Utility Locating and Characterization Technologies

address specific issues. The third-highest priorities include the detection of external voids, benchmarking of current technologies, and deformation characterization technologies. This indicates that while utility-condition assessment is valuable, it is not the most urgent issue affecting transportation projects. The relatively low priority that was placed on the benchmarking of current technologies suggests that the existing body of knowledge that describes the key capabilities and limitations of major classes of utility locating techniques is considered adequate when compared against other urgent needs.

References

1. Osman, H., and T. E. El-Diraby. *Subsurface Utility Engineering in Ontario: Challenges & Opportunities.* Report to the Ontario Sewer & Watermain Contractors Association. Centre for Information Systems in Infrastructure & Construction, University of Toronto, Dept. of Civil Engineering, Oct. 2005, p. 71.
2. C. Paul Scott, TBE Inc., James H. Anspach, So-Deep, Inc., personal communications, p. 4.
3. Sinha, S. K., H. R. Thomas, M. C. Wang, and Y. J. Jung. *Subsurface Utility Engineering Manual.* FHWA-PA-2007-510401-08, Pennsylvania Transportation Institute, Penn State University, University Park, Pa., Aug. 2007, p. 136.
4. Nelson, R., and M. Daly. Creating a Major Emphasis on Damage Prevention. *Proc., Damage Prevention Convention,* Atlanta, Ga., Dec. 1998.
5. Doctor, R. H., N. A. Dunker, and N. M. Santee. *Third-Party Damage Prevention Systems.* GRI-95/0316, NICOR Technologies, Oct. 1995, p. 199.
6. Purdue University. *Cost Savings on Highway Projects Utilizing Subsurface Utility Engineering.* Report prepared for U.S. Federal Highway Administration, No. DTFH61-96-00090, Dec. 1999, p. 174.
7. National Research Council. *Seeing into the Earth: Noninvasive Characterization of the Shallow Subsurface for Environmental and Engineering Applications.* National Research Council, Washington, D.C., 2000, 148 pp.
8. Hereth, M., B. Selig, K. Leewis, and J. Zurcher. *Compendium of Practices and Current and Emerging Technologies to Prevent Mechanical Damage to Natural Gas and Hazardous Liquids Transmission Pipelines.* GRI 8747, March 2006, p. 119.
9. Common Ground Alliance. *CGA Review of NTSB Recommendation: Sponsor Independent Testing of Locator Equipment Performance under a Variety of Field Conditions. Develop Uniform Certification Criteria for Locator Equipment.* P-97-16 and P-97-17, CGA, Feb. 2003, p. 49.
10. Common Ground Alliance. *CGA Review of NTSB Recommendation: Review State Requirements for Location Accuracy and Hand-Dig (Special Care) Tolerance Zones*. P-97-18, P-97-17, CGA, Feb. 2003, p. 50.
11. Sterling, R. L. *Utility Locating Technologies: Statement of Need (SON).* Federal Laboratory Consortium Special Reports Series no. 9, FLC, June 1999, p. 19.
12. Sterling, R. L. *Utility Locating Technologies: A Summary of Responses to a Statement of Need.* Federal Laboratory Consortium Special Reports Series no. 9, FLC, Feb. 2000, p. 53.
13. K. Kothari, personal communication, p. 15.
14. D. Jarnecke, personal communication, p. 15.
15. *NASA to Provide Sharper Underground View of World Trade Center Area.* NASA press release, NASA Jet Propulsion Laboratory (JPL), Aug. 2002.
16. Bakhtar, K. *Demonstration of BakhtarRadar Buried Utility Detection and 3-Dimensional Imaging Capabilities.* PowerPoint Presentation, 2006, 32 slides.
17. *Underground Facility Pinpointing Demonstration: Bakhtar Associates, EarthRadar.* Attachment 5 to a GTI report provided by Bakhtar Associates, Newport Beach Calif., 2006.
18. Manacorda, G., H. Scott, M. Rameil, R. Courseille, M. Farrimond, and D. Pinchbeck. The ORFEUS Project: A Step Change in Ground Penetrating Radar Technology to Locate Buried Utilities. *Proc., Presented at ISTT NoDig 2007,* Rome, Sept. 2007.
19. Center for International Disaster Information. *Church World Service: Emergency Response Program. Revised Landmine Appeal for $150,000.* Humanitarian Activities Report Landmines—CWS, CIDI, Feb. 2001, 2006, p. 3.
20. Ishikawa, J., M. Kiyota, and K. Furuta. Test and Evaluation of Japanese GPR-based AP Mine Detection Systems Mounted on Robotic Vehicles. *Journal of Mine Action,* Issue 10.1, Aug. 2006, p. 16.
21. Welch, W.M. In Age of Terror, U.S. Fears Tunnels Pose Bigger Threat. *USA Today,* March 1, 2006, p. 2.
22. U.S. Army. *Army Advanced Concept Workshop on Shallow Tunnel Detection.* University of Mississippi and U.S. Army Research Office, National Center for Physical Acoustics, Research Triangle Park, N.C., 2006. http://pangea.stanford.edu/research/enviro/Tunnel%20Conference%20White %20Paper.pdf.
23. Dizzard, W. P., III. DHS Seeks Tunnel Vision. *Government Computer News,* Feb. 2007.
24. Lanka, M., A. Butler, and R. Sterling. Use of Approximate Reasoning Techniques for Locating Underground Utilities. *A Supplement to Tunneling and Underground Space Technology,* Vol.16, No.1, 2001, pp. 13–31.
25. Crice, D. MASW, The Wave of the Future. *J. of Environmental & Engineering Geophysics,* Vol. 10, June 2005, pp. 77–79.
26. Ellis, R., M. Venner, C. Paulsen, J. Anspach, G. Adams, and K. Vandenbergh. *SHRP 2 Report S2-R15-RW: Integrating the Priorities of Transportation Agencies and Utility Companies.* TRB, Washington, D.C., 2009.
27. Best Method Available. *World of Training,* One-Call Edition, May 2006, p. 39. http://www.underspace.com/WOT/index.php.
28. American Society of Civil Engineers. *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data.* ASCE Standard No. CI/ASCE 38-02, ASCE, Reston, Va., 2002, 20 pp.
29. Read, G.F. *Sewers: Replacement and New Construction.* Elsevier, 2004, p. 576.
30. Lew, J. J., and J. Anspach. Developing Curricula for Subsurface Utility Engineering (SUE). *Proc., CIB W89 International Conference on Building Education and Research BEAR 2003,* Lowry, Salford, United Kingdom, April 2003, 13 slides.

CHAPTER 7

Development of Requests for Proposals

Phase 2 Process

Once the ranked list of proposed research areas that had been prepared in the project's first phase was approved by the SHRP 2 committee, the research team was authorized to develop specific research plans based on these proposed areas of interest. During the project's second phase, the research team studied the best way to implement each research topic in terms of specific project descriptions that could be issued within the funding levels and time period allocated for this effort by the SHRP 2 program.

Issues for Consideration

The research topics include technological development and education or training and, according to the specific topic, must involve commercial technology providers, transportation agencies, utility companies, municipalities, research organizations, and subsurface utility engineering (SUE) professional and utility locators. Specific issues addressed in developing the project descriptions were as follows:

- **Whether the award should be divided into more than one phase:** Technological development projects in which Phase 1 proof-of-concept or prototype development could occur and be tested prior to the award of Phase 2 funds for further development were the types of projects considered for more than one phase. Also, it was not considered appropriate to reduce total project funding levels for multiphase awards.
- **Number of awards expected to be made within the same topic area:** Single-phase projects were designed so that the request for proposals (RFP) process would result in the selection of a single organization or team. Projects with more than one phase were evaluated on whether there would be an advantage to allowing the potential selection of more than one research group—if sufficient meritorious proposals were received. An evaluation at the end of the first phase of such a project would determine which approach would proceed to the second phase.
- **Tasks and deliverables:** Establishing a proposal framework invests greater clarity to the evaluation of competing proposals. Thus, expected tasks were described in sufficient detail to give proposal writers a clear idea of what was expected from the successful team(s), but the description was also broad enough to allow proposal writers an opportunity to include novel approaches.
- **Team composition:** Team composition is largely left to the groups to determine; however, guidance was given as to the expected components of a successful team when a critical part of the scope of work included collaboration among technology providers, agencies, and utilities.
- **Legal, security, and administrative roadblocks:** Some issues, such as the sharing of detailed 3-D utility positional information, involve significant issues of data ownership, secure levels of access to utility data, liability issues for incorrect data, and simple administrative reluctance to change current modes of operation. The project descriptions address these issues in part through educational activities but mostly through the requirement that pilot-scale operations of proposed technologies have sufficient complexity to allow most of the operational and administrative issues that are of interest to be addressed. The pilot-scale operations, however, should be small enough that teams can participate in the trial with limited risk to their overall operations.
- **Evaluation:** During their projects, successful proposers must go through several evaluations. The first task following the project award requires that a detailed technological-development plan be submitted. Phase 1 proof-of-concept prototypes can be measured against specific levels or ranges of equipment capability that are listed as targets. Proposers are given the option of proposing higher or lower target levels, but the target levels are intended to discourage

potential technological developments with only marginal real capability improvements from being continued into Phase 2 funding.

- **Funding level:** Proposed funding levels are given for each recommended project based on an evaluation of the level of technological development required, the complexity and effort for team members in team proposals, and the reporting and evaluation costs imposed on the project. Comparative funding levels also are based on the ranking of topics made during Phase 1, the time available for expenditure of funds, and the total funding available for this focus area within the SHRP 2 program. At this writing, the research phase of the SHRP 2 program is due to finish in September 2011, providing about 2.5 years as the maximum project timetable. The total remaining funding is expected to be about $4.7 million. Not all the projects listed can be funded with the level of funding available.
- **Distribution of funding between phases:** In most multiphase projects, a certain maximum level of funding is set for each phase of the project. This is done to ensure that adequate funds are targeted for each phase and are not frontloaded to the first phase. Such a scenario would reduce the value of selecting or evaluating technologies after the first phase, because most of the funds would have been spent already. In contrast, for other projects there is flexibility to allow the Phase 1 funds to be reduced but overall funding to remain unchanged. This will allow proposers with significant existing investments in technological development to concentrate efforts where they believe those efforts will advance the technological acceptance and usage in the best way. The review panel will need to evaluate which strategies are most appropriate for different technologies at different stages of development.
- **Education and training programs:** The education and training program projects are relatively straightforward, but training kits are required that include both presentation materials and supporting information such that the education or training can be effectively used by a wider group of professionals than the development team. An opportunity is provided to evaluate the materials and presentations before they are finalized. In the technology-oriented educational materials development, provision is made for a technological update to be prepared each year for two years. If this is found to be valuable, as is expected, it could be a task that is continued by an appropriate agency or organization into the future.

Draft Request for Proposals

The project descriptions developed by the team in each of the nine ranked priority areas follow. Only the core text of each proposed project is included because the supplementary information will be similar for each RFP and will need to be finalized once funding levels and submittal dates are determined and the specific RFPs for release have been selected by the SHRP 2 committee. Also, the deliverables and meeting requirements listings are omitted for brevity.

Project R01-P01: Innovation in Technologies to Support the Storage, Retrieval, and Utilization of Three-Dimensional Utility Location Data

Objective

This project is intended to support the development of software and hardware that would take advantage of recent advances in global positioning system (GPS) and geographical information system (GIS) technologies to increase the quality and efficiency of storing, retrieving, and using utility records with three-dimensional (3-D) positional information. The project is also intended to demonstrate the collection and use of such information in a multi-utility environment. The overall objective is to reduce the time spent on repeatedly refinding known utilities so that resources can be focused on unknown or previously misrecorded utilities and so that an increasingly comprehensive record of utility information beneath public rights-of-way can be created.

Number of Awards

One or two Phase 1 awards may be made. At the end of Phase 1, one project is expected to be selected to proceed to Phase 2.

Scope

The project is intended to operate at a pilot scale within a manageable geographic area and with a manageable number of participating utility companies to provide a demonstration of the access control, data security, data pedigree [based on Construction Institute/American Society of Civil Engineers (CI/ASCE) 38-02], positioning uncertainty, available characterization data, and liability issues that would be faced in a full-scale implementation of the system. Ongoing database management issues, data ownership, and data sharing shall be discussed. Providing documented examples of solutions to administrative and legal issues is an important part of the project. The project should include implementation of positional data capture involving the participating agency and the participating utilities for new utility installations and exposure of existing utilities, and the removal or updating of the status of those utilities that may have undergone relocation. The project should include the field deployment of computerized utility data or maps for use in utility locating for design purposes and for damage prevention for excavation or construction projects. Existing laws and best practices regarding utility damage prevention should be followed, but the advantages and disadvantages of the proposed approach should be recorded.

It is expected that the proposal team will include one or more technology providers; a transportation, municipal, or other public works agency with responsibility for permitting and construction within utility corridors or public rights-of-way; and at least two independent utility companies that have agreed to participate in the demonstration project.

It is anticipated that technology providers may have existing software or hardware in commercial use, in prototype development, or in the research stage. The proposal should disclose how the proposed technological developments will improve on the current technological development's status or deployment, or both. Proposers are encouraged to provide data to show the current capabilities of the proposer's technology, including horizontal and vertical positional accuracy. Information about the earlier use of such technologies in connection with projects should be verified by a client or consultant that is not financially connected to the technological development. It is important that sufficient technical information be provided in the proposal to allow the technical reviewers to assess the likelihood of significant advances over current technology. The proposers should also demonstrate familiarity with existing national and international approaches to this problem—for example, the U.K. VISTA/Mapping the Underworld initiative, the Virginia Pilot Study of GPS-based one-call ticketing, and other commercial developments in the public domain.

Tasks

Phase 1: Technology Development and Detailed Operational Procedures

Task 1. Prepare an expanded technological-development plan across all proposed phases with more detailed development and evaluation milestones. These should amplify the plans presented in the proposal but remain consistent with the proposal plans and schedule. Prototype refinement and testing cycles should be identified. This task will be due within two months of approval to proceed.

Task 2. Conduct a literature review and an international search for examples of existing coordinated 3-D mapping protocols and projects involving multiple utilities.

Task 3. Develop detailed procedures that will guide the software and hardware trials in coordinating among the software and hardware providers and the participating utility companies or agencies. This information should include who is authorized to collect data for input into the system, the quality assurance/quality control (QA/QC) data verification procedures, the hierarchy of access controls versus accuracy and extent of data provided, response times for incorporation of the data into the system, and so forth.

Task 4. Identify any necessary new standards for data capture, display, or management, and identify the best standards development organization or other agency to develop these standards.

Task 5. Develop hardware and software as necessary to further develop the system and deploy it for the pilot study.

Phase 2: Pilot Study Operation and Reporting

Task 6. Operate the hardware and software in a pilot study mode for one year in a specified geographic area and with agreement among the technology providers, the host agency, and the participating utility companies (see the earlier discussion under "Scope").

Task 7. Prepare a final report and presentation kit that documents the project and the results of the pilot study. The principal audience of the report is to be other agencies and municipalities that might consider adopting the demonstrated system or similar mapping advances.

Funds Available

The funds requested from SHRP 2 for this project should not exceed $300,000 for Phase 1 and $1,200,000 for the total project, including both Phase 1 and Phase 2. (See "Note: Budget Considerations" for additional information.)

Contract Period

A 30-month contract period including review and final editing is anticipated.

Note: Budget Considerations

It is anticipated that either one or two Phase 1 awards may be made but that only one project is expected to proceed to Phase 2. Also, the funds for Phase 2 will not be released unless satisfactory operating parameters and procedures have been developed and the Phase 1 submittals have been approved by SHRP 2. The budget for Phase 1 may not exceed $300,000. The budget for the total of Phase 1 and Phase 2 may not exceed

$1,200,000. A detailed budget covering all phases according to the requirements of the SHRP 2 Proposal Manual is required.

Project R01-P02: Utility Locating Technology Development Using Multisensor Platforms

Objective

This project will support the technological development of multisensor approaches to improve the detection and accurate locating of buried utilities. The combinations of proposed sensor technologies should be shown to potentially offer significant advances in utility-detection performance across a wide range of soil types and site conditions. Enhanced utility detection is the primary objective, but productivity issues in commercial use also are important. Preference will be given to the integration and data fusion of sensors using at least two different geophysical phenomena. The project will consider the development of new platforms, as well as the enhancement of existing concepts and designs. Improved coupling methods to assist in identifying known utilities may also be used to improve detection performance.

Background

Deployment of multiple sensing techniques is necessary in many instances to image various utilities composed of different materials, depths, conductivity, ground conditions, surface obstacles, and so forth. Covering the same ground more than once with different instruments or techniques is inefficient if one pass with multiple equipment capabilities could achieve the desired outcome. Time constraints, equipment cost, knowledge of equipment capability, and operator training may be factors that discourage making the necessary multiple passes using different equipment. Enhanced data interpretation may be obtained on a single pass with a multisensor platform as a result of simultaneous signal processing. Combined with improved coupling techniques, a multisensor platform may lead to better quality interpretation and less expensive production. The goal of this research is not to just place two or more distinct instruments on a single platform, but by doing so to improve detection ability or production or to lower equipment and training costs.

Number of Awards

One or two Phase 1 awards may be made. At the end of Phase 1, one multisensor technology is expected to be selected to proceed to Phase 2.

Tasks

Phase 1: Proof of Concept

Task 1. Prepare an expanded technological development plan across all proposed phases with more detailed development and evaluation milestones. These should amplify the plans presented in the proposal but remain consistent with the proposal plans and schedule. Prototype refinement and testing cycles should be identified. This task will be due within two months of the approval to proceed.

Task 2. Develop a working proof-of-concept prototype of the multisensor platform that can be used in laboratory and controlled field trials (this is not intended to be a market-ready unit). The approximate dimensions of the proposed sensor platform and the anticipated means of deployment (for example, hand carried, push cart, or powered cart) should be disclosed in the proposal. It is anticipated that proposers may have existing versions of multisensor platforms either in commercial use, prototype development, or the research stage. The proposal should disclose how the proposed technological developments would improve on the existing technological development. Devices can have any combination of passive detection or active signal generation. Proposers are encouraged to provide test data to show the current capabilities of the proposer's technology. Such test data should be verified by an independent agency with expertise in utility locating technologies. It is important that sufficient technical information be provided in the proposal to allow the technical reviewers to assess the likelihood of significant advances over current technology. The proposers should also demonstrate familiarity with existing multisensor platform research (for example, the U.K. Mapping the Underworld initiative and commercial developments in the public domain).

Task 3. Participate in controlled site testing of the detection capabilities of the platform developed under Task 2. The utility and soil conditions to be tested are shown in Table 7.1. The test results will be used to assist in the selection of the platform that will continue to Phase 2.

A depth range for the test has been given because the actual field test will record the accuracy of the depth prediction provided by the equipment within the range shown. If the proposer does not believe that these depths are attainable with their proposed solution, then alternate figures should be provided for the higher value in each depth range. In addition to the results provided after signal processing and interpretation, the raw signals received from the sensors must be recorded and provided.

Depth	Soil: Clay (conduct. > 4 mmhos/cm)	Soil: Sand	Pipe: 2 in. PVC Empty	Pipe: 2 in. PVC Water Filled	Pipe: 6 in. PVC Empty	Pipe: 12 in. Steel Empty
12 in. to 24 in. w 6 in. asphalt	X		X	X		
24 in. to 36 in. w/out pavement	X		X	X		
48 in. to 60 in. w/out pavement	X		X	X	X	
72 in. to 96 in. w/out pavement		X			X	
15 ft to 20 ft w/out pavement		X				X

Table 7.1. Utility Types and Soil Conditions

Phase 2: Development of a Prototype

TASK 4: Refine the hardware and software technologies in the detection platform and develop rugged equipment suitable for testing under service conditions.

Phase 3: Pilot Testing

TASK 5: The unit resulting from Phase 2 will be used for testing in a variety of utility test beds and field environments that will allow the performance to be compared with earlier technologies. The proposer should propose at least five test locations and include the cost of the testing in the proposal budget, including any test-facility fees. Specific test sites may be noted in the final RFP, and general test sites of the following conditions should also be included: urban street utility mapping with ground conductivity > 4 mmhos/cm and with high utility density and complexity.

TASK 6: The unit will be placed in service with an independent provider of SUE services for six months. The company agreeing to use the unit in prototype operations for the six-month period should be identified in the proposal. A log showing the productivity of the units and utility mapping performance should be maintained and a report on the performance of the units produced. Costs for maintaining the equipment in working order during this period will be included in the proposal.

Funds Available

The funds requested from SHRP 2 for this project should not exceed $250,000 for Phase 1 and $500,000 for Phase 2. (See "Note: Budget Considerations" for additional information.)

Contract Period

A 30-month contract period including review and final editing is anticipated.

Note: Budget Considerations

It is anticipated that either one or two Phase1 awards may be made but that only one multisensor approach may proceed to Phase 2. Also, Phase 2 funds will not be released unless satisfactory performance of the Phase 1 working prototype is achieved and the Phase 1 submittals have been approved by SHRP 2. The budget for Phase 1 may not exceed $250,000. The budget for Phase 2 may not exceed $500,000. A detailed budget covering all phases according to the requirements of the SHRP 2 Proposal Manual is required.

Project R01-P03: Development of Guidelines for Incorporating Advanced Utility Locating and Characterization Technologies in Transportation Projects

Objective

This project will develop a set of guidelines to assist transportation agencies in planning and contracting for the use of advanced technologies to collect information on utility location and characterization. The guidelines will help in archiving project utility data (following ASCE Standard 38-02) and in identifying how to assess the risk of unlocated or mislocated utilities to ensure appropriate budget allocations are made.

Number of Awards

It is anticipated that one award will be made for this project.

Tasks

TASK 1. Contact transportation agencies, design consultants, utility owners, SUE providers and utility-locating firms to identify key issues and compile best practices specifically concerning the use of advanced technologies in the collection and archiving of utility data on transportation projects. Such contacts should be designed to build on the information collected in previous studies (for example, SHRP 2 Project R01 and SHRP 2 Project R15) rather than duplicate previous information-collection efforts.

Task 2. Prepare a document of guidelines for designers and administrative personnel in transportation agencies. These guidelines should be as prescriptive as possible to guide the reader through the choices to be made (that is, a flow chart leading to a decision or a decision matrix is preferred to a description of issues to be considered). The guidelines, to the extent possible, should be applicable nationally, but variations in the appropriate procedures should be discussed where major differences in administrative practices require different approaches. Demonstrations of improved data capture and data management are being funded under a separate project, and preliminary information from this project should be addressed in the guidelines. Issues to be addressed in the guidelines include, but are not limited to, the following:

- Reasons for accurate and timely utility data collection and the consequences of poor or incomplete data;
- Goals of each stage of the utility data collection process and the relationship between the design stages and the type and extent of the utility data collection effort;
- Budget allocation amount and timing for utility location and characterization activities;
- Guidance on how to specify the experience and equipment requirements for utility data collection providers;
- Cost and effectiveness among the different classes of utility data collection approaches (that is, SUE versus standard contract locating) and among categories of utility locating equipment [for example, ground-penetrating radar (GPR) versus multisensor platforms or basic electromagnetic locators];
- Guidance should also be included on the costs associated with field inspection processes (for example, confined space entry, traffic control, and so forth);
- Supporting data (from previous studies, not original research) on cost-benefit ratios for different utility data collection practices, including SUE;
- Proper management of utility data updates during the design and construction process; and
- Proper data archiving so that the information does not become lost to future projects in the same area.

Task 3: Prepare a 2–3 hour training session kit that consists of Microsoft PowerPoint presentations and supporting material, suitable for use in transportation agency and design personnel training sessions on the guidelines. The presentation should be annotated using the notes feature to guide future presenters of the course and provide additional detail.

Task 4. Prepare a 10–20 minute Microsoft PowerPoint presentation for use in explaining the purpose and rationale for the guidelines to transportation executives and conference audiences. The presentation should be annotated using the notes feature to guide future users of the presentation and provide additional detail.

Task 5. Demonstrate the course and the executive presentation at a venue to be agreed on by the project officer and the project team. This should be scheduled to allow revisions to be made based on feedback from the audience and SHRP 2 reviewers.

Funds Available

The funds proposed for this project should not exceed $75,000.

Contract Period

A 14-month contract period including review and final editing is anticipated.

Project R01-P04: Innovation in Smart Tagging of Buried Utility Systems

Objective

This project provides for research and development of hardware and software that support the “smart tagging” of buried utility systems during the initial installation of new pipelines or when a utility is exposed during excavations. Smart tagging refers to systems that provide either active or passive electromagnetic tags that can be attached to pipes, placed beside pipes, or incorporated into the manufacture of new pipes. Smart tags should have the capability to store information concerning the key characteristics of a utility pipe and should be updatable as the pipe is inspected, repaired, and so forth.

Number of Awards

One or two Phase 1 awards may be made. At the end of Phase 1, one smart-tagging technology is expected to be selected to proceed to Phase 2.

Tasks

Phase 1: Initial Proof of Concept

Task 1. Prepare an expanded technological development plan across all proposed phases with more detailed development and evaluation milestones. These should amplify the plans presented in the proposal but remain consistent with the proposal plans and schedule. Prototype refinement and testing cycles should be identified. This task will be due within two months of the approval to proceed.

Task 2. Perform literature research, simulation, and laboratory and field testing of candidate technologies for the proposed smart-tagging system to develop the technical capabilities of the proposed system. Key issues to be considered include the maximum burial depth of the sensors, the proposed system for long-term use or replacement of sensors (and an energy provision if an active sensor is proposed), the data storage and update capabilities, data security, the anticipated cost of the tags in commercial production, environmental restrictions, and the method of attachment or association with the pipe or appurtenance that is tagged. A report describing the results of this task shall be submitted for review. Proposals should provide information on the physical makeup and the technical capabilities of the proposed system versus the anticipated cost to deploy.

Task 3. Develop a precommercial prototype system suitable for proof-of-concept testing that will provide a physical demonstration of the capabilities of the tag system. The prototype must share similar operating characteristics with a future commercial system in terms of its size and the power of its key components.

Task 4. Conduct proof-of-concept testing in the laboratory and in the field. Burial depths for detection and interrogation of the tags will be very important in terms of the widespread applicability of a smart-tagging system. Table 7.2 indicates the minimum desired performance for a smart-tagging system. Greater potential depth of operation is of significant benefit, but this must be balanced against sensor cost and placement considerations.

If the proposer believes that greater depths, which are a highly desirable outcome, are attainable with their proposed solution, this should be specified in the proposal. Likewise, if these depths are considered unattainable with the proposed solution, then alternate figures should be provided in the proposal for the expected maximum depths of operation. The results of the testing in this task will be used as a component in the selection of the technology that is funded for Phase 2.

	Soil	
Depth	Clay (conduct. > 4 mmhos/cm)	Sand
With 6 in. asphalt pavement	24 in.	48 in.
Without pavement	36 in.	60 in.

Table 7.2. Minimum Desired Performance for a Smart-Tagging System

Phase 2: Refinement and Field Testing

Task 5. Refine the hardware and software technologies in the proposed system and develop a set of sensors sufficient for field testing with an agency or utility. The number of tags to be prepared and used in testing shall be specified in the proposal.

Task 6. The precommercial prototypes shall be used for controlled testing as a system with one or more agencies or utilities that will allow information to be collected on performance, ease of use, and so forth. The proposer should propose at least one agency or utility that has agreed to cooperate in the testing of the tag system, and the cost of the testing must be included in the proposal budget.

Funds Available

The funds requested from SHRP 2 for this project should not exceed $300,000 for Phase 1 and $700,000 in total for both phases combined. (See "Note: Budget Considerations" for additional information.)

Contract Period

A 30-month contract period including review and final editing is anticipated.

Note: Budget Considerations

Only one smart-tagging approach is expected to proceed to Phase 2. Also, the funds for Phase 2 will not be released until satisfactory performance of the Phase 1 working prototype is achieved and the Phase 1 submittals have been approved by SHRP 2. The budget for Phase 1 may not exceed $300,000. The combined total budget for Phase 1 and Phase 2 may not exceed $700,000. A detailed budget covering all phases according to the requirements of the SHRP 2 Proposal Manual is required.

Project R01-P05: Education and Training for Utility Locating and Characterization Technologies

Objective

This project will develop education and training materials for agencies on the capabilities and availabilities of utility locating and characterization technologies. It will develop education and training materials on the costs and benefits associated with the deployment of state-of-the-practice and advanced technologies for utility locating and characterization. Materials will include discussions on necessary equipment technician qualifications. A parallel project (R01-P03) is developing guidelines for incorporating such technologies in transportation projects and on the general cost-benefit implications of the use of subsurface utility engineering approaches.

Number of Awards

It is anticipated that one award will be made for this project.

Tasks

Task 1. Conduct a literature search for educational and training materials on utility locating and characterization technologies, and update existing literature searches to cover recent technological innovations.

Task 2. Contact manufacturers of advanced technologies for utility locating or characterization for examples of the cost-benefit of deploying their technologies. The results provided should be checked with the agency that uses the services. Address stakeholder expectations for utility locating equipment. Request public domain use of simulations, videos, and so forth to be used for educational and training purposes.

Task 3. Develop educational and training materials to explain the key principles behind the use of utility locating and characterization technologies, and the qualifications of its operators. This may include simulations, presentation graphics, and case study results. Confirm that all materials used are available for public domain use, with copyright releases obtained as necessary. Address the influence of site and ground conditions and interference from other utilities or structures when discussing equipment capabilities.

Task 4. Prepare a 10-hour training session kit that consists of Microsoft PowerPoint presentations and supporting material that is suitable for transportation agency and design personnel and for use as a module in related educational courses at universities and technical colleges. The presentation should be annotated using the notes feature to guide future presenters of the course and to provide additional detail. Course materials should be constructed so that methods can be explained in principle with minimal advanced mathematics but with additional presentation materials available to offer a more detailed explanation to advanced audiences.

Task 5. Prepare an annual technological update based on Task 1 that will provide transportation agencies and highway design personnel with an annual summary of advances and findings with respect to utility locating and characterization technologies. The update should be less than 10 pages long in publication format and should be suitable for stand-alone distribution or use as a paper in conference proceedings.

Task 6. Demonstrate the training course at a venue to be agreed on by the project officer and the project team. This should be scheduled to allow revisions to be made based on feedback from the audience and SHRP 2 reviewers.

Funds Available

The funds proposed for this project should not exceed $125,000.

Contract Period

A 27-month contract period including review and final editing is anticipated.

Project R01-P06: Innovation in the Location of Deep Utility Pipes and Tunnels

Objective

This project will support the research and development of locating technologies that target deep utilities currently undetectable by surface-based approaches. Such technologies may include, but are not limited to, alternative or novel surface-based approaches, direct-path detection methods deployed from inside an existing deep utility, or cross-bore techniques based on adjacent boreholes.

Project Background

Deep utilities are a particularly difficult problem for detection. Utilities are increasingly placed deeper as the near-surface space becomes crowded and utility-construction techniques become more capable. The existing surface techniques for utility detection have become ineffective due to signal-to-noise ratio factors, masking of deeper utilities by shallow ones, the presence of groundwater, and other geologic issues. Deep utilities, when encountered during construction, are generally costly to relocate or repair.

Number of Awards

It is anticipated that one award will be made for this project.

Tasks

Task 1. Prepare an expanded technological development plan with more detailed development and evaluation milestones. These should amplify the plans presented in the proposal but remain consistent with the proposal plans and schedule. Technological refinement and testing cycles should be identified. This task will be due within two months of the approval to proceed.

Task 2. Perform literature research, simulation, and laboratory and field testing of candidate technologies to detect deep utilities to develop the desired technical capabilities of the proposed system. Key issues to be considered include the utility's size and material type, its distance from the surface or distance from boreholes or utility pipes used for detection, and the time and cost expected for the detection process. Limitations of the host (the detector or receiver travel pipe) utility pipe material or size will be an important consideration. The proposed technological development may be based on enhancements of existing technologies or methodologies or on innovative technologies or methodologies. A report providing the results of this task will be submitted for review.

Task 3. Conduct proof-of-concept testing in the field and compile data on the technique's detection effectiveness, deployment, equipment required, costs, and so forth.

Funds Available

The funds requested from SHRP 2 for this project should not exceed $400,000.

Contract Period

A 30-month contract period including review and final editing is anticipated.

Project R01-P07: Development of External Soil Void Detection Technologies

Objective

This project will support the development of new technologies or the enhancement of existing technologies to locate and characterize external soil voids from within a buried pipe or culvert.

Number of Awards

It is anticipated that one award will be made for this project.

Tasks

Task 1. Prepare an expanded technological development plan with more detailed development and evaluation milestones. These should amplify the plans presented in the proposal but be consistent with the proposal plans and schedule. Technological refinement and testing cycles should be identified. This task will be due within two months of the approval to proceed.

Task 2. Perform literature search, simulation, and laboratory and field testing of candidate technologies to detect external soil voids to develop the technical capabilities of the proposed system. Key issues to be considered include the range of pipe sizes in which the technology can be deployed, restrictions on the pipe materials that allow void detection, the extent of pipe cleaning required, the need for direct or close contact to the pipe wall, and the ability to incorporate the detection technology in conjunction with other pipe inspection systems.

Task 3. Develop a working proof-of-concept prototype of the void detection system that can be used in laboratory and controlled field trials. This is not intended to be a market-ready unit. The proposal should disclose the approximate dimensions of the proposed detection equipment and the proposed speed of operation along the pipe. It is anticipated that proposers may have existing versions of void detection technologies either in commercial use, prototype development, or the research stage. The proposal should disclose how the proposed technological developments will improve on the current technology. Proposers are encouraged to provide test data to illustrate the capabilities of their technology. Such test data should be verified by an independent agency. It is important that sufficient technical information be provided in the proposal to allow the technical reviewers to assess the likelihood of significant advances over current technology. The proposers should also demonstrate familiarity with existing void detection research and commercial developments in the public domain.

Task 4. Conduct proof-of-concept testing in the field and compile data on the detection effectiveness of the technique, the deployment time, equipment required, costs, and so forth. The proposal should identify a utility company or an agency that is willing to cooperate in the field testing and should include the cost of the testing in the proposal budget.

Funds Available

The funds requested from SHRP 2 for this project should not exceed $300,000.

Contract Period

A 28-month contract period including review and final editing is anticipated.

Project R01-P08: Test Facilities and Test Protocols for the Performance Classification of Utility Detection Technologies

Objective

This project will support the use, further development, or creation of test facilities for the independent assessment of utility locating technologies. The project will create a set of utility detection equipment that will cover a wide range of common detection scenarios, and it will provide test facilities that will assess what classifications the utility locating technologies meet. Classifying the tested performance of utility locating equipment will allow equipment to be selected more cost-effectively according to the difficulty of a utility locating task.

Number of Awards

It is anticipated that one award will be made for this project.

Tasks

Task 1. Prepare a proposed set of about 10 utility detection capability classifications based on the type of pipe or cable detected, the need to impress a signal on the pipe or cable for detection, the soil conditions, the depth of detection, and so forth. This should allow the full range of existing equipment to fall into at least one equipment classification. Advanced equipment would likely cover a variety of classifications.

Task 2. Contact equipment manufacturers, associations, and others to discuss the proposed set of classifications and receive input. Prepare an updated set of recommended classifications for locating-equipment capabilities.

Task 3. Prepare designs and cost estimates for the creation or enhancement of controlled-condition utility locating test facilities. Familiarity with existing national and international test facilities should be demonstrated in the proposal. Issues to be considered include buried utility types (pipes and cables), soil types, ground surface conditions (presence of pavement or rough ground), depths and diameters included, utility layout complexity, and ability to control soil-moisture content.

Task 4. Construct the test facilities following approval by SHRP 2.

Task 5. Conduct evaluation tests on at least five equipment types that cover a broad range of utility detection needs as described by the classification system developed in Tasks 1 and 2. Manufacturers should approve the classifications under which their equipment should be tested. Tentative agreement from manufacturers to participate in the testing program should be documented in the proposal.

Funds Available

The funds requested from SHRP 2 for this project should not exceed $300,000.

Contract Period

A 28-month contract period including review and final editing is anticipated.

Project R01-P09: Development of Internal Pipe Cross-Sectional Deformation Monitoring Systems

Objective

This project will support the development of new technologies or the enhancement of existing technologies capable of characterizing and tracking the cross-sectional deformation of buried pipes and culverts over their service life through internal measurements.

Number of Awards

It is anticipated that one award will be made for this project.

Tasks

Task 1: Prepare an expanded technological development plan with more detailed development and evaluation milestones. These should amplify the plans presented in the proposal but be consistent with the proposal plans and schedule. Technological refinement and testing cycles should be identified. This task will be due within two months of the approval to proceed.

Task 2: Perform literature research, simulation, and laboratory and field testing of the proposed technology. Some key issues to be addressed in the proposal include the range of pipe sizes in which the technology can be deployed, the accuracy and repeatability of measurements at a single cross section, the ability to properly register measurements against each other that were made at different times along the pipe so that changes in cross-sectional dimensions can be inferred, any restrictions on pipe materials that can be measured, the extent of pipe cleaning required, and the ability to incorporate the detection technology in conjunction with other pipe inspection systems.

Task 3. Develop a working proof-of-concept prototype of the cross-sectional measurement system with associated software that can be used in laboratory and controlled field trials (this is not intended to be a market-ready unit). The proposal should disclose the proposed dimensions of the detection equipment and the speed of operation along the pipe. It is anticipated that proposers may have existing versions of cross-section measurement technologies in commercial use, prototype development, or in the research stage. The proposal should disclose how the proposed technological developments will improve the current status of the technological development. Proposers are encouraged to provide test data to show the current capabilities of the proposers' technology. Such test data should be verified by an independent agency. It is important that sufficient technical information be provided in the proposal to allow the technical reviewers to assess the likelihood of significant advances over current technology. The proposers should also demonstrate familiarity with existing cross-sectional measurement research and commercial developments in the public domain.

Task 4. Conduct proof-of-concept testing in the field and compile data on the technique's accuracy and effectiveness, the time for deployment, equipment required, costs, and so forth. The proposal should identify a utility or agency that is willing to cooperate in the field testing and should include the testing in the proposal budget.

Funds Available

The funds requested from SHRP 2 for this project should not exceed $300,000.

Contract Period

A 28-month contract period including review and final editing is anticipated.

CHAPTER 8

Conclusions

Utility Locating Technologies

At present, there is no prospect that a tool will be developed in the foreseeable future that can simply and quickly locate and characterize all of the buried utilities at a site. In truth, there is little likelihood that such a tool could ever be developed. However, there are many technological improvements that can and should be made that would improve our ability to cost-effectively detect utilities, integrate this information with the information in utility company databases, and retrieve information on site and in real time.

Even with improved technology, though, it is unlikely that the necessary resources and technologies would be deployed to a site without first undertaking a cost-benefit analysis that considers potential project delays, safety issues, and cost overruns that could occur if utilities are not effectively identified and located. Thus, technological advances in utility locating and characterization must be accompanied by complementary improvements in management and procedures to allow this technology to be used effectively. In fact, the management and funding of efforts to locate utilities, the required training, and the prohibitive cost of implementing effective operations are as much factors in preventing the effective use of advanced technologies in the field as the technology's limitations.

Subsurface utility engineering (SUE) is a viable engineering practice that reduces costs associated with subsurface utility risks. In SUE, an engineer collects and depicts utility location data, identifies the source of the data, and assigns the data a quality level based on its reliability. SUE is most effective when an agency adopts it in a systematic manner and introduces it early in the design stage. Once designers realize the value of SUE data in optimizing their design and apply the SUE practice, financial returns should increase.

Utility Characterization Technologies

Few aspects of utility characterization data can be reliably determined from a surface-based utility location or characterization survey. This could change substantially, however, with the introduction of utility smart-marking and -tagging systems. Using these systems, new utilities would be identified with programmable and updatable electronic markers, and existing utilities would be marked as they are exposed for maintenance or for other excavation activities.

Without smart tags, most characterization data must be obtained from utility records or by physically exposing the utility through access pits or test holes. The quality of utility records varies in the original information's accuracy and the consistency of its updates. Even the type and applicability of information that can be gained, without destruction, when the utility is physically exposed is limited.

The internal inspection techniques for pipelines, the development of consistent terminology for pipe defects and pipe condition assessment, and the use of asset management approaches to effectively manage buried utilities over their life cycle have been the areas of greatest activity in recent years in terms of utility characterization data. There has been an equivalent technological and procedural improvement in management of electrical and communication cables. Many utility companies have readily embraced asset management approaches and, hence, are in a much better position to answer questions about utility condition today than they were a decade ago.

Targeting Improvements

Chapter 6 discussed the technology improvements that the research team considers most beneficial in reducing the delays and costs incurred by inaccurately locating and characterizing utilities in transportation renewal projects. As has been emphasized, managerial and financial adjustments may improve and allow for more effective utility location and characterization work to be done early in the highway project design process. Improvements in the utility coordination processes that exist in many areas of the country are also possible, and these improvements are addressed in a companion study (*1*).

Previous discussion has addressed technological problems and potential solutions related to key locating and characterization issues, including deep utilities, nonconducting utilities, congested utilities, unfavorable site conditions, mitigation of practical limitations on theoretical performance, multisensor approaches, target recognition, 3-D location and transfer to geographic information system/computer-aided design (GIS/CAD) databases, development of additional approaches, and utility characterization improvements. Some examples were provided of the current state of the art for both utility locating and characterization. Specific areas or actions for improvement were then discussed in terms of characterization information for planning and design, available access to the utility, recordkeeping, mapping and marking; mapping and database technologies; utility marking technologies; liability and security management; funding, procedural, and contractual issues; demonstration project development; and education and training.

A broad range of potential technological improvements for utility locating and characterization were identified. These were then evaluated with respect to SHRP 2's expected time and funding constraints and the program's desire for short- to mid-term results with minimal duplication of the activities under way by other organizations. Nine target research and development activities were identified, including related educational components. This list of target activities was then ranked by a panel of 14 experts from the transportation and utility sectors, including key research team members, according to the importance of each activity to SHRP 2, as was described in chapter 2. Although the importance assigned to specific topics varied significantly, the group as a whole had a fairly clear preference in their ranking of alternatives.

The ranking results are shown in Table 6.2 in chapter 6. Storage, retrieval, and use of utility data and the development of multisensor platforms were ranked as the most important activities, with the development of guidelines ranked close behind. The second-highest priority was given to smart tagging, educating and training, and locating deep utilities. Technologies grouped in the third tier of priorities include the detection of external voids, the benchmarking of current technologies, and deformation characterization technologies.

The ranking of priorities was then developed into draft requests for proposals (RFPs) for the SHRP 2 committee to consider and from which to select the final work program within this SHRP 2 focus area.

Concluding Remarks

Buried utility congestion will only increase with time. Utility locating and imaging technologies will continue to evolve, but they are unlikely to offer a comprehensive solution for all site conditions. Project owners can mitigate utility-related problems through effective utility coordination, realistic utility risk and cost assessments, and integration of policies, procedures, scopes of work, and qualification and training requirements for utility field investigations.

The ranking process for future research opportunities indicated that greatest potential for improvement exists in the area of accurate mapping and marking of utilities as they are installed or exposed and in the area of ongoing enhancements to accessible GIS-based utility databases that contain SUE utility-quality designations. Significant administrative and legal hurdles may need to be overcome to fully implement technological improvements in these areas, but they offer significant advantages. Improvements to multisensor systems to compensate for weaknesses in the individual detection approaches for various target utilities, depths, and site conditions is also an area of great interest, and improvements to the techniques for obtaining accurate utility locations ranked as more critical than improvements to techniques for obtaining accurate utility characterization. Finally, from the recommended future research opportunities identified in this report, SHRP 2 developed three follow-on research projects that were advertised in March 2009.

Reference

1. Ellis, R., M. Venner, C. Paulsen, J. Anspach, G. Adams, and K. Vandenbergh. *SHRP 2 Report S2-R15-RW: Integrating the Priorities of Transportation Agencies and Utility Companies.* TRB, Washington, D.C., 2009.

APPENDIX A

Annotated Bibliography

The references in each category (reports/books, papers, articles, and so forth) are sorted by year in descending order, and within each year by author in alphabetical order.

Organizations and Major Research Projects

[1] Common Ground Alliance (CGA)

http://www.commongroundalliance.com

The Common Ground Alliance (CGA) is a member-driven association dedicated to ensuring public safety, environmental protection, and the integrity of services by promoting effective damage prevention practices.

[2] Engineering and Physical Sciences Research Council (EPSRC)

http://www.epsrc.ac.uk/default.htm

The Engineering and Physical Sciences Research Council is the United Kingdom's funding agency for research and training in engineering and the physical sciences.

[3] European Street Works Research Advisory Council (ESWRAC)

http://www.ESWRAC.org

This organization is a group of European utilities, cities, and transport organizations that promotes research in identifying buried utilities.

[4] Federal Energy Regulatory Commission (FERC)

http://www.ferc.gov

FERC is an independent agency that regulates the interstate transmission of natural gas, oil, and electricity.

[5] Federal Laboratory Consortium for Technology Transfer (FLC)

http://www.federallabs.org/store/greenbook/

The Federal Laboratory Consortium for Technology Transfer is a nationwide network of federal laboratories that provides the forum to develop strategies and opportunities for linking laboratory mission technologies and expertise with the marketplace.

[6] Geospatial Information and Technology Association (GITA)

http://www.gita.org/

GITA is a nonprofit educational association serving the global geospatial community.

[7] GIGA

http://www.osys.co.uk/download/gigaproject_paper.pdf

GIGA was a research study aimed at improving ground-penetrating radar (GPR) to locate buried pipes or other structures. The Thalès group, Tracto-Technik, Ingegneria dei Sistemi SpA (IDS), and Groupement européen de recherche gazière (GERG, European gas research group) partnered with the Research Division of Gaz de France.

[8] Mapping the Underworld (MTU)

http://www.mappingtheunderworld.ac.uk

This website is for the EPSRC research project aimed at locating buried utilities.

[9] Underground Utility and Leak Locators Association (UULLA)

http://www.uulla.org

UULLA is a nonprofit association of firms and individuals involved in providing underground utility and leak detection services to municipalities, private property owners, industry, engineers, architects and others.

[10] U.S. Department of Transportation, Office of Pipeline Safety (OPS)

http://ops.dot.gov/

Their top priority is preventing excavation damage. OPS has developed a comprehensive damage prevention program to protect underground facilities.

[11] Visualising Integrated Information on Buried Assets to Reduce Streetworks (VISTA)

http://www.vistadtiproject.org

VISTA is a United Kingdom project to bring together existing paper and digital records with data from satellite and ground-based positioning systems and thus create a 3-D map of pipes and cables buried underground.

Utility Locating

References listed in this section provide information on how to find utilities, including their horizontal position and depth. Methods and technologies for utility locating can also be found in these references, as well as existing practices and recommendations.

Reports/Books

[12] American Water Works Association Research Foundation and Gas Technology Institute. *Underground Facility Pinpointing—Finding a Precise Locating System for Buried Underground Facilities,* Phase II Ongoing Research #3133, 2008.

American Water Works Association Research Foundation (AWWARF) and Gas Technology Institute (GTI) evaluate the use of several emerging technologies in locating and pinpointing buried water mains. The evaluation includes pipe materials, pipe diameters, burial depths, soil environments, other issues directly relevant to water distribution networks, and field studies to evaluate recent advancements made in ground-penetrating radar.

[13] American Water Works Association Research Foundation. *Development of a Digital Leak Detector,* Ongoing Research #404, 2008.

More than 500,000 leaks on buried gas distribution system piping are incorrectly pinpointed each year. AWWARF and GTI will develop and eventually commercialize a product capable of precisely locating pinhole leaks in distribution systems. If successful, this will result in less costly repair due to both early warning and more precise location of leaks and therefore smaller, less expensive, and less invasive excavation.

[14] Common Ground Alliance. *CGA Best Practices Version 4.* March 2007, 102 pp.

A guide to underground utility damage prevention best practices that covers nine areas: (1) planning and design, (2) one-call center, (3) location and marking, (4) excavation, (5) mapping, (6) compliance, (7) public education, (8) reporting and evaluation, and (9) homeland security. This version includes four new practices, the Damage Information Reporting Tool field form, and updated membership information.

[15] Ashdown, C. *Mains Location Equipment: A State of the Art Review and Future Research Needs, Final Report.* UKWIR 01/WM/06/1, United Kingdom Water Industry Research, 2006, 39 pp.

The report examines the equipment currently used for the location of buried utility services and reports upon performance, based upon a limited assessment carried out on two trial sites. The actual performance achieved is compared with the expressed requirements of the water utilities. The need for performance specifications and a better understanding of the limitations of current equipment is discussed together with the needs for future research and development.

[16] Bakhtar, K. *Demonstration of BakhtarRadar Buried Utility Detection and 3-Dimensional Imaging Capabilities.* PowerPoint Presentation, 2006, 32 slides.

The presentation explains how the system works, concept origination, and the innovation in the concept (software, hardware, operation modes). An example of buried pipes detection is shown. Work was funded by the Naval Weapons Station in Seal Beach, California.

[17] Gas Technology Institute. *Underground Facility Pinpointing.* OTD-06/0001, Operations Technology Development (ODT), 2006, 57 pp.

Research was conducted on a wide variety of technologies used by utilities to locate underground pipes and facilities. The report reviews electromagnetic locators, GPR, and alternative locating technologies: (1) Bakhtar Associates—EarthRadar, (2) Witten Technologies, (3) Geonics Limited, (4) Continental Industries—e-line locator, (5) Harris Technologies, (6) electrical conductivity object locator, (7) GeoRadar, (8) capacitive tomography, (9) acoustic, (10) infrared thermography, (11) and emerging technologies.

[18] Gas Technology Institute. Bakhtar Associates EarthRadar. *Underground Facility Pinpointing,* 2006, 8 pp.

While standard GPR units use impulse radar, the EarthRadar system uses forced resonance radar (a proprietary system developed by Bakhtar Associates). This system allows precise location information (i.e., high accuracy on the centimeter level) to be attached to data without the need for the grid scans and route planning. The EarthRadar system has been demonstrated three times throughout the Underground Facility Pinpointing Program. The system was able to positively locate the intended targets in all three demonstrations.

[19] Environment Research Foundation. *Methods for Cost-Effective Rehabilitation of Private Lateral Sewers.* 02CTS5, Water, Alexandria, Va., 2006, 436 pp.

One chapter in the final report reviews currently used methods to locate and inspect small sewer pipes (sewer laterals).

[20] United Kingdom Water Industry Research. *Minimising Street Works Disruption: Buried Asset Data Collection and Exchange Field Trials.* 2006.

This report details the results of several projects in the U.K. (North London and Yorkshire) that evaluated various methods of data capture for buried assets, including traditional methods such as tape measures and trundle wheels as well as the latest satellite survey equipment. It also looks at the current methods of exchanging and collating utility asset data used by contractors to the water industry.

[21] Hereth, M., B. Selig, K. Leewis, and J. Zurcher. *Compendium of Practices and Current and Emerging Technologies to Prevent Mechanical Damage to Natural Gas and Hazardous Liquids Transmission Pipelines.* GRI 8747, March 2006, 119 pp.

This report provides a state of the art review of commercial, new, and emerging technologies and practices for the prevention of mechanical damage. A review of past and current practices, as well as current and emerging technologies, is also included.

[22] United Kingdom Water Industry Research. *Underground Asset Location: Review of Current Technology.* 2005.

This report presents high-level requirements for underground asset location and summarizes the current state of the art in the location of underground assets. It recognizes that the majority of effort in this area is focused on the optimization of these technologies and that there is little innovation in terms of new sensors and, therefore, reviews other disciplines as diverse as medicine, defense, archaeology, and space to identify a broad spectrum of new technologies that could potentially be harnessed to address this issue.

[23] Pipeline and Hazardous Materials Safety Administration. *Digital Mapping of Buried Pipelines with a Dual Array System.* Final Status Report, Dec. 2004, 1 p.

Witten Technologies Inc. has developed a noninvasive system for detecting, mapping, and inspecting steel and plastic pipelines. The system combines measurements from ultra-wideband radar and electromagnetic induction arrays with precise positioning and advanced image processing. This is accomplished by development of a wideband array of 3-component sensors and software, fabrication and testing of electromagnetic induction (EMI) sensors, integration of EMI and radar sensors, and development of an onboard transmitter. Research duration: 10/01/2002–12/31/2004.

[24] Read, G. F. *Sewers: Replacement and New Construction.* Elsevier, 2004, 576 pp.

This is a detailed guide to the management and construction of new sewer systems. The importance of proper site preparation and management is emphasized, and detailed guidance is given to preconstruction investigation as well as to managing traffic and public relations during the construction period. A chapter is dedicated to site investigation and mapping of buried assets.

[25] Common Ground Alliance. *CGA Review of NTSB Recommendation P-97-16/P-97-17.* Feb 2003, 49 pp.

A task group within the R&D Committee of the CGA reviewed the compendium of locating equipment as a basis for addressing National Transportation Safety Board (NTSB) recommendations. The group revised existing criteria for evaluating locating equipment and developed a list of recommendations.

[26] Common Ground Alliance. *CGA Review of NTSB Recommendation P-97-18, P-97-17.* Feb. 2003, 50 pp.

The recommendation focused on the ability of commercially available technologies to meet state requirements for locate accuracy and hand-dig tolerance zones. The committee researched each state's legal requirements for accuracy of facility locates. The committee identified 42 states with locate accuracy requirements. The state laws governing the accuracy of a locate varied widely, but in general there were between 18 in. and 24 in. measured on each side of the utility.

[27] Jeong, H. S., C. A. Arboleda, D. M. Abraham, D. W. Halpin, and L. E. Bernold. *Imaging and Locating Buried Utilities.* FHWA/IN/JTRP-2003/12, Report to Indiana Department of Transportation, Joint Transportation Research Program, Oct. 2003, 238 pp.

The state-of-the-art and the state-of-the-practice imaging technologies that have potential for being applied in locating underground utilities were identified through literature review and case studies, and the conditions under which use of these technologies are most appropriate were analyzed. Based on the characterizations of imaging technologies, a decision tool named IMAGTECH was developed in order to provide site engineers/technicians with a user-friendly tool in selecting appropriate imaging technologies. Quantitative data based on questionnaire surveys to state DOTs and SUE providers were used to present comprehensive insight into the various aspects of the rapidly growing market in SUE. A multimedia educational tool was also developed to facilitate a better understanding of underground utility locating systems by the many in the construction domain, particularly entry-level engineers who are relatively unfamiliar with these technologies.

[28] Chapman, D. N., J. B. Costello, and C. D. F. Rogers. *Report on Asset Location and Condition Assessment.* UKWIR 02/WM/12/1, University of Birmingham, United Kingdom, 2002, 36 pp.

This report reviews the techniques that are currently available for underground asset location and for the condition assessment of the buried infrastructure. It has been produced following significant revision and expansion of a review produced as part of the EPSRC Engineering Programme Network in Trenchless Technology (NETTWORK). NETTWORK aims to bring all relevant U.K. academics and industrialists together to synthesize knowledge in the broad field of trenchless technologies, agree on the research needs, disseminate this information as widely as possible, and formulate research proposals to address these needs. This review of pipeline location technology and condition assessment aims to provide details of the essential technology that is currently available for use in practice, as opposed to citation of case histories of the use of the technology.

[29] United Kingdom Water Industry Research. *Multi-Utility Buried Pipes and Appurtenances Location Workshop.* Report Ref. No. 02/WM/12/2, London, 2002, 72 pp.

Group of experts from the U.K., the U.S., and the Netherlands reviewed state-of-the-art technologies for locating of buried pipes, developed cost and performance specifications for locating tools, addressed limitations of technologies, and identified future technology development and research needs.

[30] Deb, A. K. (ed.). *New Techniques for Precisely Locating Buried Infrastructure.* American Water Works Association Research Foundation, Oct. 2001, 158 pp.

This study evaluated several technologies for locating underground assets, although they are not commonly used in the water industry (electromagnetic, ground-penetrating radar, sonic, and acoustic). The report provides guidance for water utilities to use in selecting the most appropriate technique for locating buried assets where conditions are difficult and accuracy is critical.

[31] Lanka, M. *A Fuzzy Logic Based Methodology to Manage Uncertainty in Underground Utility Location.* M.S. Thesis, Louisiana Tech University, Ruston, La., 2000.

This study examined means of depicting the uncertainty of utility position based on the type and quality of the information available.

[32] Sterling, R. L. *Utility Locating Technologies: A Summary of Responses to a Statement of Need.* Federal Laboratory Consortium Special Reports Series No. 9, FLC, Feb. 2000, 53 pp.

This report documented the results of a search for utility locating technologies under development and the extent to which the research under way could meet the needs for utility locating in practice.

[33] Sterling, R. L. *Utility Locating Technologies: Statement of Need.* Federal Laboratory Consortium Special Reports Series No. 9, FLC, June 1999, 19 pp.

This document was prepared to outline utility locating problems in practice and the potential market for improved solutions. It was used to solicit information from federal laboratories, universities, and other research groups about ongoing or potential research in the field.

[34] Brouwer, J., and K. Helbig. *Shallow High-Resolution Reflection Seismics.* Elsevier Science Limited, Oxford, United Kingdom, 1998, 391 pp.

The book covers all aspects of acquisition, processing, and interpretation of shallow reflection seismic data for geotechnical and environmental purposes.

[35] Simonson, K. M. *Statistical Considerations in Designing Tests of Mine Detection Systems: I Measures Related to the Probability of Detection Test Design.* Sandia Report, SAND98-1769/1, Sandia National Laboratories, 1998, 28 pp.

One of the primary metrics used to gauge the performance of mine detection systems is PD, the probability of detecting an actual mine that is encountered by the sensor. In this report, statistical issues and techniques that are relevant to the estimation of PD are discussed. Appropriate methods are presented for summarizing the performance of a single detection system, for comparing different systems, and for determining the sample size (number of target mines) required for a desired degree of precision. References are provided to pertinent sources within the extensive literature on statistical estimation and experimental design. A companion report addresses the estimation of detection system false alarm rates.

[36] Simonson, K. M. *Statistical Considerations in Designing Tests of Mine Detection Systems: II Measures Related to the False Alarm Rate Test Design.* Sandia Report, SAND98-1769/2, Sandia National Laboratories, 1998.

The rate at which a mine detection system falsely identifies man-made or natural clutter objects as mines is referred to as the system's false alarm rate (FAR). In this report, an overview is given of statistical methods appropriate for the analysis of data relating to FAR. Techniques are presented for determining a suitable size for the clutter collection area, for summarizing the performance of a single sensor, and for comparing different sensors. For readers requiring more thorough coverage of the topics discussed, references to the statistical literature are provided.

[37] Rush, W. F., J. E. Huebler, and V. Tamosaitis. *Identification of Plastic Pipe Location Technology through a Federal Laboratory Research and Development Contest.* GRI-97/0006, March 1997, 74 pp.

The objective of this study was to find out if any current federal laboratory technology can locate buried plastic pipe better than tracer wire. The report focuses on the essential features of identified technologies, while information on more extensive sources for each is included in the appendixes.

[38] Grau, R. H. *User's Guide: Ground-Penetrating Radar.* U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss., July 1996, 30 pp.

Description of GPR used to determine the thickness of different layers of a pavement structure and the location of water and sewer lines under a roadway system is provided. Applicability, benefits, limitations, costs, and recommended uses of the technology are discussed.

[39] Hadey, A. D., and V. Hey. *Acoustic Pipe Tracer Development.* GRI-96/0446, Gas Research Institute, Chicago, Ill., Aug. 1996, 59 pp.

Development and commercialization of the acoustic pipe tracer technology for locating polyethylene pipes underground is summarized.

[40] King, J. D. *Assessment of 3M Electronic Marker System for Locating Underground Plastic Gas Pipe.* Southwest Research Institute, San Antonio, Tex., 1996, 32 pp.

This system makes use of miniature electronic markers that are attached to the pipe prior to installation. The system was evaluated in the laboratory and at six field sites to determine performance and suitability for locating buried plastic gas pipe.

[41] Cribbs, R. W., and S. Knapp. *New Concepts for the Location of Underground Plastic Natural Gas Pipes.* GRI-95/0494, Gas Research Institute, Dec. 1995, Chicago, Ill., 39 pp.

A system to detect and locate plastic pipe from 1/2 in. to 4 in. or more in diameter in all soils, in all conditions, to a depth of four feet would be developed. Different technologies would be investigated: (1) ultra-wideband swept-frequency microwave radar, (2) chirp ultrasound for use in soils where the radar attenuation is too high, and (3) ultra-high-speed signal processing.

[42] Podney, W. *Development of a Magnetic Telescope for Evaluating Integrity of Buried Steel Gas Piping from the Surface.* GRI-94/0220, Sept. 1995, 54 pp.

The objective was to develop an instrument that uses highly sensitive, superconductive, magnetic sensors to evaluate integrity of buried gas piping from the surface, through a two meters overburden.

[43] Tranbarger, O., J. L. Fisher, R. E. Beissner, and B. J. Zook. *Fusion of Two Electromagnetic Field Sensor Technologies for Application to the Location of Buried Gas Pipes.* Gas Research Institute, July 1995, 105 pp.

Feasibility of GPR and Eddy current (EC) technologies to locate pipes was investigated. GPR produced images of 4-in. polyethylene (PE) pipe down to 3 ft and of 2-in. PE pipe to a depth of 2 ft. With EC technology, the edges of backfilled pipe trenches were detectable, and plastic pipes could be detected at shallow depths in high conductivity soils.

[44] Allen, J. W. *Geophysical Background and As-Built Target Characteristics.* U.S. Department of Energy, Sept. 1994, 75 pp.

Geophysical measurement techniques for detecting and defining cultural and environmental targets were documented and evaluated in a testing facility in Rabbit Valley, Colorado. The techniques include surface magnetics, airborne magnetics, induction electromagnetics, very low frequency electromagnetics, time-domain electromagnetics, airborne electromagnetics, resistivity/induced polarization, and GPR.

[45] Meloy, J. D. *Precision Gas Pipeline Location—A Technology Study.* PR-215-9130, Pipeline Research Council International, Incorporated, 1994, 40 pp.

This study was undertaken to survey and evaluate the technology available to accurately determine the position of submerged or buried gas transmission pipelines, and to assess the applicability of some of the emerging technologies. The objectives were to increase accuracy and reliability while reducing the cost of surveys.

[46] Wilkey, P. L. *Survey of the State of the Art in Near-Shore Pipeline Location and Burial Assessment.* GRI-91/0044, Argonne National Lab and Gas Research Institute, Nov. 1991, 14 pp.

State-of-the-art methods for locating pipelines in shallow water (less than 15 ft) and for determining and monitoring their burial depths were evaluated.

[47] Thain, W. E. *Determination of the Best Ground Penetrating Radar Source Signal Type for the Accurate Location of Underground Utilities.* NCEL-CR-88-013, Sept. 1988, 247 pp.

Four types of GPR systems were tested. The frequency-domain GPR based on a stepped-frequency design provided the highest performance capabilities.

[48] Bigl, S. R. *Locating Buried Utilities.* CRREL-SR-85-14, Cold Regions Research and Engineering Lab., Hanover, N.H., Sept. 1985, 54 pp.

This report describes how to operate buried-utility locators and identifies the uses and limitations of locators. The scope is limited to locators using the principles of magnetometry.

[49] Bigl, S. R., K. S. Henry, and S. A. Arcone. Detection of Buried Utilities: Review of Available Methods and a Comparative Field Study. *CRREL,* Rep 84-31, Dec. 1984, 43 pp.

Comparative field tests of eleven locators using these three operating methods were conducted in Hanover, New Hampshire, and eight of these were further tested at the U.S. Military Academy, West Point, New York, and the Stewart Army Subpost, Newburgh, New York.

[50] Roberts, W. E. *Location of Underground Objects.* ECRC/M-953, Electricity Council Research Centre, Capenhurst, United Kingdom, Aug. 1976, 16 pp.

The principles by which various locating instruments operate are categorized and briefly described with comments

about their limitations and suitability for underground service location. A new instrument, designed at ECRC for the detection of cables and metal pipes, is reported to be ready for field trials.

Papers (Conference Proceedings, Journals, and so forth)

[51] Proulx, C. R., and G. N. Young. Achieving a More Complete View of the Subsurface with 3-D Underground Imaging. *Proc., 87th Annual Meeting of the Transportation Research Board,* Washington, D.C., Jan. 2008, 9 pp.

This paper describes 3-D underground imaging systems that deploy multiple GPR antennas on one platform to allow creation of 3-D images of the subsurface for even more complete mapping. In addition, multisensor electromagnetic geophysical systems help image metallic targets. Relevant case histories are provided.

[52] Rogers, C., N. Zembillas, A. Thomas, N. Metje, and D. Chapman. Mapping the Underworld—Enhancing Subsurface Utility Engineering Performance. *Proc., 87th Annual Meeting of the Transportation Research Board,* Washington, D.C., Jan. 2008, 11 pp.

This paper describes research into stakeholder needs, relating it to current SUE best practice. It then describes complementary U.K. research that aims to provide advances in the SUE process, via the MTU project. MTU is researching the integration of multiple geophysical sensors into a single device able to detect all buried utilities without the need for proving excavations, together with positioning, data record integration, and asset tagging technologies.

[53] Agostini, A. Cost-Benefit Criteria for Georadar Utility Mapping Methods. *Proc., ISTT No-Dig 2007,* Rome, Sept. 2007.

One of the most important problems in georadar services is to define the appropriate underground resolution level to effectively support the decision-making process about whether to dig or not. Through the analysis of georadar utility mapping methods in urban and industrial sites, 2-D and 3-D tomography approaches can be compared. The aim is to provide an opportunity to define technical criteria that make the georadar application successful where quality is measured in terms of fulfilling the end-user's requirements.

[54] Manacorda, G., H. Scott, M. Rameil, R. Courseille, M. Farrimond, and D. Pinchbeck. The ORFEUS Project: A Step Change in Ground Penetrating Radar Technology to Locate Buried Utilities. *Proc., ISTT No-Dig 2007,* Rome, Sept. 2007.

ORFEUS is a European Commission–funded Specific Targeted Research Project (STREP) aimed at developing the next generation of GPR systems, which will raise the probability of detecting buried assets. The project will last for 36 months and will cost €5 million (~U.S.$7 million at 2009 exchange rates).

[55] Adams, G., V. Hawley, and M. Roark. A GPR Sensitivity Analysis for Locating Various Utilities. *Proc., Highway Geophysics Conf 2006,* St. Louis, Mo., Dec. 2006.

In an effort to evaluate and demonstrate the relative advantages and disadvantages of 2-D and 3-D GPR technologies, a suite of GPR profiles were acquired across a specially constructed simulated utility test site in St. Louis, Missouri. These data were processed and analyzed as conventional 2-D profiles. They were also used to generate multiple 3-D data volumes, with variable simulated acquisition parameters. The 2-D and 3-D data were evaluated in terms of interpretability and utility. The conclusion reached is that 3-D GPR imaging technologies provide for more accurate and user-friendly interpretations and that the advantages of greater reliability and improved visualization often outweigh the increased costs associated with acquisition, processing, and interpretation.

[56] Descour, J. Volumetric Characterization of the Ground Using Seismic Velocity Tomography and Single-Hole Reflector Tracing. *Proc., U.S. Symposium on Rock Mechanics,* Golden, Colo., June 2006.

Several relevant ground-imaging projects are described, one of which is application of this technique to delineate a century-old sewer line approximately 13.12 ft in diameter and almost 50 ft deep, in Pittsburgh, with the precision better than 6 in.

[57] Ishikawa, J., M. Kiyota, and K. Furuta. Test and Evaluation of Japanese GPR-based AP Mine Detection Systems Mounted on Robotic Vehicles. *J. of Mine Action,* Issue 10.1, Aug. 2006, 16 pp.

Six teams from academia and industry in Japan have been developing systems equipped with both GPR and a metal detector. The short-term R&D project is developing sensing technology that can safely and efficiently detect AP landmines. The goal is to develop vehicle-mounted GPR+MD dual-sensor systems that make no explicit alarm and provide operators with clear subsurface images. In a medium-term R&D project, two research teams are trying to develop detectors based on the neutron analysis identifying explosives through backscattering of neutrons and detection of specific energy gamma rays from capture on hydrogen and nitrogen atoms of explosives.

[58] Parker, J. Locating Buried Assets—An Overview of Technical Developments. *Proc., SBWWI Leakage Seminar,* Coventry, United Kingdom, Society of British Water and Wastewater Industries, Nov. 2006, 33 slides.

Current buried asset location tool box was reviewed: drawings, radio frequency locators, GPR, sondes, flexitrace tools, and CCTV. VISTA Field Trials 2006 identified extensive anomalies between asset records and surface surveys. Research projects were presented such as NUAG, MTU, VISTA, as well as GIGA, ORFEUS, and Waterpipe.

[59] Crice, D. MASW, the Wave of the Future. *J. of Environmental & Engineering Geophysics;* Vol. 10, June 2005, pp. 77–79.

Revolutionary innovations in geophysical methods develop when instruments, techniques, or software evolve to make them possible. A few of these cause dramatic changes in the types of surveys and analysis done. Past examples were shallow reflection surveys and scanning resistivity pseudosections. The author believes that surface wave surveys will cause a similar, perhaps extraordinary paradigm shift in geophysics because of the usefulness and interpretability of the data and the potential for dramatically higher productivity.

[60] Descour, J., T. Yamamoto, and K. Murakami. Improving 3D Imaging of Underground Structures. *Proc., FHWA Unknown Foundation Summit,* Lakewood, Colo., Nov. 2005.

[61] Falorni, P., L. Capineri, L. Masotti, and G. Pinelli. 3-D Radar Imaging of Buried Utilities by Features Estimation of Hyperbolic Diffraction Patterns in Radar Scans. *Proc., 10th International Conference on Ground Penetrating Radar,* Delft, Netherlands, June 2004, 4 pp.

The paper describes a processing method to extract hyperbolic patterns generated by the time-of-flight variation in radar scans due to buried utilities.

[62] Farrimond, M. The ESWRAC Initiative. *Proc., ISTT No-Dig 2004 Conf.,* Hamburg, Germany, Nov. 2004, 9 pp.

Research by UKWIR in 2000 and 2001 concluded that, at best, existing technologies had no better than a 50% success rate in identifying buried utilities. A group of utilities, cities, and transport organizations established ESWRAC to promote the need for more research in this area.

[63] Holmes, P. Emerging Methods for Utility Locations. *Proc., NO-DIG 2004,* New Orleans, La., March 2004, 7 pp.

GPR and electromagnetics (EM) are briefly discussed. Seismic technologies are being investigated for feasibility in utility locating.

[64] Jackson, T., and W. Whitehead. Subsurface Utility Engineering on Municipal and Utility Projects from an Engineering Firms Perspective. *Proc., NO-DIG 2004,* New Orleans, La., March 2004, 6 pp.

This paper focused on four case studies for municipal and utility projects where SUE services were performed, resulting in safe, successful, and economic projects (36 in. gas pipeline, 12 in. water line, 48/54 in. water transmission line, and bus maintenance facility).

[65] Jeong, H. S., D. M. Abraham, and J. J. Lew. Evaluation of an Emerging Market in Subsurface Utility Engineering. *J. of Construction Engineering and Management,* ASCE, March/April 2004, 10 pp.

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 (DOT) and the SUE industry are analyzed, revealing the trend of state DOTs in the use of SUE and various aspects of SUE business in private sectors.

[66] Andraka, M., and A. Spivey. Accurately Verifying Location of Underground Facilities. *Proc., UCT 2003,* Houston, Tex., Jan. 2003, 27 slides.

A yearlong pilot program was completed to investigate methods for locating underground utilities. A case history outlines an agency's budget reduction, infrastructure management, and technology enhancement using GPR and vacuum excavation.

[67] Guy, E. D., J. J. Daniels, and Z. Daniels. Cross-Hole Radar Effectiveness for Mine-Related Subsidence Investigations: Studies Near Discontinuities Imaged Using High-Resolution Seismic Reflection. *Proc., NASTT NO-DIG 2003 Conf.,* Las Vegas, Nev., March–April 2003, 15 pp.

Cross-hole radar data were acquired along a section of Interstate 70 in Ohio, where the roadway had collapsed into underground coal mine workings. The goal was to test the ability of cross-hole radar methods for providing useful information for mine-related subsidence studies and to further investigate subsurface areas.

[68] Kase, E., T. Ross, J. Descour, and D. Green. Leveraging Existing Infrastructure: Using What Is Already in the Ground. *Proc., 54th Annual Highway Geology Symposium,* Sept. 2003.

This paper reviews case studies where NSA Geotechnical Services has utilized cross-borehole seismic, cross-borehole GPR, and resistivity methods to characterize unknown bridge foundations. The applications and limitations of each geotechnical method are discussed. Also, a brief discussion of new methodologies currently under development and being considered by NSA for characterizing unknown foundations is included.

[69] Manacorda, G., and D. Pinchbeck. The European GIGA Project. *Proc., Trenchless Middle East 2003,* Dubai, United Emirates, Oct. 2003, 11 pp.

GIGA is a research study funded by the European Commission to develop a new and reliable GPR. The paper describes main axes of research and the activities completed by Ingegneria dei Sistemi (IDS) until 2003.

[70] Youn, H., C. Chen, and L. Peter, Jr. Automatic Pipe Detection Using Fully Polarimetric GPR. *Proc., 2003*

ASAE Annual Meeting, American Society of Agricultural and Biological Engineers, 2003.

An automatic pipe detection algorithm using a two-step artificial neural network (ANN) scheme on GPR data is presented.

[71] An, G., and K. Yin. The Application of GIS to Urban Underground Space. *Proc., ACUUS 2002 International Conference—Urban Underground Space: A Resource for Cities,* Torino, Italy, Nov. 2002, 5 pp.

Characteristics of GIS technique are discussed; the content of numerical simulation for the underground space is given. The combination of GIS technique and numerical simulation technique of underground space is proposed.

[72] Arioglu, S. O., D. M. Abraham, N. Zembillas, and D. Halpin. Implementation of Subsurface Utility Engineering Technologies: A Case Study. *Proc., ISTT NO-DIG 2002,* Copenhagen, Denmark, May 2002, 11 pp.

The paper focuses on several projects where SUE has been used in the U.S. and analyzes the impacts of using subsurface utility engineering in terms of performance, cost, and schedules.

[73] Birken, R., D. Miller, M. Burns, P. Albats, R. Casadonte, R. Deming, T. Derubeis, T. Hansen, and M. Oristaglio. Efficient Large-Scale Underground Utility Mapping Using a New Multi-Channel Ground-Penetrating Imaging Radar System. *Proc., Symp. Application of Geophysics to Engineering and Environmental Problems (SAGEEP 2002),* Environmental and Engineering Geophysical Society, Las Vegas, Nev., Feb. 2002.

A commercial GPR called the CART Imaging System, which was designed for mapping urban infrastructure, has been developed in a collaboration between Witten Technologies, Malå Geoscience, and Schlumberger. The Electric Power Research Institute (EPRI) sponsored research leading to the development of GPR.

[74] Jeong, H. S., D. M. Abraham, J. H. Anspach, N. M. Zembillas, J. J. Lew, and D. W. Halpin. Identification of Buried Utilities Using Subsurface Utility Engineering (SUE). *Proc., NASTT NO-DIG 2002,* Montreal, Canada, April 2002, 13 pp.

[75] Jet Propulsion Laboratory. NASA to Provide Sharper Underground View of World Trade Center Area. Press Release, NASA JPL, Aug. 2002.

Witten Technologies, Inc., of Boston, would supply NASA's Jet Propulsion Laboratory (JPL) with underground images from lower Manhattan created with ground-penetrating imaging radar.

[76] Manacorda, G. IDS Radar Products for Utilities Mapping and Ground Classification. *Proc., ISTT NO-DIG Conference,* Copenhagen, Denmark, May 2002.

In early 1990s, Ingegneria dei Sistemi (IDS) focused on the development of specialized GPR systems to be used for different applications (e.g., locating of underground objects and pipes), thus replacing the more traditional "general purpose" radar systems. This enabled overcoming some limitations of these systems, mainly low detection rate, insufficient accuracy, and low productivity.

[77] Nissen, J. Ground Penetrating Radar—A Ground Investigation Method Applied to Utility Locating in NO-DIG Technologies. *Proc., ISTT NO-DIG 2002,* Copenhagen, Denmark, May 2002, 6 pp.

During the last decade, GPR has proved its ability to act as a powerful geophysical tool for subsurface investigations. The most striking benefit is the possibility of GPR to detect nonmetallic objects such as plastic pipes and drums. Field examples demonstrate that the GPR technique is a time efficient and accurate method for detection and mapping of buried objects and structures. Field example #1 shows real-time, on-site detection, and field example #2 shows measurements with postprocessing analyses.

[78] Saito, M. Technology for the Front Lines: Robotic Scientists and Engineers Come Up with Novel Ways to Slow the Spread of Landmines. Japan Inc. Communications, Dec. 2002.

Robotics scientists and engineers from Japan are developing cutting-edge mine detectors.

[79] Falomi, P. 3-D Radar Imaging of Buried Utilities by Features Estimation of Hyperbolic Diffraction Patterns in Radar Scans. *Proc., 10th International Conference on Ground Penetrating Radar,* Delft, Netherlands, June 2001.

The paper describes a processing method to extract hyperbolic patterns generated by the time-of-flight variation in radar scans due to buried utilities.

[80] Kregg, M. A. Development of a Utility Feeder Infrared Thermography PdM Program—With Lessons Learned. *Proc., InfraMation 2001,* Orlando, Fla., Sept.–Oct. 2001, 10 pp.

In 2000, ComEd (a large electric utility company in Illinois) was given a task to perform infrared scans of overhead distribution systems.

[81] Lanka, M., A. Butler, and R. Sterling. Use of Approximate Reasoning Techniques for Locating Underground Utilities. *A Supplement to Tunneling and Underground Space Technology,* Vol. 16, No. 1, 2001, pp. 13–31.

Description of a prototype process using approximate reasoning for underground utility location is provided. The approximate reasoning process involves development of a series of techniques to handle uncertainties associated information on location of underground utilities.

[82] Michelson, F. Modern Non-Invasive Geophysical Investigation Techniques for Planning of Underground Construction Projects. *Proc., UCT '01,* Houston, Tex., Jan. 2001, 8 pp.

The focus of the presentation was on noninvasive "continuous profiling" geophysical survey techniques, which produce a noninterrupted continuous profile of the subsurface wither in real time or after processing. The most utilized methods are GPR, electromagnetic imaging, resistivity profiling, and seismic imaging. A combination of geophysical methods can be utilized for multiple target objects and to improve the accuracy of interpretations.

[83] Roemer, L., and D. Cowling. Bayesian Methods in Nondestructive Testing. *Materials Evaluation,* Jan. 2001, pp. 59–62.

[84] Berkovitch, A., L. Eppelbaum, and U. Basson. Application of Multifocusing Seismic Processing to GPR Data Analysis. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 597–606.

Multifocusing seismic processing is based on the homeomorphic image theory and consists of stacking seismic data with arbitrary source-receiver distribution according to a new local moveout correction.

[85] Christensen, N. B., et al. The Use of Airborne Electromagnetic Systems for Hydrogeological Investigations. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 73–82.

This paper presents analyses of the resolution capabilities of present-day transient electromagnetic (EM) systems and makes comparisons between airborne and the corresponding ground systems for a number of hydrogeologically relevant models.

[86] Clement, W., and M. Knoll. Tomographic Inversion of Crosshole Radar Data: Confidence in Results. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 553–562.

Crosshole radar tomography is increasingly being used to characterize the shallow subsurface and to monitor hydrologic processes. Although tomographic inversion produces a subsurface model, confidently interpreting the resulting image can be challenging. A simple modeling study was conducted to better understand the capabilities and limitations of tomographic inversion.

[87] Cull, J., and D. Massie. Modulated Active Magnetic Surveys for Sub-Surface Utility Mapping. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 1077–1084.

A quasistatic magnetic method has been developed to indicate the exact location of subsurface utilities. Standard radio frequency EM transmitter methods are complicated by distortions associated with induction in secondary targets, including underground services and surface metallic artifacts. Similarly, standard high-definition magnetic methods are subject to high ambient noise levels and ambiguities associated with superposition of responses from multiple sources. The modulated active magnetic system (MODAM) has now been developed to avoid these complications. Static magnetic fields are readily removed from the total held response by comparing on-time and off-time magnitudes, allowing spatial vectors (defining the transmitter location) to be resolved with great precision. Results obtained from MODAM field trials have been confirmed with electronic total station surveys, giving an agreement better than 1.64 ft at 39.37 ft depth.

[88] Daily, W., et al. Imaging UXO Using Electrical Impedance Tomography. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 791–800.

The results of tests are reported where electrical impedance tomography (EIT) is used for detecting and locating buried unexploded ordnance (UXO). The method relies on the polarization induced at the boundary between soil and buried metal to produce a measurable phase difference between the injected current and the measured voltage.

[89] Handlon, B., S. J. Lorenc, L. Bemold, and G. Lee. Tool Integrated Electromagnetic Pulse Induction Technology to Locate Buried Utilities. *Proc., ISCAS 2000—IEEE International Symposium on Circuits and Systems,* Geneva, Switzerland, May 2000, 4 pp.

In this paper, several pulse-induced electromagnetic sensor coils are discussed which have been designed, fabricated, and tested for underground utility pipe recognition. The work has been performed through the Buried Utilities Detection System (BUDS) Consortium at North Carolina State University. Characteristics of the sensor coils, including resolution and range, are provided and field-test results are discussed.

[90] Hanna, K., and J. M. Descour. Timely and Accurate Subsurface Characterization for Highway Applications Using Seismic Tomography. *Proc., 1st International Conference on the Application of Geophysical Methodologies and NDT to Transportation Facilities and Infrastructure,* St. Louis, Mo., Dec. 2000.

This paper describes new developments in seismic tomography aimed at providing greatly improved subsurface information during highway maintenance and construction. Three case studies are discussed in which cross-hole seismic tomography was used to (1) assess highway settlement causes and determine the effectiveness of remedial grouting, (2) detect abandoned coal mine entries beneath a retaining wall foundation in Illinois, and (3) locate a rock tunnel beneath an interstate highway.

[91] Keiswetter, D., et al. Advances in Frequency Domain Electromagnetic Induction Techniques for Improved Discrimination and Identification of Buried Unexploded Ordnance. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 811–818.

Recently completed field tests have demonstrated that frequency domain sensors, such as Geophex Ltd.'s GEM-3, can reliably separate UXO targets from clutter objects based on their complex broadband EM signatures. These field tests have also identified a number of areas where improvements are needed before this technology is transitioned to full-scale UXO cleanup applications.

[92] Keiswetter, D., and I. J. Won. Multifrequency EM Mapping for Improved Site Characterization: Case Histories. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 1167–1175.

[93] LaBrecque, D., and X. Yang. Difference Inversion of ERT Data: A Fast Inversion Method for 3-D In Situ Monitoring. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 907–914.

A new three-dimensional inversion algorithm has been developed for electrical resistivity tomography (ERT). The new algorithm is optimized for in situ monitoring applications. Instead of direct inversion of electric potential data, the new inversion algorithm inverts the difference between the background data and the subsequent data sets. The resistivity obtained by the inversion of background data serves as the a priori model in the difference inversion.

[94] Lippincott, T., et al. Geophysical Site Characterization in Support of Highway Expansion Project. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 587–596.

A site slated for roadway development was characterized applying GPR, shallow high-resolution reflection seismic, and dipole-dipole electrical resistivity methods.

[95] McCann, D. M., and P. J. Fenning. Underground Pipe Location—Geophysics or Surveying. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 887–896.

Surveys for the detection of underground pipes are a statutory requirement in the United Kingdom in the construction and water supply industries. The volume of surveys undertaken suggests that this is a multimillion dollar operation with surveys being undertaken by surveyors rather than geophysicists. The reasons for this approach are examined and the problems associated with the detection of underground pipes with geophysical methods are discussed.

[96] Orrey, J., P. Sirles, and C. Archambeau. 3-D Imaging of Subsurface Features Using GPR Array Beam Imaging. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 423–432.

This paper provides a brief review of standard survey and analysis methods for GPR and then introduces a new method for producing three-dimensional images of the subsurface using GPR array beam imaging (ABI). Also discussed are the relative advantages of the ABI method over traditional methods and some potential future applications of the method.

[97] Pipan, M., L. Baradello, E. Forte, and A. Prizzon. Polarization and Kinematic Effects in Azimuthal Investigations of Linear Structures with Ground Penetrating Radar. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 433–452.

Azimuthal variations of GPR response may be diagnostic of elongated subsurface targets. Tests were performed on two classes of targets of interest in archaeological and engineering applications: walls (archaeological remains) and underground utilities (plastic and metallic pipes). The response of targets buried at different depths in soils ranging from clays to coarse sands was measured to compare the performance of azimuthal multifold and conventional GPR techniques.

[98] Radzevicius, S., J. Daniels, E. Guy, and M. Vendl. Significance of Crossed-Dipole Antennas for High Noise Environments. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 407–413.

Crossed-dipole antennas can be used to reduce clutter and improve the signal-to-noise ratio of GPR surveys, depending upon field conditions and the targets of interest. The crossed-dipole antenna consists of transmit and receive antennas oriented orthogonal to each other and is sensitive to field components oriented parallel to the long axis of the receive antenna. The physical shape and composition of targets will influence the polarization of the scattered field, and this enables cross-pole and co-pole antenna configurations to discriminate between different classes of targets for clutter removal. The improved isolation and ability to discriminate between different targets result in an improved signal-to-noise ratio.

[99] Yang, X., D. LaBrecque, G. Morelli, W. Daily, and A. Ramirez. Three-Dimensional Complex Resistivity Tomography. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 897–906.

A new three-dimensional complex-resistivity forward-modeling and inversion program was developed. Complex finite-difference equations were solved using either the bi-conjugate gradient method or quasiminimal residual method. A symmetric successive over-relaxation preconditioner was implemented for both solvers.

[100] Young, T., and T. Larson. Combining Surface and Borehole Geophysical Techniques to Locate and Define a Buried Outwash Aquifer in Central Illinois. *Proc., SAGEEP 2000,* Arlington, Va., Feb. 2000, pp. 1085–1094.

A few thick narrow bands of outwash deposits, 600 to 1,200 feet wide, were deposited in bedrock channels or trailing away from receding glacial fronts. These narrow deposits, now buried by 50 to 130 feet of younger drift, are difficult and impractical to locate using test drilling as the sole means of exploration. However, because the outwash deposits are enclosed within clayey glacial till and overlie shale bedrock, they are excellent targets for electrical earth resistivity (EER) surveys. When used together, surface and borehole geophysical methods provide a powerful means for locating, confirming, and delineating sand and gravel aquifers as well as aiding in optimum construction of water supply wells in this hydrogeologic setting.

[101] Hyun, S. Y., et al. Measurement on Pipe Detectability of the GPR Consisting of Self-Designed Antenna. *J of the Institute of Electronics Engineers of Korea,* Vol. 36-D, No. 3, 1999, pp. 19–26.

The detectability of pipes buried in dry sand is investigated by using the GPR with self-designed bow-tie antenna. It is shown that without additional signal processing the presence of various buried targets can be found by discriminating hyperbolic pattern in B-scan data.

[102] Olhoeft, G. R. Applications and Frustrations in Using Ground Penetrating Radar. *Proc., Ultra Wideband Conference,* Washington, D.C., Sept. 1999, 13 pp.

In this paper the author concentrates on the narrow portion of the electromagnetic spectrum from a few MHz to a few GHz where geophysicists use GPR. GPR is deployed today from the space shuttle, aircraft, on the surface, in and between boreholes, and sometimes from within or between mine shafts. The author discusses these applications and some of the problems involved.

[103] Ciochetto, G., A. Giavelli, R. Polidoro, F. Roscini, and G. De Pasquale. Automatic Output of Underground Utility Maps Using GPR. *Proc., GPR '98,* Lawrence, Kans., May 1998, 4 pp.

The paper describes GPR field tests in Torino and data obtained from the investigations on a digital cartography of the urban area. It also briefly describes a new GPR system developed in Italy used in these tests.

[104] Zeng, X., and G. A. McMechan. GPR Characterization of Buried Tanks and Pipes. *Geophysics,* Vol. 62, No. 3, 1997, pp. 797–806.

Ray-based numerical simulations of monostatic and bistatic GPR responses for several tank and pipe configurations reveal the potential for noninvasive diagnostic evaluations.

[105] Anspach, J. H. Subsurface Utility Engineering: Utility Detection Methods and Application. *Proc., SAGEEP 1996,* Keystone, Colo., April–May 1996, pp. 443–449.

This paper provides an overview of the utility locating problem, the use of subsurface utility engineering process, and the capabilities of different utility detection methods.

[106] Bradford J., M. Ramaswamy, and C. Peddy. Imaging PVC Gas Pipes Using 3-D GPR. *Proc., SAGEEP 1996,* Keystone, Colo., April–May 1996, pp. 519–524.

Improvements in GPR data acquisition, 3-D processing, and visualization schemes yield good images of PVC pipes in the subsurface. Data have been collected in cooperation with a local gas company and at a test facility in Texas. Surveys were conducted over both a metal pipe and PVC pipes of diameters ranging from 0.5 in. to 4 in. at depths from 1 ft to 3 ft in different soil conditions. The metal pipe produced very good reflections and was used to fine tune and optimize the processing run stream. It was found that the following steps significantly improve the overall image: (1) statics for drift and topography compensation, (2) deconvolution, (3) filtering and automatic gain control, (4) migration for focusing and resolution, and (5) visualization optimization.

[107] Bruce, B., N. Khadr, R. DiMarco, and H. H. Nelson. The Combination Use of Magnetic and Electromagnetic Detection and Characterization of UXO. *Proc., SAGEEP 1996,* Keystone, Colo., April–May 1996, pp. 469–478.

Data has been collected on a test field of inert unexploded ordnance (UXO) with both a Geometrics 822A total field magnetometer and a Geonics EM61 pulsed electromagnetic induction sensor. This study allows comparison of the two instruments' detection capabilities.

[108] Gucunski, N., V. Ganji, and M. H. Maher. SASW Test in Location of Buried Objects. *Proc., SAGEEP 1996,* Keystone, Colo., April–May 1996, pp. 481–486.

The spectral-analysis-of-surface-waves (SASW) method is a seismic nondestructive technique that has so far been typically used in the evaluation of elastic moduli and layer thicknesses of layered systems like soils and pavements. The paper discusses the most important findings on the effects of underground obstacles on the Rayleigh wave dispersion obtained from the SASW test, and the application of the test in detection of buried objects.

[109] McDonald, J. R., and R. Robertson. Sensor Evaluation Study for Use with Towed Arrays for UXO Site Characterization. *Proc., SAGEEP 1996,* Keystone, Colo., April–May 1996, pp. 451–464.

Development of a multisensor towed array detection system (MTADS) is described. The objective is to extend and refine ordnance detection technology to more efficiently characterize ordinance and explosive waste sites.

[110] Powers, M. H., and G. R. Olhoeft. Modeling the GPR Response of Leaking Buried Pipes. *Proc., SAGEEP 1996,* Keystone, Colo., April–May 1996, pp. 525–534.

Using a 2.50 dispersive, full waveform GPR modeling program that generates complete GPR response profiles in minutes on a Pentium PC, the effects of leaking versus nonleaking buried pipes are examined. The program accounts for the dispersive, lossy nature of subsurface materials to GPR wave propagation and accepts complex functions of dielectric permittivity and magnetic permeability versus frequency through Cole-Cole parameters fit to laboratory data. Steel and plastic pipes containing a ONAPL chlorinated solvent, an LNAPL hydrocarbon, and natural gas are modeled in a surrounding medium of wet, moist, and dry sand. Leaking fluids were found to be more detectable when the sand around the pipes is fully water saturated. The short runtimes of the modeling program and its execution on a PC make it a useful tool for exploring various subsurface models.

[111] Zhu, K. Analysis of Response of the Electromagnetic Induction for Detecting of Buried Objects. *Proc., Intl. Geoscience and Remote Sensing Symposium (IGARSS) 1996,* IEEE, 96CB35875, Tokai University, Kanagawa, Japan, 1996, pp. 2041–2043.

In this paper, the low-frequency electromagnetic technique is used. The analysis of the response of buried objects to electromagnetic induction is made.

[112] Anspach, J. H. Subsurface Utility Engineering: Upgrading the Quality of Utility Information. *Proc., Intl. Conf. on Advances in Underground Pipeline Engineering II,* ASCE, Reston, Va., 1995, pp 813–824.

[113] Anspach, J. H. Subsurface Utility Engineering: A Damage Prevention Tool for Trenchless Technology. *Proc., NASTT NO-DIG '95,* Toronto, Canada, April–May 1995, pp. 2C1:1–8.

Progressive permitting agencies are beginning to require use of SUE before any excavation near existing utilities. There is a new emphasis on utility damage prevention programs at the federal level due to recent explosions and other disruptions. The trenchless technology industry must be aware of damage prevention tools at its disposal and produce industry standards to encourage their use in applicable situations.

[114] Blejer, D., C. Frost, and S. Scarborough. *Detection Technologies for Mines and Minelike Targets, SAR Imaging of Minelike Targets over Ultra-Wide Band-Widths.* MIT-MS-11042, Massachusetts Institute of Technology, April 1995, 18 pp.

The Lincoln Laboratory ground-based ultrawideband (UWB) rail synthetic aperture radar (SAR) was used to collect UHF and L-band data on a variety of mine-like targets. The target set consisted of metal pipes, bomb fragments, and M-20 metallic antitank mines, above- and belowground.

[115] Herman, H., and S. Singh. First Results in Autonomous Retrieval of Buried Objects. *Automation in Construction,* Vol. 4, No. 2, 1995, pp. 111–123.

For locating buried objects, the system uses a surface sensor (a laser rangefinder used to build the surface model) and a subsurface sensor (GPR). An industrial robot equipped with an excavator bucket is used for automated excavation. One of the potential applications is in the maintenance of gas pipes.

[116] Ho, G. S., et al. Automatic Detection of Buried Pipes from Subsurface Radar Image. *Trans. Inst. Electronics, Information and Communication Engineers,* Vol. 1995, No. 2, Japan, p. 184.

[117] Honjoh, K., et al. Examination of Buried Objects Detection Technology for Hole Excavator: A Study of Vibrational Buried-Pipe Detection Techniques for the Auger-Crane System. *Proc., IEICE General Conference,* No. 2 (19950327), Institute of Electronics, Information and Communication Engineers, Japan, 1995, p. 397.

Vibration sensor in the excavator senses vibration changes due to a buried pipe.

[118] Katsan, I. F., A. I. Potapov, and O. L. Sokolov. Radar Introscope for the Automated Detection and Identification of Small-Sized Objects. *Defektoskopiya,* Dec. 1995, pp. 70–79.

Design of radar introscope using super-wideband electromagnetic signal with duration of 1 ns and less is proposed. Small-sized objects in the ground or other media would be detected and identified. The results of radar introscopy of ground bed to detect a pipe are considered. The interference-killing features of proposed device are estimated.

[119] Lee, K. C., G. Junkin, and S. P. Kingsley. New Strategy to Locate Buried Objects in Highly Lossy Ground. *IEE Proc.—Radar, Sonar, and Navigation,* Vol. 142, No. 6, Dec. 1995, pp. 306–312.

An electromagnetic scale model, with well-defined and variable electrical parameters, has been constructed to investigate experimentally the optimum GPR strategies for use in extremely lossy conditions. A new geometry is proposed that reduces the dynamic-range requirements of a ground-probing radar, allows the permittivity of the medium to be estimated, and provides a clear time window for close targets to be detected. An image-retrieval algorithm is described for image reconstruction.

[120] Miyazaki, T., T. Sugimoto, and M. Okujima. Shear Elastic Wave Exploration of Buried Objects in Underground at Test Field in Nara National Cultural Properties Research Institute. *Proc., 1995 Spring Meeting of the Acoustical Society of Japan,* Suppl. 1-2-15, March 1995, Tokyo, pp. 945–946.

[121] Shouyi, X., W. Chengyi, and S. Chang. *Improved Labeling Region Calculation Area and Tabling Line Following Methods with Applications to Recognition of Buried Pipe Object.* Nanyang Technological University, Singapore, 1995.

Two methods for recognizing buried pipe objects from the subsurface radar image are introduced.

[122] Honda, S., Y. Tomita, and S. Nagashima. Analysis of the Location Technology of Buried Pipe Lines. *Transactions of the Society of Instrument and Control Engineers,* Vol. 30, No. 6, Japan, 1994, pp. 603–608.

Alternating magnetic field location technology has been used to establish the location and the depth of a buried pipe without digging. AC voltage applied to the conductive pipe makes current flow out both ways and leaks away to the surrounding soil. These currents along the pipe create a magnetic field of a cylindrical shape, which can be detected above the ground.

[123] Kasahara, H. Detecting Pipes from Underground Radar Image with Estimation of Dielectric Constant using Hough Transform. *Proc., 1994 Far East Conference on NDT (FENDT '94) and ROCSNT Ninth Annual Conference,* 1994, pp. 199–203.

[124] Zhenye, X., et al. *Identification of Multiple Underground Metal Pipes in Short Range by Means of Curve Fitting.* IEEE, New York, N.Y., 1994.

Data is sampled manually on a single underground metal pipe at a worksite with an existing electromagnetic induction underground metal pipe detector. Then the off-line computer processing is performed. Thus, a fitted experiential, formula of the secondary electromagnetic field of a single underground metal pipe is obtained. According to this experiential formula, identification of multiple pipes can be performed by fitting for experimental data.

[125] Arai, I., and T. Suzuki. Experimental Results of Subsurface Radar with Improved Resolution Short-Range Sensing. *J. of Electromagnetic Waves and Applications,* Vol. 7, No. 11, 1993, pp. 1479–1495.

Several new techniques, including noise and clutter rejection techniques, were introduced in order to develop subsurface radar that has high target resolution, extended range, and clear image. Experimental results are presented to demonstrate improved capabilities.

[126] Chikara, N., et al. The Development of Ace Mole 10 Series Shield Machine Front Detection Technology. *NTT Gijutsu Janaru,* Vol. 5, No. 10, Japan, 1993, pp. 62–64.

The problem of underground collisions between the Ace Mole machine and buried objects resulted in the development of sensors that detect objects buried in the pathway of the machine.

[127] Yamaguchi, Y., and M. Sengoku. Detection of Objects Buried in Sandy Ground by a Synthetic Aperture FM-CW Radar. *IEICE Trans. Communications,* Vol. E76-B, No. 10, Oct. 1993, pp. 1297–1304.

An FM-Continuous Wave radar system for the detection of objects buried in sandy ground is explored and is applied to a field measurement.

[128] Yiwei, H., U. Toru, A. Saburo, and M. Takunori. Two-Dimensional Active Imaging of Conducting Objects Buried in a Dielectric Half-Space. *1992 International Symposium on Antennas and Propagation,* IEICE Transactions on Communications, Vol. E76-B, No. 12 (19931225), 1993, pp. 1546–1551.

Proposed two-dimensional quasiexact active imaging method for detecting the conducting objects buried in a dielectric half-space is described.

[129] Baoyi, W., X. Runming, D. Yangjian, and Y. Huiqing. Nanosecond Electromagnetic Pulse for Detecting Underground Pipes and Holes. *Acta Electronica Sinica,* Vol. 20, No. 12, Dec. 1992, pp. 36–41.

A system for detecting underground targets by nanosecond electromagnetic pulse method is described.

[130] Nagashima, S., K. Suyama, and T. Kobori. Techniques for Locating Underground Utilities. *Proc., ISTT No-Dig 92,* Washington, D.C., April 1992, 15 pp.

Tokyo Gas previously developed ground-probing radar and an electromagnetic induction type pipe locator, and Tokyo Gas utilized both in the field. This paper presents an outline of these two techniques by mainly introducing the achievements of the development work performed by Tokyo Gas.

[131] Weil, J. G. Non-Destructive, Remote Sensing of Buried Tanks. *Proc., ISTT No-Dig 92,* Washington, D.C., April 1992, 6 pp.

Remote-sensing, infrared thermography is a refined and accurate process for the noncontact, nondestructive testing of subsurface areas for the presence and location of buried tanks and industrial/utility equipment. This technology has been thoroughly proven to be a precise, cost-effective, efficient, and repeatable tool during its 10-year development and testing process. This technical paper details a case study in which infrared thermography was used to locate buried industrial waste materials along with buried underground storage tanks (UST) and miscellaneous waste items as small as 55-gallon drums.

[132] Kaneko, T. Radar Image Processing for Locating Underground Linear Objects. *IEICE Transactions on Information and Systems,* Vol. E74-D, No. 10, Oct. 1991, pp. 3451–3458.

This paper presents an image-processing method using ground-probing radar data taken by synthetic aperture radar. The method locates underground linear objects such as pipes carrying telephone/electricity cables, and it realizes high measurement accuracy with short computation time.

[133] Liu, C., and L. C. Shen. Numerical Simulation of Subsurface Radar for Detecting Buried Pipes. *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 29, No. 5, Sept. 1991, pp. 795–798.

A subsurface radar for the detection of dielectric or metal pipes buried in the ground was investigated numerically.

[134] Wensink, W. A., J. Hofman, and J. K. Van Deen. Measured Reflection Strengths of Underwater Pipes Irradiated by a Pulsed Horizontal Dipole in Air: Comparison with continuous Plane-Wave Scattering Theory. *Geophysical Prospecting,* Vol. 39, No. 4, Delft, Netherlands, 1991, pp. 543–566.

At Delft Geotechnics, GPR is in use for the detection of buried objects such as pipes. In order to give "measurements in the field" a more quantitative interpretation, a series of experiments has been started under well-defined conditions.

[135] Honda, S., and Y. Miyamoto. Analysis of Alternating Magnetic Field Location Technology of Buried Pipe Lines. *IEEE Transactions on Magnetics,* Vol. 25, No. 5, Sept. 1989, pp. 3281–3283.

The magnetic field induced by currents flowing through the ground between a buried pipe and an earth contact electrode is analyzed and numerically evaluated.

[136] Yuji, N., M. Jun-Ichi, S. Yoshikazu, and O. Kyouichi. Underground Radar Apparatus Using Pattern Recognition in Frequency Domain. *NTT R D,* Vol. 38, No. 6, 1989, pp. 667–676.

A new signal processing technique to improve the detection accuracy of an underground radar system (pulse radar) is described.

[137] Miyamoto, Y., Y. Wasa, K. Mori, and Y. Kondo. Pipe Locator for Imaging Underground Pipelines. *J. of Applied Physics,* Vol. 64, No. 10, Nov. 1988.

Pipe locator system for imaging the complex underground pipelines (such as tee, bend, riser, etc.) using magnetic remote sensing techniques has been developed.

[138] Wasa, Y., et al. Magnetic Detection for Underground Pipes. *J. of Applied Physics,* Vol. 64, No. 10, Nov. 1988.

Magnetic detection has been investigated for use in detecting the location of underground pipelines, such as gas and water lines, by inputting a signal current into a pipeline and detecting magnetic field generated by that current.

[139] Ueno, K., and N. Osumi. Underground Pipe Detection Based on Microwave Polarization Effect. *International Symposium on Noise and Clutter Rejection in Radars and Imaging Sensors,* Tokyo, Japan, Oct. 1984, pp. 673–678.

A polarization diversity method for underground object imaging is proposed and applied to detection of linear objects, such as pipes.

Miscellaneous Articles

[140] Association Takes Position on Marking Laterals. *Underground Construction,* Jan. 2007.

This article discusses the responsibilities of contractors and owners with respect to the marking of sewer laterals.

[141] Pollock, M. Keyhole Technology: After 40 Years—An Overnight Success. *Trenchless Technology,* Vol. 14, No. 7, July 2005, pp. 54–55.

In addition to utility maintenance, the keyhole technology has other direct applications and can be used for inspection holes for SUE.

[142] Proulx, C. R. GPR: Past, Present, and Future. *Trenchless Technology,* Vol. 12, No. 4, April 2003, pp. 18–20.

The article describes GPR history, how GPR works, its suitability for utility locating, and its limitations.

[143] Rada, G. Hydroexcavation: Utility Locates and Much, Much More. *Proc., Damage Prevention Conference and Exposition,* Tampa, Fla., Dec. 2003, 14 pp.

This is a short PowerPoint presentation describing the use and benefits of hydroexcavation in the utility location process.

[144] Rahman, S. Study Recommends Methods for Locating PVC Pipes. *PVC News,* Vol. 26, No. 1, Uni-Bell PVC Pipe Association, Spring 2003, p 5.

This article references the AWWARF research listed in bibliography entry 30, *New Techniques for Precisely Locating Buried Infrastructure.* The technologies discussed include GPR, electromagnetic (EM), sonic and acoustic (SA), magnetometry (MAG), and infrared (IR).

[145] Damage Prevention Benefiting from Web-Based Systems. *Underground Focus,* Vol. 16, No. 5, Nov./Dec. 2002, pp. 14–15.

Internet-based locate request systems will provide a high-resolution aerial photo of the dig site area when an address or latitude/longitude coordinates are provided.

[146] Crouch, A., and G. Chell. Making the "Smart Pig" Smarter. *Technology Today,* Southwest Research Institute (SwRI), San Antonio, Tex., Fall 2002.

A new nondestructive evaluation technology based on nonlinear harmonics (NLH) to improve traditional in-line inspection (ILI) methods for pipelines was developed. The NLH method consists of impressing an alternating magnetic field onto a magnetic material such as steel and sensing the amount of magnetism produced in the part. The amplitudes of harmonic excitations are considered related to the level of stress and strain in the steel pipe wall.

[147] Rush, J. Urban Microsurgery: Keyhole Technology Keeps Traffic Flowing. *Trenchless Technology Magazine,* Vol. 11, No. 6, June 2002, p. 28.

Keyhole technology allows access to buried pipelines for repair or renovation. Advancement is being made through developing more efficient air excavation equipment that uses a focused laser-like air stream.

[148] Miller, K., and M. R. Wallbom. New System Developed for Locating Sewer Laterals. *Underground Focus,* Vol. 14, No. 7, Nov./Dec. 2000, pp. 8–10.

The DrillSafe system is described. It integrates the Aries lateral camera with a special electronic sonde, which maps depth, location, and direction of each lateral from the mainline.

[149] Miller, R. J., and M. J. Culig. Borehole Geophysics Clears for Pipe Bursting. *Trenchless Technology,* July 1998, pp. 34–35.

In Oak Ridge, Tennessee, an existing sewer pipe had to be replaced and there was a concern about potential damage to utilities within the zone of influence. For locating these utilities, electromagnetic induction and magnetic susceptibility methods were applied through the pipe to be burst.

[150] Pasquale, G. D., and G. Pinelli. No-Dig Application Planning Using Dedicated Radar Techniques. *No-Dig International,* Vol. 9, No. 2, Feb. 1998, pp. I.12–I.14.

The use of GPR for utility mapping and soil surveying is investigated.

[151] Hayward, P. Ground Investigation and Utility Location. *No-Dig International,* Vol. 8, No. 5, May 1997, pp. 19–24.

This article reviews remote utilities location equipment and ground probing radar system.

[152] Meade, R. B., and R. J. Chignell. Tool Advances Pipe Location and Construction Planning. *Pipeline and Gas Journal,* April 1997, pp. 42–46.

A robust single-unit development of GPR has now been developed for the utility industry, offering a method of locating buried piping of any material, without excavation.

[153] Chernekoff, J., and D. Toussaint. Pipe Location Technology Has Rich History. *Water Engineering Management,* Vol. 141, No. 4, 1994, pp. 28–31.

The locators may use engineered plastics, microprocessors, transistors, and integrated circuits, but the physics of underground locating has not changed.

[154] Marking Hard-to-Find Pipes. *Pipeline and Gas Journal,* Vol. 217, No. 9, 1990, pp. 32–36.

New technology for locating buried pipes and cables is presented. It promises to eliminate many of the problems experienced with conventional methods.

[155] Finding Buried Lines. *Pipeline and Gas Journal,* Vol. 214, No. 7, July 1987, pp. 32–34.

There are four primary devices available for relocating underground facilities: permanent magnets, radioactive markers, active direct buried devices, and passive direct buried devices.

[156] Howell, M. I. Pipeline and Cable Location. *Pipes and Pipelines International,* Vol. 32, No. 5, Sept.–Oct. 1987, pp. 12–17.

This paper outlines some existing methods for the survey of buried conductors and attempts a forecast of a successor. Topics discussed include the cosine antenna, properties of alternating currents in buried conductors, other signal-current sources, sum of currents in a network, sources of signal current, and the triple sine antenna.

Utility Characterizing

These references provide information on how to identify utility type, material, condition, and operating characteristics. Methods and technologies for pipe inspection and condition assessment are also described.

Reports

[157] Pipeline and Hazardous Materials Safety Administration. *Design, Construction and Testing of a Segmented MFL Sensor for Use in the Inspection of Unpiggable Pipelines.* Ongoing Research #160, DTRS56-05-T-0002, Northeast Gas Association for Pipeline and Hazardous Materials Safety Administration, 2008.

The objective of the proposed project is to develop a segmented magnetic flux leakage (MFL) sensor and respective module for integration in a robotic platform (TIGRE—being developed through a parallel project, which is part of this consolidated program) that will allow the inspection of presently unpiggable transmission pipelines. The sensor will cover only a portion of the pipe's internal surface but should be able to provide the same level of sensitivity and accuracy as a state-of-the-art MFL sensor used in smart pigs. Through multiple passes of the pipe, or through rotation and translation of the sensor down the pipe, the entire surface of the pipe will be inspected.

[158] Pipeline and Hazardous Materials Safety Administration. *Characterization of Stress Corrosion Cracking Using Laser Ultrasonics.* Ongoing Research #188, DTPH56-06-T-000003, Intelligent Optical Systems, Inc., Laboratory for Pipeline and Hazardous Materials Safety Administration, 2008.

The objective of the proposed effort is to apply the proven technologies of laser ultrasonics and finite difference simulation toward the development of a tool that can provide the ability to map the stress corrosion cracking (SCC) colonies accurately and provide spatially precise three-dimensional data, and to develop an application that can do so in an efficient manner in the field.

[159] Pipeline and Hazardous Materials Safety Administration. *Define, Optimize, and Validate Detection and Sizing Capabilities of Phased-Array Ultrasonics to Inspect Electrofusion Joints in Polyethylene Pipes.* Ongoing Research #187, DTPH56-06-T-000002, Edison Welding Institute, Inc., Laboratory for Pipeline and Hazardous Materials Safety Administration, 2008.

Research was conducted to define the detection and sizing capabilities of current state-of-the-art phased-array technique for nondestructive inspection of electrofusion and saddle lap-joints in polyethylene gas distribution pipelines. Additional tasks include the development of an optimized phased-array procedure and determination of the performance of the technique and proposed improvements.

[160] Gas Technology Institute. *Pipeline Assessments Through Keyholes.* Ongoing Research, Gas Technology Institute, Chicago, Ill., 2007.

Available technology for pipeline inspection is being adapted to allow inspections to be made easily through small "keyholes." The technology measures pipe-wall thickness externally. Special tools and system modifications will be developed to eliminate currently required open-cut excavation to access the pipe. The solution is based on broadband electromagnetic (BEM) sensors.

[161] Pipeline and Hazardous Materials Safety Administration. *Infrasonic Frequency Seismic Sensor System for Pipeline Integrity Management.* Ongoing Research #183, DTRS57-05-C-10110, Physical Sciences, Inc., Laboratory for Pipeline and Hazardous Materials Safety Administration, 2007.

The infrasonic gas pipeline evaluation network (PIGPEN) system has been successfully developed. It detects and warns of third-party damage before it occurs. PIGPEN uses low frequency seismic/acoustic sensor technology to proactively detect and warn of unauthorized activity near underground gas pipelines before damage occurs, thereby preventing third-party damage and subsequent pipeline leaks or failure. Under the Small Business Innovative Research (SBIR) phase I work, Physical Sciences, Inc., successfully demonstrated the basic feasibility of the concept and will transition the technology from its current proof-of-concept stage to a precommercial prototype in phase II.

[162] Pipeline and Hazardous Materials Safety Administration. *Hazardous Liquids Airborne Lidar Observation Study (HALOS).* Ongoing Research #153, DTRS56-04-T-0012, ITT Industries Space Systems for Pipeline and Hazardous Materials Safety Administration, 2007.

ITT is extending the airborne natural gas emission lidar (ANGEL) technology to the detection of small hazardous liquid and refined product leaks. The ANGEL system is designed to remotely detect, quantify, and map small plumes of methane and ethane, the principal constituents of natural gas. In addition to the hardware and software systems, ITT has developed expertise in the spectroscopy, modeling, and empirical/physical testing and validation of airborne dispersed hazardous vapors. These tests have yielded preliminary results that indicate the detection of vapors from hazardous liquids is possible with minimal changes to the existing ANGEL system.

[163] Pipeline and Hazardous Materials Safety Administration and Office of Pipeline Safety. *Mechanical Damage Study.* Ongoing Research, Pipeline and Hazardous Materials Safety Administration and Office of Pipeline Safety, 2007.

Pipeline and Hazardous Materials Safety Administration/ Office of Pipeline Safety has commissioned a synthesis study on mechanical damage. This study will evaluate the state of technology as well as gaps in the accepted technology necessary to understand, identify, assess, manage, and mitigate mechanical damage of pipelines.

[164] Pipeline and Hazardous Materials Safety Administration. *Airborne LIDAR Pipeline Inspection System (ALPIS) Mapping Tests.* Ongoing Research # 93, DTRS56-01-X-0023, LaSen and U.S. Air Force Research Laboratory for Pipeline and Hazardous Materials Safety Administration, 2007.

The airborne LIDAR pipeline inspection system (ALPIS) is an airborne remote sensing system for detecting leaks associated with natural gas and hazardous liquid pipelines. Data collected with ALPIS can be incorporated into a geographic information system (GIS) to create mapping databases. Project goals were to achieve survey speeds of up to 150 miles per hour and cost equal to or less than much slower survey methods currently available.

[165] Reed, C., A. J. Robinson, and D. Smart. *Potential Techniques for the Assessment of Joints in Water Distribution Pipelines.* AWWA 64358, American Water Works Association, Feb. 2007, 354 pp.

The objective of this study was to identify and document key problems associated with the failure of joints in water distribution pipelines and to investigate and report on the performance of existing and emerging techniques for the location, condition assessment, and repair of these joints. Consideration has also been given as to how the information relating to testing and condition assessment can be used by water utilities. A decision support tool has been developed to assist with the selection of appropriate technologies.

[166] Pabla, A. S. *Electric Power Distribution.* McGraw-Hill Professional, 2005, 878 pp.

Information is given on avoiding power reductions and failures, as well as meeting tests posed by new technologies and greater loads, maintenances issues, and privatization. Detection systems for electrical cable faults are also described.

[167] Thomson, J., and L. Grada. *An Examination of Innovative Methods Used in the Inspection of Wastewater Collection Systems.* WERF Report 01-CTS-7, Jan. 2005, 216 pp.

A comprehensive review of the current state of the art of investigation technology is provided for both gravity and force mains.

[168] Baker, M., Jr. *Dent Study.* U.S. Department of Transportation, Research and Special Program Administration, Office of Pipeline Safety, Nov. 2004, 45 pp.

This study is about potential effects of dents on the integrity of both gas and liquid pipelines, in particular of dents located between the four o'clock and eight o'clock positions, commonly referred to as "bottom-side" dents. However, several aspects of dents in general (i.e., issues germane to bottom-side dents as well as other dents) were also reviewed and, for completeness, were reported therein. Since dents with and without associated surficial damage (e.g., scratches, gouges, etc.) are fairly common, PHMSA/OPS determined that there was a need to address the ability of pipeline operators to detect and evaluate occurrences, particularly bottom-side dents, in the context of integrity management.

[169] Baker, M., Jr. *Pipe Wrinkle Study.* U.S. Department of Transportation, Research and Special Program Administration, Office of Pipeline Safety, Oct. 2004, 74 pp.

This report examines effects of corrosion metal loss on pipe wrinkles and buckles in steel pipelines. The report focuses on the ability of in-line inspection (ILI) to detect corrosion-related defects within the deformed pipe section and evaluates the possibility of developing a demand-capacity criteria framework for evaluation of wrinkles and buckles with general metal loss due to corrosion.

[170] Mide Technology Corporation. *Piezo Structural Acoustic Pipeline Leak Detection System.* June 2004, 90 pp.

An innovative method for detecting leaks in pipelines has been developed. A structural-acoustic sensing and alert system continuously monitors a pipeline without a need for an external power source. The system is based on Mide's patented PowerAct conformable packages piezoelectric actuator and sensor. The sensor produces voltage in response to strain induced in active material. When bonded to a structure such as pipe, any disturbances in the pipe will show up as a voltage trace over the poles of the sensor. These sensors are extremely sensitive with very high gain and can detect the most minute and high-frequency strains. Since leaks in high-pressure gas pipelines fit this description, this is a good sensor to apply to the specific problem.

[171] United Kingdom Water Industry Research. *Service Pipe Leakage.* Ref: 02/WM/08/28, Pipeline Developments Ltd., 2002, 120 pp.

This report looks principally at detection and location methods to find leakage in water pipes, and a comprehensive decision chart has been developed to aid the user in selecting what will most likely be the lowest-cost repair solution. A prototype twin wall insertion probe has been developed which enables the precise location of a service pipe leak to be determined. The bulk of the report is dedicated to the experiments conducted using neural networks to attempt to characterize service pipe leaks. The aim was to use the acoustic signals given off by a leaking pipe to determine the location and size of the leak as well as the material from which the pipe was made. Approaches to valuing changes in external costs are developed. In addition, the methodology provides an approach to updating historical estimates of cost, taking account of existing interventions aimed at internalizing external costs, and allowing for sunk capital. The methodology is illustrated with case studies.

[172] Bubenik, T. A., J. B. Nestleroth, R. J. Davis, B. N. Leis, R. B. Francini, A. Crouch, S. Udpa, and M. A. K. Afzal. *In-Line Inspection Technologies for Mechanical Damage and SCC in Pipelines.* Report No. DTRS56-96-C-0010, U.S. Department of Transporation, Office of Pipeline Safety, Battelle Memorial Institute, Columbus, Ohio, June 2000, 299 pp.

The project evaluated and developed in-line inspection technologies for detecting mechanical damage and cracking in natural gas transmission and hazardous liquid pipelines. Covered are (1) inspection methods for mechanical damage, (2) methods of detecting stress-corrosion cracks, and (3) verification testing and improvements in the analysis methods. The intended audience is government representatives, pipeline companies, and inspection vendors.

[173] National Research Council. *Seeing into the Earth: Noninvasive Characterization of the Shallow Subsurface for Environmental and Engineering Applications.* National Research Council, Washington, D.C., 2000, 148 pp.

The book examines why noninvasive characterization is important and how improved methods can be developed and disseminated. It also provides background on (1) the role of noninvasive subsurface characterization in contaminant cleanup, resource management, civil engineering, and other areas; (2) the physical, chemical, biological, and geological properties that are characterized; and (3) methods of characterization and prospects for technological improvement.

Papers (Conference Proceedings, Journals, and so forth)

[174] Bresciani, F., and F. Peri. Guided Waves Inspection of Pipelines: Experiences of Italian Institute of Welding. *Proc., ISTT NoDig 2007,* Rome, Sept. 2007, S2_04.

The experiences of the Italian Institute of Welding in inspection of aboveground pipelines and road crossings using advanced diagnostic techniques, above all guided waves technology. Guided ultrasonic technique involves transmitting ultrasonic lamb waves along the pipe length. Using this method, several hundred feet of pipe can be inspected from a single location.

[175] Dayananda, D., C. G. Wilmut, and B. J. Dsouza. Effective Identification of Service Line Defects with Electro-Scan Technology. *Proc., Texas Water 2007 Conference,* San Antonio, Tex., March 2007.

Electroscan technology in the form of the FELL-41 (focused electrode leak locator) system is used for inspecting wastewater mains from manholes for pipe sizes that were a minimum of 6 in. in diameter. The sonde was redesigned to cater to smaller wastewater lines like service lines. The new service line sonde is called the FELL-21, and it is effective in testing pipes in the 3-in. to 6-in. pipe diameter range with access through cleanouts.

[176] Kuroiwa, M., and N. Arita. Airflow-Push Type Intelligent TV Camera-System for the Pipes with Several Right-Angle Bends. *Proc., ISTT No-Dig 2007,* Rome, Sept. 2007.

A new camera system for inspection of small-diameter pipes (2 in. to 3 in. in diameter with multiple 90° bends) has been developed. The system propels the camera head forward by airflow and has flexible cables that provide low

resistance. Also, software has been developed to acquire data required for creating three-dimensional drawings by loading a small three-axis acceleration sensor into the camera head.

[177] Sakaki, K. Measures for the Prevention of Road Cave-ins—An Inspection Technique Utilizing Electromagnetic Waves to Identify External Pipe Voids Surrounding Sewer Laterals. *Proc., ISTT No-Dig 2007,* Rome, Sept. 2007.

A new inspection method, which emits an electromagnetic wave from within the pipe and detects the voids surrounding sewer laterals directly by reflected waves (electromagnetic radar), has been developed. This inspection technique can be performed at the same time as the conventional CCTV survey.

[178] Willems, H., M. Nadler, M. Werle, and O. A. Barbian. New Tool Looks For Circumferential Cracks. *Pipeline and Gas Journal,* March 2007, pp. 32–36.

An automated ultrasonic inspection system (intelligent pig) has been developed for the detection of transverse crack-like defects in pipelines.

[179] Ariaratnam, S. T., and N. Guercio. In-Pipe Ground Penetrating Radar for Non-Destructive Evaluation of PVC Lined Concrete Pipe. *Solid Mechanics and Its Applications: Advances in Engineering Structures, Mechanics and Construction,* Vol. 140, 2006, pp. 763–772.

This paper describes the testing, development, and application of a novel assessment technology, which combines in-pipe GPR with digital scanning and evaluation technology (DSET) robotics to collect accurate information about the condition of the inside wall of concrete sewer pipes. A case study applying this innovative technology to sections of large-diameter PVC-lined concrete pipe in the City of Phoenix is presented. The study and adoption of innovative pipeline assessment methods provide better information to improve the decision-making process, thereby making economical decisions to optimize resources in more efficient ways.

[180] Grigg, N. S. Condition Assessment of Water Distribution Pipes. *J. of Infrastructure Systems,* Vol. 12, No. 3, Sept. 2006, pp. 147–153.

The paper reviews utility practices in condition assessment of water distribution systems and compares the practices in leading utilities. It is indicated that the utilities could utilize available information better; however, they are impeded by lack of a standard procedure for recording data on leaks, breaks, and condition indicators. Advanced applications are required for the future. These might include real-time assessment, smart pigs to collect data, small chip sets, and automated pipe data registration.

[181] Jaganathan, A., E. N. Allouche, and N. Simicevic. Pipeline Scanning: Novel Technology for Detection of Voids and Internal Defects in Non-Conductive Buried Pipes. *Proc., ISTT 2006 No-Dig Conference,* Brisbane, Australia, 2006.

Nonconductive buried pipe systems deteriorate over time under the action of various applied and environmental loads, chemical and microbiological induced corrosions, and differential settlements. Defects hidden beneath encrustation, cement mortar lining, or a thermoplastic liner, as well as voids immediately outside of the pipe, are difficult to detect. It is proposed to develop a novel inspection technology, employing UWB pulsed radar system, for detecting “below surface” defects, corrosion, and out-of-pipe voids in non-metallic buried pipes. This paper presents the theoretical foundation for the proposed method, followed by the results of a detailed numerical simulation. The numerical simulation employed custom-developed finite difference time domain (FDTD) code using a cylindrical coordinate system. Results from simulating the scanning of selected soil-pipe interface scenarios are presented. Experimental validation efforts of the proposed pipe scanning approach are also described.

[182] Galleher, J. J., Jr., G. E. C. Bell, and A. E. Romer. Comparison of Two Electromagnetic Techniques to Determine the Physical Condition of PCCP. *Proc., Pipeline 2005,* Houston, Tex., Aug. 2005, pp. 401–410.

Two providers of electromagnetic inspection services (generally using similar methods) were evaluated by comparing their findings; both providers had surveyed the same segment of the pipeline with differing results. Next, their results were directly compared with actually observed defects. This paper reviews the results and documents the predicted electromagnetic results along with the observed physical condition of the pipe sections and emphasizes the importance of proper records and the utilization of other impact factors that affect the performance.

[183] Xiangjie, K., and B. Mergelas. Condition Assessment of Small Diameter Water Transmission Mains. *Proc., Pipeline 2005,* Houston, Tex., Aug. 2005, pp. 252–262.

A majority of the concrete pressure pipe that has been manufactured and installed in the U.S. is less than 48 in. in diameter. Depending on the design requirements, embedded and lined cylinder pipe (AWWA 301) and bar wrapped pipe (AWWA 303) are commonly used in this size. However, the mechanical behavior and failure mechanisms of prestressed concrete cylinder pipe (PCCP) and bar wrapped pipe are different. Nonetheless, three distinct assessment tools designed to detect broken wires (or bars) or leakage are useful for understanding the condition of these high-value assets.

[184] Harris, R. J., and J. Tasello. Sewer Leak Detection—Electro-Scan Adds a New Dimension. Case Study: City of Redding, CA. *Proc., Pipelines 2004,* San Diego, Calif., Aug, 2004.

This study shows that sewer electroscanning is able to pinpoint pipe defects that are large sources of collection system infiltration. These defects were not located using other investigation methods. In a pilot study in Redding, California,

electroscanning 25,000 ft of main line sewers was investigated to pinpoint the sources of the infiltration in a subbasin that had particularly high peak wet weather flows.

[185] Jarnecke, D. Keyhole Technology: Taking Big Steps to Get Small. *Proc., UCT '04,* Houston, Tex., Jan. 2004, 25 pp.

The Gas Technology Institute was working to develop a keyhole process for main leak repair (steel and polyethylene [PE]), service leak repair (steel and PE), new service connections, service replacement/installation, and service abandonment (steel and PE).

[186] Seleznev, V., and V. Aleshin. Computation Technology for Safety and Risk Assessment of Gas Pipeline Systems. *Proc., 2004 Asian International Workshop Advanced Reliability Modeling,* Hiroshima, Japan, Aug. 2004.

Computation technology for investigating failures at gas pipelines is presented. High accuracy mathematical models describing failures in gas pipelines from failure initiation to localizing its consequences are simultaneously created and numerically analyzed.

[187] Seung, M. S., H. S. Jin, and B. K. Sang. Real-Time Monitoring System to Detect Third-Party Damage on Natural Gas Pipeline Using Acoustic Detection Method. *Proc., International Conference: Advances in Dynamics, Instrumentation and Control (CDIC) 2004,* Nanjing, China, Aug. 2004.

This paper presents propagation model and its experimental results to detect third-party damage on natural gas pipeline using acoustic detection method. The paper also involves an evaluation based on the modeled mathematical equations using the developed monitoring system.

[188] Sinha, S. K. A Multi-Sensory Approach to Structural Health Monitoring of Buried Sewer Pipelines Infrastructure System. *Proc., Pipelines 2004,* San Diego, Calif., Aug. 2004.

A research project at the Pennsylvania State University is carried out to determine if a multisensory method could be used for structural health monitoring of buried pipeline infrastructure system. This paper presents preliminary research efforts.

[189] Vengrinovich, V. L., Y. Denkevich, S. Zolotarev, A. Kuntsevich, and S. Emelyanenkov. New Technique for Pipes Wall Thickness Assessment Considering Scattering Effect. *8th European Conference on Nondestructive Testing,* Barcelona, Spain, June 2002.

The problem of image reconstruction from incomplete X-ray data, applied to in situ pipes wall thickness assessment, is considered. Main critical points are (a) limited number of X-ray projections, (b) limited angle for object observation by X-ray setup (c) presence of an isolation, (d) presence of a process liquid, and (e) X-ray scattering effect.

[190] Tafuri, A. Locating Leaks with Acoustic Technology. *Journal of AWWA,* Vol. 92, No. 7, July 2000, pp. 57–66.

The project sought ways to use acoustic technology to pinpoint leaks as small as 0.1 gph in petroleum pipelines, a regulatory requirement for those lines. Because all experiments were conducted using water and on pipelines of size and material similar to those found in many water distribution systems, results also apply to these pipelines. Although leaks of 0.1 gph are unusually small to search for in water distribution systems, researchers were able to locate small leaks within 1 ft, which is comparable to the best practice of commercially available leak-pinpointing technology for water distribution systems.

[191] Whiteley, R. J. Increasing The Confidence of Ground Condition Assessments for Existing and New Buried Infrastructure. *Proc., GeoEng 2000,* Vol. 2, Melbourne, Australia, Nov. 2000, p. 591.

Recently, specially developed seismic imaging technologies such as SRT, SEWREEL, and SUBS, which are analogous to Medical CT scanning, have demonstrated the ability to elucidate external ground conditions and to locate significant voids or weak ground. These technologies may be implemented from the conduit or boreholes according to site requirements.

[192] Strommen, R. D., H. Horn, and K. R. Wold. FSM Non-Intrusive Monitoring of Internal Corrosion, Erosion and Cracking in Subsea Pipelines and Flowlines. *Proc., ASPECT '96: Advances in Subsea Pipeline Engineering and Technology,* Society for Underwater Technology, London, 1996, pp. 25–39.

Field Signature Method is a monitoring technique of both general and localized corrosion, erosion, and cracking in steel and metal structures, piping systems, and vessels. It is commercially available for a variety of applications, one being corrosion monitoring in buried pipelines.

[193] Porter, P. Use of Magnetic Flux Leakage (MFL) for the Inspection of Pipelines and Storage Tanks. *SPIE, Nondestructive Evaluation of Aging Utilities,* Vol. 2454, May 1995, pp. 172–184.

The MFL technique has been used to inspect operating pipelines and aboveground storage tanks. The technique has been adapted for the inspection of in-service distribution pipelines.

[194] Skarda, B. C. Water Pipe Network—Future Strategy: Detection and Prevention of External Corrosion in Zurich. *Water Supply,* Vol. 12, No. 3–4, 1994, pp.139–150.

The annual repair costs amounting to approximately 7% of the Zurich Water Supply turnover are too high. External corrosion/settlement, which is responsible for 90% of the 600 to 800 damaged pipes, is attributed to the combined effect of corrosion currents from tramlines, reinforced concrete structures, and macroelements. These are accelerated by aggressive, partly water-saturated heterogeneous soils and galvanic compounds, mainly earthing installations. Countermeasures are comprised in the Zurich Pipe Network Strategy and in the long-term financial plan. Only the best pipe network material is good enough.

[195] Weil, G., and K. L. Coble. Infrared Scanning Finds Sewer Weak Spots. *Operations Forum,* Vol. 2, No. 11, Nov. 1985, pp. 12–15.

St. Louis Metropolitan Sewer District had sewers inspected for leaks with infrared technology.

Miscellaneous Articles

[196] Automation Blessing: Self-Healing Pipes. *InTech,* Feb. 2007, 1 p.

Artificial platelets (small pieces of polymeric or elastomeric material) are inserted into the pipeline upstream and are carried by the flow of the fluid down the pipe toward the leak. There they clog up the escaping fluid and "heal" the leak. The platelets vary in size from approximately 0.01 in. to 1.97 in., with shapes ranging from discs to cubes. They can be used for locating the leaks as well.

[197] Elmer, R. Low-Mileage Line Benefits from Smart Pigging. *Pipeline and Gas Journal,* Vol. 230, No. 12, Dec. 2003, pp. 20–23.

Smart pigs are highly sophisticated in-line inspection tools. Contracted by Kirkland, Washington–based National Energy Systems Company (NESCO) at a cost of over $250,000, they are used to thoroughly inspect nearly 3.7 miles of 8-in. underground gas supply pipeline connected to the natural gas–fired power plant.

[198] Hare, S., R. Case, and B. Snodgrass. Smart Pigging Proves Useful Inspecting Deepwater Tiebacks. *Pipeline and Gas Journal,* Vol. 230, No. 12, Dec. 2003, pp. 24–28.

A recent project in the Gulf of Mexico demonstrated that deepwater tiebacks can be cost-effectively inspected as part of routine pigging runs. The integrity management capability was shown during a recent first-time inspection of the Canyon Express flowlines operated by Total E&P USA, Inc., using Weatherford Pipeline & Specialty Services' SAAM[R] smart utility pigging technology.

[199] Clarke, I. Trunk Main Leak Location—Development of a New Locator System. *Proc., No-Dig International,* Vol. 11, No. 12, Dec. 2000, pp. 24–25.

The development and application of a new in-pipe leak detection system is described.

[200] Hayward, P. CCTV & Inspection Systems. *No-Dig International,* Vol. 8, No. 6, June 1997, pp. 24–29.

Utilities Mapping

These references provide information on how to create, update, store, and retrieve records of location/type of existing utilities.

Reports

[201] Geospatial Information & Technology Association. *Geospatial Technology Report 2006–2007.* Geospatial Information & Technology Association, Aurora, Colo., 2007.

The report contains detailed information on the completeness, complexity, and direction of GIS projects being implemented at nearly 400 infrastructure-based organizations. The 2006 report includes some new information such as budget information for 2006, project expenditure details, maintenance cycles, and so forth. The executive summary is available online.

[202] Rogers, C. D. F. Mapping the Underworld—UK Utilities Mapping. *Proc., 11th International Conference on Ground Penetrating Radar,* Columbus, Ohio, June 2006, 4 pp.

Mapping the Underworld, a major U.K. initiative to improve the way buried utilities are located and mapped and to improve the way information is shared, is described.

[203] Transportation Research Board. *Research Results Digest 310: Integrating Geospatial Technologies into the ROW Data-Management Process.* Transportation Research Board, Washington, D.C., Dec. 2006, 13 pp.

This digest presents the key findings from a project on integrating geospatial technologies into the right-of-way data-management process.

[204] Transportation Research Board. *Geospatial Information Technologies for Asset Management.* Transportation Research Board, Washington, D.C., Oct. 2006, 78 pp.

This report is the proceedings of a peer exchange held in Kansas City, Missouri, October 30–31, 2005. The peer exchange focused on moving spatial technology applications to the next level by managing change, data integration, and communication. Participants at the exchange identified research to address three areas of interest: temporal issues, symbology, and data and visualization models. The roles of national organizations in sharing best practices and in promoting standards and open data architectures were also explored.

[205] Transportation Research Board. *Integrating Geospacial Technologies into the ROW Data-Management Process.* Transportation Research Board, Washington, D.C., June 2006, 251 pp.

ROW issues commonly cause project delay and increased costs. While many state DOTs use technology such as CADD to draft ROW plans, the final, approved plans are often manually recorded and filed on paper or Mylar. The automation of ROW functions and development of data-integration models using existing technology, including geospatial applications, are needed to enable multiple users to access the ROW information quickly and easily. The objectives of this research were to (1) identify the data elements needed to be included in a data model for a ROW information system that includes a geospatial component and (2) provide examples of return on investment when geospatial capabilities are added to such systems.

[206] United Kingdom Water Industry Research. *National Underground Assets Group: Capturing, Recording, Storing and Sharing Underground Asset Information—A Review of Current Practice and Future Requirements.* Ref: 06/WM/12/13, UKWIR, 2006.

The National Underground Assets Group is sponsoring the National Referencing Standards Project, Phase 1 of which aims to develop methodologies, standards, and best practices that address the short-term standardization needs to 2008 for capturing, recording, storing, and sharing underground asset information. This report makes a series of recommendations for a mandatory revised records code of practice, and a mandatory national standard high-level framework to enable effective deployment of the new code based on a user survey of a representative sample of utilities and highway authorities.

[207] Cullen, M. *Use of Common Framework for Positioning Referencing of Buried Assets.* Institution of Civil Engineers, 2005.

This report gave recommendations as to what information should be kept by buried-assets owners.

[208] Institution of Civil Engineers. *Use of a Common Framework for Positional Referencing of Buried Assets.* Buried Services Working Group Report, Institution of Civil Engineers, United Kingdom, Jan. 2005, 21 pp.

This report examines the status of buried services and calls for a standard approach to the way buried services are located and recorded. The recommendation is to establish a common framework with all geospatial data recorded using the digital national framework (DNF) system. The DNF is a tool that generates all coordinates using the same datum to provide a consistent method of identifying and reusing geographical information. Common encoding standards enable users to reference their own geospatial content to a definitive geographic base. All information can then be recorded within the geographical information system (GIS). This enables buried apparatus to be identified, catalogued (for example, listed as a water main), and referenced to the responsible body (with emergency contact details). Location data can also be recorded to an absolute accuracy. This data then works with related datasets to ensure interoperability, consistency, and internal integrity. The report also recommends that all new installations or replacements should be recorded three-dimensionally rather than two-dimensionally within three years (also recommended in the Traffic Management Act), that a specialist dedicated champion for the continued development of a common framework must be established, and that transferable recorded data should identify the top of the buried item.

[209] Colorado City Ordinance Requires Permit Applicants to Map ROW's. *Underground Focus,* Vol. 17, No. 7, Oct. 2003, pp.8–9.

The ultimate solution to preventing damages to vital subsurface infrastructure is to know where all the underground lines are positioned, so that excavation equipment does not hit the lines. That is easier said than done, but Greenwood Village, Colorado, has developed a workable solution that is now in the second year of implementation.

[210] American Society of Civil Engineers. *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data.* ASCE Standard No. CI/ASCE 38-02, ASCE, Reston, Va., 2002, 20 pp.

This ASCE standard presents a credible system for classifying the quality of utility location information that is placed in design plans. The standard addresses issues such as how utility information can be obtained, what technologies are available to obtain that information, how that information can be conveyed to the information users, who should be responsible for typical collection and depiction tasks, what factors determine which utility quality level attribute to assign to data, and what the relative costs and benefits of the various quality levels are. Used as a reference or as part of a specification, the standard will assist engineers, project and utility owners, and constructors in developing strategies to reduce risk by improving the reliability of information on existing subsurface utilities in a defined manner.

[211] Engineering and Physical Sciences Research Council's Programme Network in Trenchless Technology. *Underground Mapping, Pipeline Location Technologies and Condition Assessment.* University of Birmingham, United Kingdom, March 2002, 77 pp.

This report aims to describe the various techniques available for buried infrastructure location and condition assessment. The report concludes on the research needs determined both at a university-industry workshop organized by the Engineering and Physical Sciences Research Council's Programme Network in Trenchless Technology (NETTWORK) and drawn from research reports that have addressed the efficacy of the various techniques.

[212] Geospatial Information and Technology Association. *The Geospatial Technology Report 2000.* GITA, Aurora, CO, 71 pp.

This report presents a survey of organizations implementing geospatial information technologies. It provides insights to the technologies the GITA members are using as well as applications they are implementing. It discusses land-base maintenance and accuracy issues, sophistication of facility conversion, and the integration of applications with geospatial technology.

[213] Wood, P. Application Integration for Improved Utility Operations. *Proc., AWWA Computer Simulation Conference (CSC) 1994,* 9 pp.

Control and Supervisory Council and Data Acquisition (SCADA) systems are designed for process control, operator interface, data collection, and reporting. System managers have a wealth of real-time and historical data about the process being monitored and controlled. More often than not, the stored information is never retrieved. Many utilities are asking how information collected by control systems can be productively used. Managers, engineers, maintenance supervisors, and secretaries are burdened and frustrated with reading data from reports generated by applications used by other groups and entering that data into their computers. This paper considers methods for implementing integration.

[214] Pickering, D., J. M. Park, and D. H. Bannister. *Utility Mapping and Record Keeping for Infrastructure.* Urban Management Programme, The World Bank, Washington D.C., 1993, 84 pp.

This discussion paper reviews recent developments in urban infrastructure recordkeeping and mapping—a key component of good management of low-cost sewerage systems.

[215] Arnett, C. J., and R. A. Fleck. Automated Mapping/Facilities Management/Geographical Information System. *AWWA Computer Simulation Conference (CSC) 1992,* 17 pp.

In developing an integrated automated mapping/facilities management/geographical information system (AM/FM/GIS) approach, various options available for developing a computerized mapping system must be evaluated. The AM/FM/GIS system would allow for an efficient management of utilities information in both the water distribution and wastewater collection systems. Thorough discussions and evaluations with company staff and outside consultants are necessary to develop an overall technical approach designed to assist in developing this computerized mapping system. The information discussed is useful in the project development. Hardware and software solutions are recommended as well as steps necessary for implementation of the overall AM/FM/GIS.

[216] Purves, A. J., and A. Cesario. AM/FM/GIS and CAD Implementation within the Water Industry. *AWWA Computer Simulation Conference (CSC) 1992,* 8 pp.

A survey of the American Water Works Association (AWWA) utility membership has been conducted by the AWWA Computer Assisted Design Committee. The survey objectives were to determine the status of AM/FM, GIS, and CAD implementation within the AWWA membership; identify comparable utilities undertaking similar efforts; and illustrate level of interest in technology.

[217] Marx, P. Implementing an AM/FM/GIS for Seattle's Municipal Water Utility. *AWWA Computer Simulation Conference (CSC) 1991,* 16 pp.

This paper describes how the fast-growing City of Seattle, Washington, is using GIS technology in many departments, including water and electric. First, a common land database was formed, which contained land-specific data common for many city departments; at the same time, water and electric database and map development were under way. Planning and development activities of GIS in relation to the water department are discussed in some detail; an appendix gives the process in the form of a flow chart. Nine lessons learned are summarized.

[218] Zurawski, R. Lewis Automated Mapping System One Small Step for Mapping; One Giant Leap for Users: LAMS. *AWWA Annual Conference and Exhibition (ACE) 1990,* 12 pp.

This paper describes the underground mapping system for NASA's Lewis Research Center in Ohio. The center covers 350 acres, and modifications to the underground utility system are frequent. Many of the system drawings have been revised more than 30 times, rendering them difficult to read. A mapping system developed at the University of Akron, Ohio, was used to convert the drawings to a computerized mapping system. The paper details how the system was converted and describes the final results. In addition to basic maps, custom color plots will be available at any scale, of any area, in a range of colors, and of any combination of the 85 designated layers. Future enhancements include additional layers and programming to allow the maps to be updated without use of a pencil or by manually digitizing survey data. Add-on programs have been used for analysis on the water system and will be used for analysis of three sewer systems.

Papers (Conference Proceedings, Journals, and so forth)

[219] Thomas, A. M., C. D. F. Rogers, N. Metje, and D. N. Chapman. Soil Electromagnetic Mapping for Enhanced GPR Utility Location. *Proc., ISTT NoDig 2007,* Rome, Sept. 2007, S2–03.

Higher frequency GPR is required for detection of small utilities, but this greatly limits the depth of signal penetration. Wide signal bandwidth is required to balance resolution and penetration results. Mapping of soil electromagnetic properties over large geographical areas is difficult and requires a vast number of measurements to achieve even the most basic geospatial resolution. A U.K. research project, Mapping the Underworld, explores the possibility of using data for selected urban mapping of GPR relevant soil properties.

[220] Yamashita, H., H. Tanaka, S. Baba, and Y. Yamazaki. Development of Conduit Position Measurement Technology Using a Gyroscope and GPS. *Proc., ISTT NoDig 2007,* Rome, Sept. 2007, S2–01.

A new conduit position measurement technology eliminates the necessity of aboveground measurement and can accurately and efficiently obtain conduit route data with absolute coordinates. This technology runs a gyroscope inside a conduit to measure the conduit route and uses GPS technology to establish absolute coordinates for manhole and conduit positions.

[221] Bassi, R. Reports on Radio Frequency Identification. *IT and Construction Process,* No. 67, Oct. 2006, p. 6.

The final report will give a brief introduction to radio frequency identification (RFID) tagging and wireless technologies and will highlight the business benefits they can offer to the construction industry. RFID, or "smart tagging," has been developed in the retail sector to track produce through the logistics and sale stages of its life.

[222] Booth, S. Mapping Four Billion Buried Assets. *Engineering Surveying Showcase,* Oct. 2006, pp. 14–16.

There are currently two major research programs under way in the U.K. about properly locating and recording the position of buried services. Mapping the Underworld is a four-year program aiming to develop technologies to help locate buried infrastructure. Visualizing Integrated Information on Buried Assets to Reduce Streetworks (VISTA) aims to develop a simple format for recording the position of all buried services within a 3-D coordinated reference frame. It brings together the ordnance survey, utilities, contractors, and technology companies.

[223] Roberts, G., X. Meng, A. Taha, and J. P. Montillet. The Location and Positioning of Buried Pipes and Cables in Built Up Areas. *XXIII FIG Congress: Shaping the Change,* Munich, Germany, Oct. 2006.

The research looking at the feasibility of producing a mammoth subterranean map of the U.K., which would show where all of its buried assets are located, is described

[224] Zembillas, N. M., and B. J. Beyer. Proactive Utilities Management: Conflict Analysis & Subsurface Utility Engineering. *Proc., NASTT No-Dig 2005,* Orlando, Fla., April 2005.

Subsurface utility engineering (SUE) is the branch of engineering that specializes in utility identification, location, and advising. An organizational tool for SUE is conflict analysis. Conflict analysis provides a greater sense of coordination by working with utility companies, designers, transportation departments, and contractors and employing a powerful new data management tool, the conflict matrix. SUE and conflict analysis form the link of proactive utilities management that efficiently reduces needless utility relocations, minimizes utility complications, and diminishes overall cost.

[225] Shellshear, D. Geophysical Methods for Defect Mapping and Pipeline Integrity Surveys—Geophysical Methods for Defect Mapping and Utility Risk Analysis. *Proc., ISTT NO-DIG 2000,* Perth, Western Australia, Oct. 2000, pp. 296–300.

GPR systems are commonly available to assist with non-destructive testing of pipeline and sewer system utilities. Several additional geophysical techniques have been extensively tested in Brisbane to complement CCTV and radar data. Encouraging results have been obtained with transmission electron miscroscopy (TEM) resistivity data to provide an indication of structural integrity in terms of variations in substrate resistivity. High-definition seismic systems are required to provide more detail on the nature of the target, and new research programs have been developed for this purpose.

[226] Morgan, A., and N. Taylor. The Technical and Economic Case for the Use of Three-Dimensional Mapping for the Installation of Electric Power Cables. *Proc., NASTT NoDig '96,* New Orleans, La., March–April 1996, pp. 677–687.

The paper reviews the experimental work carried out by MEB on the practical usage of three-dimensional mapping. Evidence is provided to show how the technique has proved to be an effective preplanning tool that has significantly reduced cable installation costs and increased the use of trenchless technology.

[227] Smit, A. L. Utility Base Map for Rotterdam. *Proc., ISTT No-Dig 90,* April 1990, Doelen, Netherlands, 4 pp.

The utility base map (UBP) is a special map that shows the exact X, Y location of all utilities in the entire city. More information about the depth of existing utilities could be needed when using trenchless technology.

[228] Moutal, H. Automated Mapping and Facilities Management Approach for Underground Utilities. *Proc., ISTT No-Dig 88,* Washington, D.C., Oct. 1988, 10 pp.

This document is a case study of utility mapping. New York City has over 6,000 miles of sewers recorded on some 60,000 drawings of varying size, scale, and level of detail. In 1983, the city embarked on automated mapping/facilities management program for sewers. Sewer maps were entered on a CADD system and a sewer database.

[229] Hooper, D., and A. N. Sinclair. Digital Mapping for Watermains in Torbay. *WES Summer Conference,* Torquay, Devon, May 1987.

The development of a digital mapping and database system for water supply and distribution is described. The procedures adopted in producing the user requirement specification and preparing the existing records for conversion to digital form are outlined, and the manual digitization methods used for data conversion are detailed.

Articles

[230] Clarke, I. The Changing Market for Ground Investigation and Utility Mapping Systems. *No-Dig International,* Vol. 13, No. 10, Oct. 2002, pp. 18–21.

A questionnaire was designed to give an indication of the changing face of the ground investigation and utility mapping market worldwide. The questionnaire was circulated to various survey systems manufacturers and contactors.

[231] Morgan, A. Millennium Products Status for 3D Mapping Systems. *No-Dig International*, Vol. 10, No. 4, April 1999, p. 26.

Mapping technology is becoming increasingly important for utility installers.

[232] Twohig, M. A. Utility Mapping the USA Way. *No-Dig International,* Vol. 9, No. 3, March 1998, pp. N7–N9.

This article provides an overview of utility mapping and tracing in the U.S.

[233] Naylor, R. J. A Graphic Information System for Utilities. *Transactions of the Electric Supply Authority Engineers,* Institute of New Zealand Inc., Vol. 56, 1986, pp. 55–69.

This paper discusses how the department manages the network it has developed (now extends to some 1,305 miles and

approximately 31 miles is added each year) and particularly how the plans are used to record the locations of the services.

Other

[234] VISTA. *Seeing is Believing: Safely Exposing Buried Utilities.* VHS, 2001.

Knowing the colors and meaning of utility markers is only part of the answer to safe, damage-free digging. Exposing buried utilities in a safe, efficient way is critical. This video covers one-call requirements, vacuum systems, damage response, open trenches, and hand digging.

Guidance and Regulations for Utilities and ROW

Guidelines/regulations are given as to where to place utilities within the right-of-way.

Reports

[235] Sinha, S. K., H. R. Thomas, M. C. Wang, and Y. J. Jung. *Subsurface Utility Engineering Manual.* FHWA-PA-2007-510401-08, Pennsylvania Transportation Institute, Pennsylvania State University, University Park, Pa., Aug. 2007, 136 pp.

The Pennsylvania Department of Transportation (PennDOT) has one of the largest construction programs in the U.S. Like many state departments of transportation, PennDOT is decentralized. The districts in Pennsylvania have considerable autonomy over the use of SUE design, construction, procurement, and other issues. Thus, the use of SUE is not uniform across the state, and on some projects SUE may not be effectively used. Project- and site-specific procedures are needed that can be used by the central office to encourage all districts to make wider use of SUE as a means of conveying the details of damage-prevention best practices so SUE can be used effectively. The objective of this project is to develop a SUE manual for PennDOT to assist department and consultant designers, utility relocation administrators, and others in identifying the appropriate levels of investigation needed to locate and designate underground utilities.

[236] California Department of Occupational Safety and Health. *Notice of Proposed Modification to California Code of Regulations, Title 8: Chapter 4, Subchapter 4, Article 6, Section 1541 of the Construction Safety Orders,* Oct. 2006. http://www.dir.ca.gov/Title8/sub4.html.

[237] Goodman, A. S., and M. Hastak. *Infrastructure Planning Handbook.* ASCE Press and McGraw Hill, Sept. 2006, 672 pp.

The book features global case studies and numerous research resources, and it covers major infrastructure projects in context, master planning, infrastructure project performance, prioritization of projects and services, project finances and economics, environmental and social impacts, uncertainty and risk, and research for planning and analysis.

[238] American Association of State Highway and Transportation Officials. *Right of Way and Utilities Guidelines and Best Practices.* Strategic Plan 4-4, AASHTO, Standing Committee on Highways. Jan. 2004, 71 pp.

One chapter describes best practices in utility mapping related to highway projects. Guidelines on how to address relocation of utilities during highway projects are also given.

[239] Arboleda, C., H. Jeong, D. Abraham, S. Gokhale. Evaluation, Analysis, and Enhancement of INDOT's Utility Accommodation Policy. FHWA/IN/JTRP-2004/22, Jan. 2004, 122 pp.

The utility accommodation policy (UAP) is a collection of the regulations and practices to control the utility occupancy of all public highway rights-of-way under jurisdiction of the different states. UAPs not only help to regulate the installation of new utilities and the renovation of currently installed utilities by construction companies, subcontractors, and utilities companies, but also provide a framework to develop and preserve a safe roadside and to minimize possible interferences and impairment to the highway, its structures, appearance, safe operation, construction, and maintenance. The current utility accommodation policy of the State of Indiana was adopted on September 10, 1990. It was revised on March 26, 1998, to include the placement of telecommunication towers within highway right-of-way of partial or full-access control. In order to achieve an effective accommodation of existing and new utilities, Indiana Department of Transportation's (INDOT) current UAP was revisited and analyzed by comparing UAPs in Midwest states and incorporating experts opinions from INDOT and related industry. The advances in construction technologies such as trenchless technology and subsurface utility engineering, as well as the demands for new types of utilities, and issues related to right of way, permits, appurtenances, emergency responses, and so forth were analyzed. The implications of these were addressed in INDOT's new UAP.

[240] California Department of Transportation. Chapter 600: Utilities Permits. In *Encroachment Permits Manual,* 7th ed., 2002, 64 pp.

This chapter addresses the initial placement, adjustment, relocation, and replacement of utility facilities in all state highways.

[241] Chen, Q. *Class Location Criteria for Gas Pipelines.* PR-244-0015, Pipeline Research Council International, Inc., 2002, 56 pp.

Current standards and regulations for gas transmission pipelines classify pipeline corridors into location classes and specify design factors accordingly. The primary objective of this project was to examine the current class location system and develop supplementary criteria that would enhance pipeline safety by applying risk-based or reliability-based methods.

[242] Brady, K. C., M. Burtwell, and J. C. Thomson. *Mitigating the Disruption Caused by Utility Street Works.* TRL Limited Report No. 516, 2001, 35 pp.

A summary of the findings of an international review of the policies and construction practices adopted for street works is provided in the report. A wide range of views was found regarding the "rights" of utilities to install and repair pipes and cables in public roads. The requirement and use of trenchless methods for utility street works varies according to, for example, the geographical and geological setting, but the most important factor was the existing policy and legislation defining the rights of the utilities and the public.

[243] American Water Works Association. *Location of Utilities in Public Rights-of-Way—Examples from Various Cities.* Feb. 2000, 22 pp.

Many communities have established and successfully used location guidelines for utilities in their streets. This report highlights some examples of such guidelines (Phoenix, Arizona; Prow, California; Austin, Texas; Cincinnati, Ohio).

[244] U.S. General Accounting Office. *Impacts of Utility Relocations on Highway and Bridge Projects.* GAO/RCED-99-131, U.S. GAO, June 1999, 39 pp.

Delays in highway and bridge projects caused by relocating of utilities and facilities were examined. The following were looked at:

(1) Extent to which states experience such delays, and the causes and impacts of the delays;

(2) Number of states that compensate construction contractors for the added costs incurred on their projects because of untimely relocations by utility companies;

(3) Available technologies, such as subsurface utility engineering (SUE), that are being used during project design to reduce the number or impact of utility relocation delays; and

(4) Mitigation methods that states are using (incentives, penalties, and litigation) to encourage or compel cooperation by utility companies that are relocating utilities on federal-aid highway and bridge projects.

[245] Iseley, T., and S. B. Gokhale. *NCHRP Synthesis of Highway Practice 242: Trenchless Installation of Conduits Beneath Roadways.* Transportation Research Board, Washington, D.C., 1997, 82 pp.

This TRB report describes the trenchless installation technologies (methods, materials, and equipment) currently employed by state DOTs and other agencies to install conduits beneath roadways.

[246] American Association of State Highway and Transportation Officials. *Guidance on Sharing Freeway and Highway Rights-Of-Way for Telecommunications.* AASHTO, Washington, D.C., Aug. 1996, 44 pp.

New communications networks are being built both in the public and private sector. There is interest in public-private arrangements where each party taps the special resources of the other. The private partner gains access to public ROW and the public partner gains access to some form of compensation: in-kind telecommunications facilities or service, cash, or both. Such partnerships are termed "shared resource" projects. These guidelines identify key elements involved in the implementation of shared resource projects. It is designed as an overview of steps and activities that are typically involved in the process. The guidance is descriptive rather than prescriptive.

[247] American Public Works Association. *Excavation in the Right-of-Way.* APWA, Kansas City, Mo., 1996, 65 pp.

This publication reviews the need for coordinating and regulating activities within the public ROW and recommended guidelines for establishing the need implementation mechanisms (with sample ordinances). It reviews the issues involved and includes examples of North American practices to improve coordination efforts.

[248] American Association of State Highway and Transportation Officials. *A Guide for Accommodating Utilities Within Highway Right-of-Way.* AASHTO, Washington, DC., 1994, 27 pp.

The AASHTO guidelines in this publication help to develop and preserve safe highway operations and roadsides by (1) minimizing possible interference and impairment to the highway and its structures, (2) providing good appearance, and (3) minimizing maintenance.

[249] Keating, A. D. *Invisible Networks: Exploring the History of Local Utilities and Public Works.* Krieger Publishing Company, Malabar, Fla., 1994, 168 pp.

This is a useful reference for people involved or interested in urban history or the technological infrastructure on which American cities are built.

[250] United Kingdom Government. *New Roads and Street Works Act (NRSWA) 1991 (c. 22)—Part III Street Works in England and Wales.* 1991. http://www.opsi.gov.uk/ACTS/acts1991.

Section 79 of NRSWA specifies duties and liabilities of street-works undertakers. Section 80 requires that a utility carrying out works in the street, where another utility has been discovered, must make and keep a record of the location and nature of that utility and inform the street authority of the discovery.

[251] U.S. Department of Transportation. *Planning and Scheduling Work Zone Traffic Control.* U.S. Federal Highway Administration, Implementation Package, FHWA-IP-81-6, User Guide, U.S. DOT, Washington, D.C., Oct. 1981, 66 pp.

The primary objective of this guide is to provide highway agency decision makers with analytical procedures and decision methodologies that can be applied in the early planning and design stages of a major street or highway project to select the most appropriate traffic control strategy to be implemented. The process should assist in formulating decisions regarding the type of work zone (lane closure, detour, crossover, etc.) which is most cost-effective for the project.

[252] American Public Works Association and American Society of Civil Engineers. *Accommodation of Utility Plant Within the Rights-Of-Way of Urban Streets and Highways.* Manual of Improved Practice, APWA and ASCE, New York, N.Y., 1974, 101 pp.

This manual has been prepared as a guide to local governmental agencies, other regulating agencies, utilities, consultants, and the public. The manual describes current practice and recommendations for improved practices.

[253] American Public Works Association. *Feasibility of Utility Tunnels in Urban Areas.* APWA-SR-39, Chicago, Ill., Feb. 1971.

This report is a comprehensive examination of the technical, legal, and economic aspects of placing urban utilities in tunnel structures.

Papers (Conference Proceedings, Journals, and so forth)

[254] Quiroga, C., D. Ford, T. Taylor, S. Kranc, and E. Kraus. Construction Specification Framework for Utility Installations. *Proc., 87th Annual Meeting of the Transportation Research Board,* Washington, D.C., Jan. 2008, 21 pp.

Summarized is the work completed to develop a prototype framework of construction specification requirements for utility installations, with a focus on water, sanitary sewer, and communication specifications. It includes five groups of specifications: earth work, pipes and boxes, appurtenances, other, and general (that includes specifications such as mobilization and traffic control, which highway construction contracts typically include but, at the same time, are relevant to the utility relocation process). The framework uses tables that summarize the main characteristics of proposed new or modified standard specifications and includes a listing of pay items, subsidiary items, and corresponding measurement units. The framework also includes specification requirements.

[255] Witing, P. Integrated Utility Planning: Combining Greenways and Utility Corridors. *Proc., Pipelines 2004 International Conference,* San Diego, Calif., Aug. 2004, pp. 1–10.

Utility corridors traditionally have been engineered for the purpose of accommodating sewer, water, and other utility lines and providing access for their maintenance. This paper illustrates the subtle complexities introduced when a greenway is designed and constructed in conjunction with a utility project.

[256] Worlton, M. A., and B. Squire. Keys to Successful Utility Coordination. *Proc., Pipelines 2004 International Conference,* San Diego, Calif., Aug. 2004, 4 pp.

Utility crossings projects may encounter crossings with electrical, fiber optic, natural gas, and a host of other utilities. When poorly identified, each utility crossing poses a liability to engineers and a threat to the safety of contractors. Although this thesis is well established by case history, steps may be taken to avoid new utility-related construction disasters.

[257] Sterling, R. Direct and Indirect Benefits of Underground Placement of Infrastructure. *AUA North American Tunneling Conference 2002,* Seattle, Wash., May 2002.

This paper discusses the impact of underground infrastructure on the quality and livability of cities, how the underground utility network develops as a city grows, and the importance of planning the use of underground space beneath public rights of way.

[258] Zimmerman, R. Social Implications of Infrastructure Network Interactions. *J. of Urban Technology,* Vol. 8, No. 3, Dec. 2001, pp. 97–119.

Urbanized and soon-to-be urbanizing areas are increasingly dependent upon infrastructure transmission and distribution networks for the provision of essential public resources and services for transportation, energy, communications, water supply, and wastewater collection and treatment. In large part, the increasing spread of population settlements at the periphery of cities and the increasing density and vertical integration of urban cores have increased reliance upon the connectivity that these networks provide. These infrastructure networks are, in turn, dependent upon one another, both functionally and spatially, in very complex ways, and that interdependence is increased as new capacity-enhancing infrastructure technologies are developed. The extent of these dependencies appears to be escalating, and it results in interactions among the systems and produces effects upon environments that are difficult to predict.

[259] Sterling, R. The Value of Land Beneath Public Rights-Of-Way. *Proc., ISTT No-Dig 98,* Lausanne, Switzerland, June 1998, pp. 41–50.

Although issues surrounding property rights for underground space are of general interest to this paper, the principal issue of concern is whether underground space beneath public right-of-way has its own intrinsic value which should be taken into account in decisions about how such space should be used for the public good.

[260] Sterling, R. L. Indirect Costs of Utility Construction and Repair. *Proc., No-Dig 97 Conference,* Genoa, Italy, April 1997.

This paper examines the indirect and social costs of utility work beneath public streets and highways. Issues examined include traffic congestions, environmental impacts, road pavement damage, and the effective use of the space beneath public rights-of-way.

[261] Sterling, R. L. *Indirect Costs of Utility Placement and Repair Beneath Streets.* Final Report, University of Minnesota, Minneapolis, March 1994, 52 pp.

The report examines policy issues related to the placement of utilities beneath public rights-of-way. The principal issues discussed are recognition of the present and future value of the space beneath public rights-of-way in space allocation decisions, methodologies for assessing the full societal costs of utility work in congested roadways, implementation of contractual practices and fee structures to mitigate conditions involving high societal costs, and the work that would be necessary to attempt to include the impact of utility cuts on life-cycle pavements costs.

[262] Slee, L. G., and A. W. G. Thijsse. Integration and Planning of the Infrastructure: The Policy Pursued by Rotterdam. *Proc., ISTT No-Dig 90,* Rotterdam, Netherlands, April 1990, 5 pp.

The coordination and integration of activities related to road surfacing and underground infrastructures is generally a complicated process in urban areas where there are a large number of participants, each responsible for the installation and maintenance of his own facility. This paper discusses in more detail the measures in Rotterdam, Netherlands, for good coordination and integration.

Other

[263] *Maine DOT Utility Coordination Process.* http://www.maine.gov/mdot/utilities/coordination/utilitycoordinationprocess.php.

A typical utility coordination process is outlined as it relates to a project development process funded with state and/or federal dollars administered through the Maine Department of Transportation.

Market Issues Related to Utility Technologies

These references provide information on the extent of the underground utility network, demand for locating services, and costs of damage and delays.

Reports

[264] Transportation Research Board. *Research Results Digest 78: Managing Capital Costs of Major Federally Funded Public Transportation Projects.* TCRP G-07, TRB, Washington, D.C., Sept. 2006, 12 pp.

This is a summary of the contractor's final report.

[265] Booz Allen Hamilton. *TCRP Report Web Only Document 31: Managing Capital Costs of Major Federally Funded Public Transportation Projects.* TRB, Washington, D.C., Nov. 2005, 297 pp.

The report explores strategies, tools, and techniques to better estimate, contain, and manage capital costs of federally funded public transportation projects based, in part, on the experience of the case study projects.

[266] United Kingdom Water Industry Research. *Minimising Street Works Disruption: The Real Costs of Street Works to the Utility Industry and Society.* Ref: 05/WM/12/8, 2004.

The program identified a group of projects that looked at how work could be improved just by making better use of current technology. One project was identified to develop a better understanding of what street works cost the utility industry and what they cost society in general. This report details the results from that project. It reviews literature on the subject and endeavors to estimate both the direct cost of street works to utilities and the costs of street works to society. It identifies the ways in which these costs can be minimized, as well as gaps in knowledge requiring further research.

[267] Independent Pricing and Regulatory Tribunal. *Electricity Undergrounding in New South Wales.* IPRAT of New South Wales, Australia, May 2002, 80 pp.

Costs, benefits, and funding of undergrounding electric cables in Australia are reviewed.

[268] U.S. Department of Transportation. *National Transmission Grid Study.* May 2002, 108 pp.

This report is a study of benefits of establishing a national electricity transmission grid and to identify transmission bottlenecks and measures to address them.

[269] U.S. General Accounting Office. *Impacts of Utility Relocations on Highway and Bridge Projects.* GAO/RCED-99-131, U.S. GAO, June 1999, 39 pp.

Delays in highway and bridge projects caused by relocating of utilities and facilities were examined. The following were looked at:

(1) Extent to which states experience such delays, and the causes and impacts of the delays;

(2) Number of states that compensate construction contractors for the added costs incurred on their projects because of untimely relocations by utility companies;

(3) Available technologies, such as subsurface utility engineering (SUE), that are being used during project design to reduce the number or impact of utility relocation delays; and

(4) Mitigation methods that states are using (incentives, penalties, and litigation) to encourage or compel cooperation by utility companies that are relocating utilities on federal-aid highway and bridge projects.

[270] Office of Pipeline Safety. *Cost-Benefit Analysis of Pipeline Mapping.* OPS, Sept. 1999, 43 pp.

This is an appendix to the OPS 1999 final report, *A Collaborative Framework for Office of Pipeline Safety Cost-Benefit Analyses.* The objective of the workgroup was to illustrate, test, and refine the OPS cost-benefit framework, and pipeline mapping was chosen for analysis because extensive cost data are available that describe a voluntary pipeline mapping program.

[271] Purdue University. *Cost Savings on Highway Projects Utilizing Subsurface Utility Engineering.* No. DTFH61-96-00090, Prepared for U.S. Federal Highway Administration, Dec. 1999, 174 pp.

Several states have programs whereby the state DOT contracts SUE providers to map utilities on their projects. Employing SUE can reduce costs and delays on highway projects. This study provided independent review and study of these cost savings. The study concludes that the systematic use of SUE should result in minimum national savings of approx $1 billion annually.

[272] Automobile Association. Digging up the Roads. From a Survey "Living with the Car," P. (01236) 493014, Automobile Association Group Public Policy, Hampshire, U.K., 1997.

This document is referenced in bibliography entry 62, Farrimond 2004.

[273] American Public Works Association. *Managing Utility Cuts.* APWA, 1997, 68 pp.

The report examined procedures and selected case studies of utility cut excavations and restorations. It concluded that none of the reviewed studies offers a standard specification for restoring cuts or a universal method for addressing the cost of lost pavement life. Utility locating procedures and equipment were reviewed on three pages.

[274] Heinrich, J. *Assessment of the Cost of Underground Utility Damages.* North Carolina State University, Raleigh, Aug. 1996, 17 pp.

[275] U.S. Department of Transportation. *The Status of the Nation's Highways, Bridges, and Transit: Conditions and Performance.* Report to U.S. Congress, Jan. 1993, 238 pp.

Detailed information on system characteristics, finance, and trends in condition and performance is provided. The report also includes capital investment requirements from all sources to either maintain or systematically improve current overall system condition and performance for the period 1992–2011.

Papers (Conference Proceedings, Journals, and so forth)

[276] Von Winterfeldt, D. The Costs and Benefits of Converting Overhead Electrical Power Lines to Underground Designs. *Proc., AUA North American Tunneling Conference 2002,* Seattle, Wash., May 2002.

[277] Zimmerman, R. Implications of Trends in and Opportunities for Underground of Utility Distribution Systems for Urban Planning. *Proc., AUA North American Tunneling Conference 2002,* Seattle, Wash., May 2002.

[278] Sterling, R. L. Indirect Costs of Utility Construction and Repair. *Proc., ISTT No-Dig 97,* Genoa, Italy, April 1997, International Society for Trenchless Technology, London.

This paper examines the indirect and social costs of utility work beneath public streets and highways. Issues examined include traffic congestions, environmental impacts, road pavement damage, and the effective use of the space beneath public rights-of-way.

[279] Khoghali, W., and E. H. H. Mohamed. Managing Utility Cuts: Issues and Considerations. *Innovations in Urban Infrastructure 1999,* Seminar at the APWA International Public Works Congress and Exhibition, Denver, Colo., Sept. 1999, 11 pp.

The research project presented here was developed in response to the need of improving the long-term performance of restored utility cuts by identifying and resolving technical difficulties involved in the restoration process.

Articles

[280] Griffin, J. Complex Crossbore Issue. *Underground Construction,* April 2007, pp. 19–22.

Described are recent significant developments related to the issue of who should be responsible for locating and marking laterals. Two industry associations have released position statements supporting legislation requiring location and marking of sewer laterals (Distribution Contractors Association and National Utility Contractors Association). Many contractors and others in the industry are increasingly active and vocal about the seriousness of the issue.

[281] Wimberley, R., and M. Kulikowski. Mayday 23: World Population Becomes More Urban Than Rural. Press Release, North Carolina State University, May 2007, 2 pp.

Wednesday, May 23, 2007, represents a major demographic shift, according to scientists from North Carolina State University and the University of Georgia. For the first time in human history, the earth's population is more urban than rural.

[282] Casper, M. Sinha's $787,000 NSF Grant to Benefit Nation's Infrastructure. News Release, Pennsylvania Transportation Institute, Jan. 2006.

The sustainable water infrastructure management system (SWIMS) investigates how an innovative evaluation system, renewal engineering, and visualization system can be integrated for efficient water and wastewater pipeline management.

Damage Prevention

References in this section provide information on damage prevention, procedures for one-call services, hand dig requirements, and so forth.

Reports

[283] United Kingdom Department for Transport. *Working Together: A Good Practice Guide to Managing Works in the Street.* Department for Transport, Welsh Assembly Government, London, May 2007, 33 pp.

This guide shares good practice for coordinating and managing works on the street. It gives examples of how promoters can carry out works with the least disruption to highway users, frontages, and local communities to improve and maintain the road network.

[284] Common Ground Alliance. *CGA DIRT Analysis and Recommendations for Calendar Year 2005.* Volume II, Dec. 2006, 53 pp.

Stakeholders throughout the U.S. voluntarily provided the data for analysis in this report. CGA collected and summarized the data and published this report to facilitate improvements in safety and damage prevention efforts.

[285] Technologies for Pipeline and Hazardous Materials Safety Administration. *Effectiveness of Prevention Methods for Excavation Damage.* Completed Research #147, DTRS56-04-T-0006, C-FER Technologies for PHMSA, 2006.

A new fault tree model was developed that estimates hit frequency due to third-party excavation based on pipeline condition and prevention practices. In addition to the evaluation of prevention effectiveness, this model can be used to facilitate the selection of the most cost-effective prevention methods and to evaluate risk and reliability of existing or new pipelines.

[286] Gas Technology Institute. *Third-Party Damage Real-Time Monitoring.* Ongoing Research, GTI, Chicago, Ill., 2005.

Transmission pipelines are occasionally subjected to large impact forces from third-party excavating equipment. A system that can detect the resulting contact and quickly alert the pipeline operator would be developed.

[287] U.S. Department of Transportation, Office of Pipeline Safety. *Common Ground: Study of One-Call Systems and Damage Prevention Best Practices.* Aug. 1999, 252 pp.

Best practices in preventing damage to underground utilities were identified and validated. Separate chapters cover one-call centers, locating and marking, and mapping. Emerging technologies are reviewed in the appendix.

[288] Directional Crossing Contractors Association. *Guidelines for Successful Directional Crossing Survey Standards.* DCCA, Oct. 1998, 6 pp.

Preconstruction design covers the issue of locating existing utilities. Pipe locators, GPR, seismic survey, and non-destructive air/hydro-vacuum excavation are described.

[289] National Transportation Safety Board. *Safety Recommendation.* NTSB, Washington, D.C., Jan. 1998, 16 pp.

[290] National Transportation Safety Board. *Protecting Public Safety Through Excavation Damage Prevention.* NTSB, Washington, D.C., 1997, 114 pp.

One chapter is focused on the accuracy of information regarding buried facilities, existing underground detection technologies and mapping, and SUE.

[291] Doctor, R. H., and N. A. Dunker. *Field Evaluation of a Fiber Optic Intrusion Detection System—FOIDS.* Final Report, GRI-95/0533, Dec. 1995, 90 pp.

An early warning fiber optic detection system was tested and evaluated. The technology uses a fiber optic cable that lies parallel to the pipeline and helps protect the line by sensing and detecting potentially destructive intrusions by signaling the operator. Buried sensors use light waves to sensitize the fiber optic sensor over long distances. The system can monitor long sections of pipeline without needing electrical power or connections in the monitored area.

[292] Doctor, R. H., N. A. Dunker, and N. M. Santee. *Third-Party Damage Prevention Systems,* GRI-95/0316, NICOR Technologies, Oct. 1995, 199 pp.

The objective of this project was to identify process improvements and develop technology options that will increase safety and reduce costs associated with third-party damage to underground facilities. Recommendations to reduce third-party damage and increase safety were made.

Papers (Conference Proceedings, Journals, and so forth)

[293] Foillard, R., H. Moussard, and J. Butterworth. Continuous Monitoring of Railway Tracks under the Impact of Horizontal Boring, Micro Tunnelling or Directional Drilling Works. *Proc., ISTT NoDig 2007,* Rome, Sept. 2007, S2_10.

The OSMOS fiber optic system is a surveillance system that can be used for continuous monitoring of railway tracks when trenchless construction is conducted underneath. The system is installed before work begins and left in place during and after the work. The strain in a system of sensors is continuously monitored, informing immediately of any movements of tracks that could lead to accidents.

[294] Utility Notification Center of Colorado. *Perspectives on Facility Damage—2005.* UNCC, Sept. 2006, 76 pp.

[295] Nagel, R. G. Understanding the Significance, Benefits of Subsurface Utility Engineering. *Proc., UCT '04,* Houston, Tex., Jan. 2004, 47 pp.

[296] Noone, J. F. Use of ASCE 38-02 and Subsurface Utility Engineering for Better Design, Cost Savings and Dam-

age Prevention in Airport Planning and Design. *Proc., Pipelines 2004 International Conference,* San Diego, Calif., Aug. 2004.

ASCE/CI 38-02 applies to projects where existing utilities will be impacted and requires that the project approach used by engineers be modified in order to conform to the standard. The paper reviews the standard guideline and proceeds to discuss how to incorporate it and SUE services into an airport project.

[297] Holmes, P. Impacting Issues of Digging and Working Around Buried Utilities. *Proc., Damage Prevention Conference and Exposition,* Tampa, Fla., Dec. 2003, 12 pp.

[298] Vick, J. K. SUE = Increased Safety, Fewer Claims and Lower Costs. *Proc., UCT '03,* Houston, Tex., Jan. 2003.

A lack of reliable information on the location of underground utilities can result in costly conflicts, damages, delays, service disruptions, redesigns, claims, and even injuries and lost lives during construction activities. While the location of subsurface utilities might be found on plans and records, experience has often shown that the utility locations are not exactly as recorded or the records do not fully account for the buried utility systems. This may be especially true of our nation's aged roadway infrastructure.

[299] Milliken, B. How Accurate are Locates? *Proc., Damage Prevention Convention,* Atlanta, Ga., Dec. 1998.

[300] Nelson, R., and M. Daly. Creating a Major Emphasis on Damage Prevention. *Damage Prevention Convention,* Atlanta, Ga., Dec. 1998.

[301] Stinson, W. Preventing Damage to Unlocatable Infrastructure. *Damage Prevention Convention,* Atlanta, Ga., Dec. 1998.

[302] Brown, J. A., and J. R. Sherburn. A GIS Based One-Call Management System for BP Oil Pipeline Co. in the State of Ohio. *Proc., URISA 1995 Annual Conference: Urban and Regional Information Systems Association,* Washington, D.C., 1995, pp. 1:335–342.

Nearly 900 miles of BP Oil Pipeline Company's pipeline network in Ohio is being used as the pilot for this new system.

[303] Anspach, J. H. Subsurface Utility Engineering: A Damage Prevention Tool for Trenchless Technology. *Proc., NASTT No-Dig '95,* Toronto, Canada, April–May 1995, pp. 2C1:1–8.

[304] Miller, J. R. Subsurface Exploration in Support of Trenchless Excavation. *Proc., NASTT No-Dig '94,* Dallas, Tex., April 1994, 10 pp.

Colorado School of Mines has created a test bed where targets are placed at depth and various subsurface search systems can be evaluated.

[305] Clow, D. G. Damage to Buried Plant Causes and Prevention. *NJUG Conference 1987,* National Joint Utility Group, 1987.

Miscellaneous Articles

[306] Congress Passes Pipeline Safety Bill. American Gas, Feb. 2007, 43 pp.

With passage of the Pipeline Inspection, Protection, Enforcement and Safety Act on December 7, 2006, Congress for the first time gave the U.S. DOT broad authority to deal with excavation damage prevention.

[307] Griffin, J. Report Provides Insight into Utility Damage. *Underground Construction,* Feb. 2007, pp. 37–40.

Utility damage hits in 2005 were reported to CGA through its damage information reporting tool (DIRT). CGA completed a DIRT report.

[308] Kannenwischer, J. Protecting Buried Utilities. *Trenchless Technology,* Vol. 14, No. 5, May 2005, pp. 55–57.

Locating utilities with radars, potholes, and one-call systems before excavation is briefly discussed.

[309] Simmonds, C. The Case for the Use of Ground Probing Radar Becoming Law. *NoDig International,* Vol. 14, No. 4, April 2003, pp. 13–14.

The Construction, Health, and Safety Executive (CHSE) guidelines offer recommendations to prevent injury from damage to underground services while excavating. The article describes a draft of the Involuntary Homicide Bill by the Law Commissions in the United Kingdom that would cause many employers, operatives, and even service owners to reconsider how they break ground.

[310] Williams, C. Georgetown: Down Under. *Washington Post,* March 24, 2002.

The three-year project (2002–2004) in Washington, D.C., will rebuild the utility infrastructure beneath Georgetown's historic M Street. At work were the D.C. Department of Transportation, Pepco, Verizon, Washington Gas, and the D.C. Water and Sewer Authority. No technical details were provided in this newspaper article.

[311] Griffin, J. Modern Tools of Underground Damage Prevention. *Underground Construction,* Vol. 56, No. 4, April 2001, pp. 26–28.

DrillSafe is a self-contained system that incorporates two closed-circuit cameras: a color positioning and inspection camera and a fixed-position black-and-white camera with a radio transmitter for locating functions.

[312] Barron, J. Straight Talk on Damage Prevention. *Utility Contractor,* Vol. 23, No. 3, March 1999, pp. 22–25.

Prior to water main installation in Washington, D.C., the utility marked red where electric lines ran parallel to the water main to be installed, and the contractor potholed up to the point where the lines veered.

[313] Aucoin, M. P. Contract Locating Provides an Extra Layer of Safety. *Pipeline and Gas Journal,* Sept. 1998.

The use of one-call centers is discussed, as well as improvements made in line-locating equipment and technological advancements (tracer wire, protective warning tapes, improved quality of prints for the GIS systems, and magnetic locating balls).

[314] Carver, C. Examine Hidden Costs of Utility Hits When Allocating Damage Prevention Dollars. *Underground Focus,* Jan./Feb. 1998, pp. 8–9.

A study by North Carolina State University identified factors to consider when planning prudent damage prevention. Two models have been developed. One model reviews the economic impact of utility damages, and the other shows how to optimize damage prevention dollars.

[315] Krawiec, K. R., and R. J. Ross. Rerouting Boston's Utilities. *Civil Engineering,* Vol. 67, No. 12, Dec. 1997, ASCE, pp. 50–53.

During tunnel construction in downtown Boston, engineers had to move utility lines over and under both new and existing infrastructure and maintain utility service to customers.

Research and Planning

References listed in this section cover topics such as research and development planning and intellectual property arrangements.

Reports

[316] Federal Laboratory Consortium for Technology Transfer. *Federal Technology Transfer Legislation and Policy (Green Book*). FLC, 2006, 25 pp.

This document provides the principal statutory and presidential executive order policies that constitute the framework of the federal technology transfer program.

[317] Air Force Research Laboratory. *Technology Transfer/ Education Interaction Mechanisms: Q uick Reference Guide.* ARFL, June 2003, 18 pp.

A total of 22 technology transfer mechanisms and 10 education interaction mechanisms are listed and described. Features/characteristics of each are given.

[318] Gould, J. P., and A. C. Lemer (eds.). *Toward Infrastructure Improvement: An Agenda for Research.* National Research Council, Washington, D.C., 1994, 129 pp.

The report identifies infrastructure technologies that can be incorporated into or overlay current systems, allow for alternative future urban development, and are likely to be valuable in different modes of infrastructure.

[319] Kim, M., and G. N. Rao. Barriers for Innovation and Technology Transfer in the Public Works Infrastructure R&D. *Infrastructure Planning and Management,* ASCE, New York, N.Y., 1993, pp. 51–55.

[320] Dibner, D. R., and A. C. Lemer. *The Role of Public Agencies in Fostering New Technology and Innovation in Building.* National Research Council, Washington, D.C., 1992, 131 pp.

The book explores innovation in U.S. construction-related industries (e.g., facilities operation and maintenance) and recommends a strategy for fostering new technology.

Papers (Conference Proceedings, Journals, and so forth)

[321] Clambaneva, S. Technology Innovation in the Construction Industry. *Structural Engineer,* Vol. 82, No. 3, Feb. 2004, pp. 23–24.

While other industries have applied computer technology to product design, the construction industry has merely used computer spreadsheets for estimating and bidding. Building complexity is expanding exponentially, but blueprints—the major tool of the building trade—have remained static, unable to match the rapid pace of modern change.

[322] U.S. Congress. Technology Innovation. U.S. Code Annotated, Chapter 63, Title 15, 2000, Sections 3701–3715.

This is a U.S. law to promote technology development through the establishment of cooperative research centers, stimulate improved utilization of federally funded technology developments, encourage development of technology through the recognition of outstanding individuals and companies, and encourage exchange of scientific and technical personnel among academia, industry, and federal laboratories.

Standards

[323] ASTM F2550-06. *Standard Practice for Locating Leaks in Sewer Pipes Using Electro-Scan—The Variation of Electric Current Flow Through the Pipe Wall.* American Society for Testing and Materials, 2006.

Procedures for using the electroscan method to detect and locate defects that are potential sources of leaks in pipes fabricated from electrically nonconductive material such as plastic, clay, and concrete (reinforced and nonreinforced).

[324] EN 50249:2002. *Electromagnetic Locators for Buried Pipes and Cables—Performance and Safety.* 2002.

This European standard specifies the performance and safety requirements for outdoor portable electromagnetic locators for the location of buried conductive pipes, cables, and wires (including allied components) by means of detecting the electromagnetic field caused by a flow of AC current.

Patents

[325] Weil, G. J. 2007. System of subterranean anomaly detection and repair using infrared thermography and ground penetrating radar. U.S. Patent 7,218,267, May 15, 2007.

[326] Clodfelter, J. F. 2002. Talking buried object detector. U.S. Patent 6,396,433, May 28, 2002.

[327] Eslambolchi, H. 1998. Method and apparatus for locating buried conveyances using locating and confirmation signals with an array of sensors. U.S. Patent 5,798,644, Aug. 25, 1998.

[328] Peterman, E. J. 1997. Method for locating the joints and fracture points of underground jointed metallic pipes and cast-iron-gas-main-pipeline joint locator system. U.S. Patent 5,686,828, Nov. 11, 1997.

[329] Powell, J., M. Reich, and G. Danby. 1997. Magnetic imager and method. U.S. Patent 5,650,725, July 22, 1997.

[330] Tuttle, J. E. B. 1997. Buried pipe locator utilizing a change in ground capacitance. U.S. Patent 5,617,031, April 1, 1997.

[331] Arroyo, C. J. 1996. Magnetically locatable optical fiber cables containing integrated magnetic marker materials. U.S. Patent 5,577,147, Nov. 19, 1996.

[332] Powell, J. R. 1996. Magnetic detection of underground pipe using timed-release marking. U.S. Patent 5,585,725, Dec. 17, 1996.

[333] Ward, P. 1996. Method and apparatus for locating a buried element of inductive material using probe with detector coils. U.S. Patent 5,554,934, Sept. 10, 1996.

[334] Crawford, B. B. 1994. Distributed acoustic sensor. U.S. Patent 5,373,487, Dec. 13, 1994.

[335] Eberle, A. C. 1995. Acoustic tracing of buried conduits. U.S. Patent 5,412,989, May 9, 1995.

[336] Goodman, W. L. 1994. Method of making a magnetically detectable plastic pipe. U.S. Patent 5,354,521, Oct. 11, 1994.

[337] Barrett, Z. 1992. Reflective indicator for hidden or buried utilities. U.S. Patent 5,101,755, April 7, 1992.

[338] Rippingale, J. B., and E. O. Schonstedt. 1992. Methods, apparatus and devices relating to magnetic markers for elongated hidden objects. U.S. Patent 5,114,517, May 19, 1992.

[339] Cosman, A. D., J. T. Minarovic, and D. C. Worboys. 1991. Self-dispensing spaced electronic markers. U.S. Patent 5,045,368, Sept. 3, 1991.

[340] Flowerdew, P. M. 1991. System for detecting the location and orientation of a temporarily inaccessible object. U.S. Patent 5,014,008, May 7, 1991.

[341] Minarovic, J. T. 1990. Electrofusion marker. U.S. Patent 4,947,012, Aug. 7, 1990.

[342] Moshofsky, J. F. 1991. Marker for buried objects. U.S. Patent 4,991,536, Feb. 12, 1991.

[343] Rothstein, M. B. 1991. Insulated underground antenna and method for utilizing same. U.S. Patent 5,057,844, Oct. 15, 1991.

[344] Tavernetti, R. E., and P. W. Dodd. 1991. Self-calibrating electromagnetic field sensor for locating buried conduits. U.S. Patent 5,043,666, Aug. 27, 1991.

[345] Turner, L. H. 1991. Utility locator. U.S. Patent 5,056,454, Oct. 15, 1991.

[346] Klatt, R. J. 1989. Location marking stake. U.S. Patent 4,852,512, Aug. 1, 1989.

[347] Rippingale, J. B. 1989. Magnetic locating and tracing system and method using dual-antenna transmitter to distinguish between concealed adjacent objects. U.S. Patent 4,818,944, March 28, 1989.

[348] Gunton, D. J. 1988. Microwave reflection survey technique for determining depth and orientation of buried objects. U.S. Patent 4,728,897, March 1, 1988.

[349] Marthaler, G. A., and R. H. Marthaler. 1988. Permanent marker for utilities. U.S. Patent 4,738,060, April 19, 1988.

[350] Bridges, J. E. 1986. Underground pipeline and cable detector and process. U.S. Patent 4,600,356, July 15, 1986.

[351] Keene, T. M. 1986. Plastic-pipe locator tool. U.S. Patent 4,573,829, March 4, 1986.

[352] Young, J. D., C. W. Davis III, L. Peters, Jr., and R. Caldecott. 1977. Underground, time domain, electromagnetic reflectometry for digging apparatus. U.S. Patent 4,006,481, Feb. 1, 1977.

[353] Brown, J. R. 1975. Underground pipe warning and identification system. U.S. Patent 3,871,536, March 18, 1975.

[354] Hakata, G. 1971. Method and apparatus for locating a buried metallic line employing magnetic field gradient measurements. U.S. Patent 3,617,865, Nov. 2, 1971.

APPENDIX B

Case Histories

The following case studies were obtained through discussion with practicing professionals, a literature search, a survey of subsurface utility engineering (SUE) projects conducted by the TBE Group Inc., and a research report released by the University of Toronto. These cases represent successful applications of SUE technologies and practices in a variety of transportation-related projects. In addition, several nontransportation-related projects that had data available on the relative cost of the SUE effort and the estimated benefit-to-cost ratio, or both, are also briefly described.

Case Study No. 1: Service Road 167, Renton, Washington, 1998

In the late 1990s the Washington Department of Transportation undertook a series of culvert replacement projects along Service Road (SR) 167, a four-lane highway paralleling the Pacific coastline. The objective was to support the upstream migration of salmon in local tributaries for conservation purposes. The project called for the installation of a 6-ft diameter, 200-ft long culvert using trenchless technology. The crossing was to take place where the elevated highway traverses a floodplain. When building the highway, the contractor used whatever was locally available as fill material, including tree trunks, boulders, concrete blocks, and old rail cars. A similar project conducted a year earlier some distance north, near the town of Everett, resulted in significant construction delays, cost overruns, and claims when the microtunneling boring machine (MTBM) encountered various obstacles immediately below the road surface. The MTBM got jammed and required the initiation of a costly recovery operation using a pipe-jacking technique. To avoid a repeat of such difficulties, an innovative subsurface utility engineering investigation was developed and executed. The investigation consisted of three bores directionally drilled across the highway. One of these bores was located along the proposed centerline of the new culvert, while the other two were placed 6 ft north and south of it. A 4-in. polyethylene conduit was installed in each of the bores. A suite of geophysical tools, including borehole ground-penetrating radar, induction, gamma, and seismic technologies were used to conduct out-of-pipe and cross-bore studies. The results from the studies conducted at the different points were correlated with each other and with observations made at locations along the bores where obstacles were encountered during the horizontal directional drilling (HDD). Twenty-one possible targets were identified along the proposed centerline, compared with only six along the alignment 6 ft to the south of it. Subsequently, the culvert alignment was moved 6 ft southwards, and the project was completed uneventfully using pipe ramming.

Case Study No. 2: Hartsfield-Jackson, Atlanta, Georgia, Airport Infrastructure Electronic Marking, May 2006

Hartsfield-Jackson Atlanta is the world's busiest passenger airport, serving more than 89 million passengers in 2005. To expand the airport capacity, a new 9,000-ft runway was constructed and officially commissioned in May 2006. As new cables were buried parallel to the new runway, about 1,000 discrete locations were electronically marked to support routine maintenance activities and future construction work. Typically, buried utilities at airports are marked using 2-ft × 2-ft × 6-in. concrete markers flush with the ground, which are placed immediately above marked features. Such physical markers are costly (about $100 a piece) and require ongoing maintenance, such as painting and grass removal. Also, they are susceptible to unintentional displacement by moving equipment and soil erosion, which can compromise excavation accuracy. Locating the buried utilities is accomplished using multifrequency electromagnetic cable locators. While it is effective for tracing an individual metallic cable, ambiguous results could arise when there are multiple utilities in close proximity.

To overcome these shortcomings, the Federal Aviation Administration (FAA) adopted an innovative radio frequency identifiers (RFID) buried-marker technology that has low vulnerability to moving equipment, requires no maintenance, and provides precise locating information. These RFID sensors act as passive antennas, reflecting back the query signal from the locator without requiring an internal power source. Interrogation is accomplished from the surface using a locating device. The information preencoded in the markers can range from the markers' exact coordinates to the diameter and material of the buried utility or utilities beneath it. Another advantage of RFID buried-marker technology is the relative ease of distinguishing among multiple adjacent buried utilities.

The marking system selected for the project consisted of 4-in. round ball markers (3M Dynatel 2200MiD Series), each containing a unique and remotely readable identification number. Each marker can be programmed with custom script that includes the purpose and composition of the buried utility, its coordinates, and its depth below grade. An operator scripts each ball using a portable locating device and places it in the trench as utility installation progresses. In the Atlanta project, markers were placed at 200-ft intervals for straight sections and at shorter intervals at turn points and in congested areas. Each utility was marked on both sides of all road crossings. The marker locator used a GPS feature that automatically collects GPS coordinates for markers as they are buried. GPS information was then transferred to the mapping database along with a marker identification number and other relevant information, allowing for the creation of an electronic as-built map in a geographic information system (GIS) format for ease of use in future construction planning and maintenance operations.

Case Study No. 3: Urban Electrical Duct Bank Relocation, Orlando, Florida

The Orlando Utilities Commission sought to redesign their electrical duct bank system in downtown Orlando. This redesign was made particularly complex by the region's urban environment and the redesigning of Interstate 4 and the State Road 408 Interchange, two major limited-access highways in central Florida. The SUE consultant was assigned the task of locating and identifying underground facilities. The investigation successfully identified not only known facilities but several utilities for which records were not provided. The design and construction processes were performed and executed smoothly.

Case Study No. 4: I-70 Fast Track, Indianapolis, Indiana

To avoid utility delays that will negatively affect the project's demanding schedule, Indiana DOT (INDOT) regularly uses SUE to identify and coordinate utility impacts and relocations. Examples of this practice are the I-70 Fast Track and Super 70 projects in Indianapolis and the I-74/US 421 roadway improvements for a new Honda plant in Greensburg. The INDOT I-70 Fast Track project involved reconstruction to accommodate expansion of the Indianapolis Airport, including relocating and lowering a 2.3-mile section of interstate I-70 by 20 ft. To meet tight scheduling demands, test holes and utility designations were made within the first month. In addition, proactive utility coordination efforts were initiated to support the aggressive fast-track schedule. The project went forward with minimal utility disturbance-related issues.

Case Study No. 5: Utility Composite Plans Assessment, Dulles, Virginia

Dulles Transit Partners hired a SUE firm to assess utility composite plans compiled using as-built data for the Dulles Metrorail Extension Project in the Tysons Corner area of Fairfax County, Virginia. Records included one-call marks, as-built drawings, facility maps, and design plans. The SUE investigation, which employed electromagnetic equipment to confirm the record, discovered many misreported or unknown utilities. Consequently, the owner decided to expand the SUE investigation to the entire project area. Findings from the SUE investigation helped to avoid significant construction-related impacts associated with unmarked or mismarked utilities, and the project was completed without a serious incident. Fairfax County started using SUE in 1980 in an effort to reduce construction expenses caused by unexpected utility hits, redesign costs, and contractor claims. Using SUE during project design has dramatically reduced the number of utility conflicts.

Case Study No. 6: Hamilton, Ontario, Canada, 2002

A SUE investigation was completed as part of the design phase of a major streetscape/water main/sewer project in downtown Hamilton, Ontario, Canada. The project involved the installation, reconstruction, and replacement of municipal utilities in the area and major streetscape enhancements to improve the overall aesthetics of the downtown area. The study included the collection of utility records that were the basis for more than 10,000 ft of utility designating (quality level B) that was conducted using electromagnetic cable-located equipment. The work also included 25 test holes (quality level A) installed to confirm the exact depth and size of pipes in critical locations. The information derived from the study was used to support the design of the utility alignments. The data from the SUE study identified several conflicts because of erroneous or missing records. Specifically, a large unmarked underground hydro tunnel was found to cross the proposed alignment of the new water main. Among the other unmarked utilities that were identified and that had potential to cause construction delays and cost increases were abandoned gas mains and a phone duct structure. In addition, exact location and characterization information was provided on other utilities for which records were incomplete. A study conducted by the University of Toronto suggested that the City of Hamilton enjoyed a savings of about $282,000 because of the SUE investigation, yielding a benefit-to-cost ratio of 6.6:1. The cost of the SUE investigation was $42,785 and amounted to about 1% of the total project cost.

Case Study No. 7: I-75 Water and Sewer Main Relocation, Georgia

The Georgia Department of Transportation (GDOT) was preparing to relocate a water and sewer main from a rest area parallel to I-75. GDOT hired a SUE consultant to provide utility information for the project. GDOT believed that conflicts existed between newly proposed utility services and the existing utility lines in the right-of-way. A quality level B study and a subsequent quality level A investigation involving excavation of test holes revealed that no conflict existed at the critical sections. The utilities were not relocated, resulting in a savings of thousands of dollars.

Case Study No. 8: State Highway 130, Preconstruction SUE Investigation, Texas

A SUE investigation was undertaken as part of the preconstruction phase of State Highway 130, a major design-build transportation project involving a four-lane highway, toll facilities, and major interchanges. The design called for the relocation of many utilities and the construction of new utilities needed to support the toll roadway. The SUE firm designated about 1.5 million linear feet and excavated more than 600 test holes. Based on the SUE information the road designers revised their plans, shifting the right-of-way by about 300 ft to avoid the relocation of several high-pressure pipelines. This change prevented project delays and resulted in savings estimated at $3 million.

Case Study No. 9: Utility Investigative Survey, Kitchener, Ontario, Canada

The first SUE pilot project initiated by the Ontario Ministry of Transportation (MTO) took place at the Homer Watson Boulevard and Highway 401 interchange, at the city of Kitchener-Waterloo. The project involved the reconstruction of the Homer Watson interchange with Highway 401 and included the following activities: bridge reconstruction, lane widening, modifications to existing ramp alignments, and the construction of new ramps. At the time of data collection, design was about 30% completed. Utility-records information served as the basis for the designation (quality level B) that was performed using multifrequency electromagnetic cable-locating equipment in zones where the new ramps were to be constructed. A number of potential conflicts were identified and 16 test holes (quality level A) were made to confirm the vertical depth and characteristics of selected utilities at critical locations. A number of unmarked underground utilities were located, including a fiber-optics line located at the same location where the formation of the bridge was to be installed. Based on data provided by the SUE investigation, designers decided to lower several utilities that were in grade conflict with the excavations for the proposed ramp. The SUE investigation cost $25,000. A study by the University of Toronto suggests that MTO saved more than $62,000 because of the subsurface investigation, which translates into a return on investment of $2.48 for each dollar spent. The cost of the SUE investigation amounted to 0.125% of the overall project budget.

Case Study No. 10: Design-Build Bridge Project, South Carolina

A contractor on a design-build bridge project needed to determine the exact locations of a water main and a sewer main that had been bored deep beneath a local swamp and river and that served a local educational facility. An innovative SUE approach was used to locate the exact positions of the mains beneath the water surface. The consultant shut and pumped down the mains on a national holiday, so that electromagnetic sound could be pulled through the pipes. Using a receiver on the surface, the exact location of the deep utilities was determined. Based on the information provided, the contractor completed the design and construction of the bridge pilings while avoiding the utilities.

Case Study No. 11: Street Reconstruction, Oshawa, Ontario, Canada

The municipality of Durham sought to engage in a full-depth reconstruction of the four-lane Ritson Road in Oshawa, Ontario, because of deteriorating pavement conditions. The municipality elected to use the opportunity to renew an existing water main and construct a separate storm-water collection system. Previous incidents involving inaccurate underground utilities information and the age of the area's infrastructure increased the likelihood of inaccurate or incomplete utility records, so it was decided to conduct a comprehensive SUE investigation. A quality level B designated investigation was conducted along the proposed alignment for designating gas, electrical, and telecommunications utilities. Forty-three test holes were made to confirm the designation and provide the exact depth of utilities at critical locations. The information collected by the SUE investigation was compared with that provided by owners of the various utilities. A critical discrepancy was identified that involved a thought-to-be-in-conflict gas main that was found to be 8 ft away from the location indicated by the utility's records. Consequently, the relocation of the gas main was canceled, as no conflict existed with the planned waterline. In addition, several other inaccuracies in the as-built drawings were detected and corrected, eliminating potential conflicts and subsequent claims. The cost of the SUE investigation was $91,000, or about 2% of the project's total cost. The return on investment for the investigation was estimated by the University of Toronto's research team to be 2.1:1.

Case Study No. 12: Street Reconstruction, York, Ontario, Canada

A utility project involved constructing a 3-mi long, 42-in./30-in. diameter, pre-cast concrete feeder main along Major Mackenzie Drive in York, Ontario, at a projected cost of $8 million. Funding for the SUE investigation was justified by claims in previous projects that arose from inaccurate utility information as well as from the nature of the project, which called for pre-cast concrete pipe. This pipe type has lead to limited flexibility, as all bends and chambers are pre-fabricated in the plant and shipped to the site. Thus, field modifications are costly because elements must be reordered with the new dimensions and configurations, resulting in extra construction costs and delays. SUE was used at the point at which about 30% of the design was completed. At the time, a preliminary route had been selected based on known data. The SUE investigation revealed several unmarked abundant utilities. In addition, several potential conflicts with poorly marked traffic control and electrical utilities were identified. The accurate location of existing utilities and the identification of several unmarked pipes and conduits resulted in changes in the route and in the grade of the new pipe to avoid these conflicts. For example, as a result of the information provided, they were able to avoid placing the new pipe beneath an 18-ft deep sewer force main, a costly and risky task because of the deteriorated structural condition of the force main. The investigation included about 30,000 linear ft of utility designation and five test holes, at a cost of $20,000, or about 0.25% of the project total cost. A study by the University of Toronto placed a benefit-to-cost ratio of about 3.9:1 for the SUE component of the project.

Case Study No. 13: Weston Rd./Walsh Ave., Toronto, Canada

A new 16-in. PVC water main was to be constructed to replace an existing 6-in. steel main that was nearing the end of its service life. When the design was about 60% completed, a SUE investigation was initiated. The study included quality level C verification of maps and records, and 6,000 ft of quality level B designation. Thirteen test holes were excavated at critical locations along the proposed alignment. The SUE's main findings had to do with a 12-in. steel gas main that was found to be nearly 2 ft off its marked location along the north side of Weston Road, as well as an unmarked 12-in. steel gas main branch serving properties on the street's south side that were in direct conflict with the proposed alignment. Based on data provided by the SUE investigation, the route of the water main was moved from the south to the north side of the street, resulting in significant savings from shorter service connections and reduced pavement restoration requirements. In addition, several unmarked electrical ducts and a storm sewer were located, and their locations were incorporated into the design. The cost of the SUE investigation was $31,000, while the savings associated with elimination of construction delays and reduced pavement restoration costs were estimated by a University of Toronto study to be just over $100,000, yielding a benefit-to-cost ratio of about 3.25:1.

Case Study No. 14: Richmond Hill, Ontario, Canada

A 12-in. diameter, 2,000-ft long water main was to be constructed along Dunlop Street in the town of Richmond Hill. The town requested a SUE investigation late into the design process after other projects brought to light utility misinformation in its records and the potential adverse impacts in terms of contractor claims and schedule delays. For example, in a similar water main replacement project, a $55,000 cost overrun was incurred on a $675,000 project. The SUE investigation included nearly 10,000 ft of utility designation and three test holes. The investigation's main finding was that telecommunication cables shown to be under the sidewalk were found to be 7.5 ft into the roadway. Because the SUE investigation was conducted when design was 90% completed, substantial redesign was required to accommodate the investigation's findings. Specifically, the city required the owner of the telecommunication cables to relocate them at the utility's expense, saving the city $50,000, which was the expected cost to relocate 150 ft of a 12-in. gas main that was called for in the original design. The cost of the SUE investigation added about 2% to the total project cost.

Case Study No. 15: London, Ontario, Canada

A new sanitary sewer system was needed to replace a 60-year old combined sanitary/storm system beneath King Street in downtown London, a major city in southern Ontario. The city's records for this area were very old and based mainly on utility information compiled in 1966. An earlier project conducted in the mid 1990s in the same part of the downtown core was abandoned after numerous conflicts with existing utilities were encountered during construction, resulting in no return for an investment of $80,000. To avoid a similar situation, the city decided to conduct an extensive SUE investigation early on, when the design process was about 30% completed. The SUE investigation included designating 6,600 ft of telecommunication, gas, electrical, water, sewer, and steam utilities as well as 19 test holes. The SUE provider supplied the design team with detailed drawings of the location and width of existing utilities, some of which were known to exist, but the locations of which were unknown, while records for others were completely missing, particularly those related to service connections. Also, the in-service or abandoned status of the utilities was determined, easing the process of getting utility owners to remove or relocate their lines. The main finding was that steam pipes used for heating city facilities were in direct conflict with the proposed sewer line. Neither the city nor the steam company had records of the location of these pipes. Based on data provided by the SUE investigation, it was determined that the preliminary design was not feasible, and a complete redesign was required. Consequently, construction was postponed for two years because of restrictions in the downtown core that permit excavation work every other year. The cost of the SUE study was $40,000, while a conservative estimate of the savings to the city, according to the University of Toronto, came to just below $80,000, a return on investment of about 2.0:1.

Case Study No. 16: Street Reconstruction, Richmond Hill, Ontario

Richmond Hill is a fast-growing community near Toronto, Ontario. To support its rapid residential development, plans were drawn to convert Hall Street, a rural roadway with drainage ditches into a curb-and-gutter cross section. The plan also called for removal of the drainage ditches. Due to previous successes with SUE technology, the town decided to consider using SUE on all projects in which there is significant potential for conflict with existing utilities. The SUE study revealed that a gas main marked to be 6 ft off the curb was actually located inside the roadway and thus required relocation before the transportation project commenced. The cost of the SUE study was $11,000, and the estimated return on investment associated with the SUE investigation was 3.0:1.

Case Study No. 17: York, Ontario, Canada

The York Durham Trunk Sanitary Sewer was reaching its design capacity, and it was decided as a short-term solution to construct a bypass sanitary sewer to parallel the existing line, tying into the North Don Collector Trunk. The area is highly developed and is served by a dense network of buried utilities. Furthermore, the design team had little flexibility due to the need to accommodate existing inverts of the upstream and downstream connections and several known crossings by other on-grade sewer lines. The consultant performed SUE quality level D and C investigations and hired a specialized subcontractor to perform quality level B and A studies at critical locations. The SUE investigation was conducted when design was 30% completed. All utilities within the right-of-way of the proposed sewer bypass were designated, along with 39 test holes constructed to confirm the accurate utility depth at locations of potential conflict. The main finding was that a 16-in. sewer that crossed the proposed line was 8-in. deeper than originally indicated by the records, eliminating the need for its relocation. The SUE study cost $62,000 and resulted in an estimated saving of $123,000, according to a University of Toronto estimate, or a benefit-cost ratio of about 2:1.

Case Study No. 18: Locating a 69 kV Electric Power Line Underneath the St. John's River, Jacksonville, Florida

Jacksonville Electric Authority (JEA) owns a 69 kV electric power distribution line that crosses under the riverbed floor of the St. John's River in Jacksonville, Florida. Rehabilitation work was being performed along the shore of the river waterfront. As part of this work, a new seawall was to be constructed. The engineering firm performing the construction hired a SUE company to locate the depth and position of the high-voltage line along the north shore so that they could avoid hitting the line when placing the metal-sheet piling into the riverbank.

Electromagnetic measurements were performed using Witten Technologies' prototype array of induction receivers (AIR) system. The AIR system is based on electromagnetic induction measurement techniques and operates on the same basic principles as traditional handheld radio-detection devices. An electric current is induced in a subsurface utility line. The induced current produces a magnetic field that is detected at the surface. The AIR system provides 48 simultaneous magnetic field measurements over an 8 ft swath. Magnetic field data are typically collected on a 1-ft × 1-ft grid spacing over the entire survey area. The position of the AIR system is tracked using an accurate positioning system such as a robotic laser tracking system that provides centimeter position accuracies. The data is processed using advanced electromagnetic modeling techniques. The combination of the sensitive broadband three-component sensors, the volume and density of the data collected, and the advanced data processing and interpretation techniques used enabled detection of deep pipes in complicated environments.

In the JEA project, the AIR system determined the utility line to be about 7-ft deep at the shallowest point on shore and about 35-ft deep at the deepest point on shore. Additionally, waterborne measurements were performed at various points on the river that detected the utility line crossing the river at a depth in excess of 50 ft.

Case Study No. 19: Alaska Way Viaduct and Seawall Utility Mapping Project, Washington DOT

To a large degree, this project incorporated many of the techniques, equipment, and concepts developed over the past half century for utility mapping. The utility mapping scope of work for the viaduct project was robust and included characterization data not normally obtained for transportation projects. This extra characterization was necessary because of the tight corridor for utility relocations, cost and time estimating for utility owners, and continuity of utility service. It also provided enough data for a preliminary 3-D model. This characterization included quality levels, ownership, size, inverts on all cables or conduits leaving all vaults, vault depth and outside dimensions, depictions of every cable or conduit between vaults or its terminating point, utility depths at all valves, utility depths from records interpretations, pole or circuit riser numbers, and basement-wall termination points. Vault diagramming forms were included for each vault on the project.

GPR, five different pipe and cable locators, magnetic tools, active and passive acoustics, terrain conductivity, and many differing coupling and insertion techniques were used to detect and trace utilities. A vast majority of utilities from records were mapped at quality level B, and many additional utilities not on record were found and mapped. The project environment presented many challenges. These included right-of-way (ROW) scheduling and access issues, heavy, high-speed traffic on the southern portion, heavy pedestrian and vehicle traffic through the downtown portion, security issues related to the homeless or panhandlers, and an extremely congested and complex underground utility environment. Underground basements, corridors, and parking garages routinely extended beyond building walls and needed investigative access. Coordination of sports events and other special events was required. Over 500 vaults were entered, roughly 100 of which needed dewatering. About 200 test holes for quality level A data were constructed. Project hydraulic designers needed to know the elevations, size, shape, material, and type of footings for three large-diameter sewer lines. One of these sewers, in the middle of S. Royal Brougham, was a 112-in. diameter reinforced concrete pipe (RCP), set in a concrete cradle on wood piers. The entire structure was 13-ft across and over 13-ft deep. The bottom of the cradle was below groundwater. The pipe was cracked, and sewage was evident in the excavation.

Case Study No. 20: Prairie Parkway (SR-71), Kendall County, Illinois

The Illinois Department of Transportation (IDOT) hired a SUE company to perform quality level B and quality level A mapping in a limited area of District 3. The scope of work was to designate various gas, petroleum, and crude oil pipelines ranging in size from 10-in. to 36-in. in diameter. The SUE consultant used a variety of pipe and cable locators with different connection methods. GPR was found to be ineffective because of the conductive nature of the local soil conditions. Test holes were excavated at several points of conflict with the proposed interchange. After reviewing the results, IDOT elected to change the location of the interchange. Early use of the SUE deliverables in the design process permitted IDOT to adjust which properties were to be purchased.

Case Study No. 21: Road Improvements, ILL 159, Collinsville, Illinois

In IDOT District 8, a SUE consultant designated over 178,000 ft of underground utilities as well as overhead utilities, mobilizing six field-designating teams and providing continuous input to the client to keep this high-profile project on schedule. Sewer mapping required manhole access and the insertion of composite core reels. This project was unique in that all quality level B services were performed before background mapping was developed. A total of 56 test holes were excavated at potential conflict zones for precise depth and elevation (quality level A data).

Case Study No. 22: New Mississippi River Bridge Crossing, Illinois

In IDOT District 8, a SUE consultant mapped about 23,000 ft of underground utilities. This included a large unimproved landfill area with no available utility records. A variety of utility search and trace techniques were used to identify metallic and nonmetallic utilities. This project was exceptional because of the necessary coordination with several railroads that crisscrossed the area.

Case Study No. 23: IL Route 157, St. Clair County, Illinois

In IDOT District 8, a SUE consultant performed designating, surveying, and utility mapping at quality level B of about 46,000 ft of utilities, as well as excavating a total of 44 test holes for precise depth and elevation. One test hole on a sanitary line was more than 15 ft deep.

Case Study No. 24: I-35/I-670 Improvement, Jackson County, Missouri

The Missouri Department of Transportation (MoDOT) hired a SUE consultant to perform quality level B mapping and discovered an extensive number of fiber-optic facilities that had a direct link into and out of an AT&T building in the northeastern portion of the project. Due to inadequate utility records and inadequate confidence in the utility's ownership, it became imperative to gain access to the large quantity of fiber-optic splice chambers present within and outside project limits. After extensive research and discussions with the numerous fiber-optic utility owners, access to the splice chambers was granted, enabling successful designation of the fiber-optic facilities within the project's limits. This required toroid clamps and composite core insertion coupling techniques, combined with low-frequency pipe and cable locators to distinguish individual cables.

Case Study No. 25: Raleigh-Durham International Airport, North Ramp General Aviation Redevelopment, North Carolina

A SUE company completed quality level B investigation of more than 71 acres of airport property, including public access roads and the general aviation area of Raleigh-Durham International Airport (RDU). During this work, 67,437 ft of underground utilities were designated using quality level B. A variety of pipe and cable locators, magnetic locating tools, and GPR were used. The breakdown by utility and owner systems is as follows: water (RDU): 6,926 ft; power (Progress Energy, RDU, FAA): 10,200 ft; communication (BellSouth, FAA): 29,108 ft; gas (PSNC Energy): 5,825 ft; FSS (RDU): 1,1960 ft; unknown utilities: 13,419 ft. The designation process included accessing and inspecting 15-plus utility vaults housing facilities owned by BellSouth, Progress Energy, FAA, and RDU. This mapping was supplied in AutoCAD and incorporated into the airport's GIS.

Case Study No. 26: Honolulu International Airport, Honolulu, Hawaii

A SUE subcontractor was hired by M-K International, contractors for the terminal upgrade and other improvements at Honolulu International Airport. The scope of the work included collecting and depicting all utility information in the affected areas. This airport included a large military shared presence, and existing records were of very dubious quality. The SUE consultant evaluated the veracity and origin of the existing records, upgraded their quality through field surface geophysical imaging and, where necessary, through excavation. Over 250,000 ft of existing utilities of all types were subsequently depicted at quality level B. A wide variety of pipe and cable locators, coupling techniques, magnetic tools, and elastic wave techniques were used to detect and trace utilities. Confined space entry with vault dewatering was extensive.

Case Study No. 27: Dulles International Airport and Reagan National Airport, Northern Virginia

Parsons Management Consultants (PMC), a consortium of firms that operate as construction manager for Metropolitan Washington Airports Authority's (MWAA) upgrades at Dulles International Airport and Reagan National Airport, hired a SUE contractor to provide utility mapping services on an on-call basis. One of the projects involved verifying and upgrading the airport's existing GIS utility data for a design involving the parking deck at Reagan National Airport. Between the airport-supplied utility GIS data (shown at quality level D) and the field investigation data (quality level B), there was a 30% rate of error, omission, or both. These discrepancy findings resulted in significant project savings to MWAA. In addition, this data served as an important catalyst for many recommendations found in the FAA's ASA-500 Final Report *Cable Cuts: Causes, Impacts, and Preventive Measures.*

Case Study No. 28: Lambert Field, St. Louis, Missouri

This was the nation's first project using the FAA's 2003 policy on subsurface utility engineering as a design and damage prevention tool. Portions of the project were on the Air National Guard base. Pipe- and cable-locating equipment frequencies and power were tightly controlled and coordinated with the base munitions officer. Specific pipe and cable locators with acceptable frequencies, magnetic tools, insertion techniques, terrain conductivity, and elastic wave techniques were used, along with specific discrete area coupling methods. GPR was not used because of potential interference with FAA communications. A security benefit was realized when an unsecured large-diameter sewer was discovered running from off base to under the munitions storage area.

Case Study No. 29: Virginia DOT, Richmond

The Virginia Department of Transportation (VDOT) used subsurface utility engineering in a major highway project in the City of Richmond, including designation and surveying of the route to determine "as-built" utility positions. In total, 156 test holes were excavated, and nearly half (75 sites) of the utilities verified via test holes were in conflict with the proposed utility facilities. As a result, design changes were made and 61 of the potential conflicts were eliminated. By making these changes, $731,425 worth of utility adjustments were avoided. The cost of digging the test holes was only $93,553, resulting in a savings of $637,872 and a benefit-to-cost ratio of 6.82:1. In the words of Mr. Richard Bennett, former state utilities engineer, "We feel like we eliminated over $700,000 worth of utility conflicts, and the cost . . . was less than $100,000. We can't imagine going back and doing a project without having this information available to us." Overall, VDOT credits SUE with helping to reduce the time needed to design highways from five years to four years, a 20% time reduction.

Case Study No. 30: Route 29 Bypass, Warrenton, Virginia

VDOT was interested in obtaining the elevation of a telephone duct run in Warrenton. The duct run made a turn between manholes that were about 600 ft apart. Snaking the ducts to obtain an adequate designating signal proved ineffective because of the facility's extreme depth. Numerous test holes were excavated to get an alignment on the facility at the point where VDOT needed data. That facility was deep, and large debris in the backfill thwarted vacuum excavation. Finally, a track loader was used to remove the top 8 ft of cover. This method was still not enough to obtain the information. Working with VDOT, a large track excavator was used to cut the top 17 ft and a trench box was emplaced. Designating technology was then used to refine the horizontal location, and vacuum excavation within the trench box was used to expose the utility.

Case Study No. 31: Virginia DOT, Crystal City

During the planning of major highway upgrades in a highly congested area, the SUE study found major relocation problems. In one case, an access ramp was designed to be placed directly over an underground shopping mall. This one relocation alone saved over $1 million. Utilities were difficult to designate because, in some cases, utility conduits were integrated with the underground structures. Trenchless technology methods were planned to emplace a storm drain over an existing electric duct that was a main power circuit for the Pentagon and Reagan National Airport. The SUE company recommended quality level A data on the duct, even though the profile depicted on the plans, through invert measurements in adjoining vaults, showed no conflicts. It was found that the electric duct, which was bowed upward between the vaults, was in direct conflict with the proposed microtunneling, a finding that averted major utility damage.

Case Study No. 32: Virginia DOT, Route 620, Fairfax County

A utility coordination services effort revealed numerous conflicts between the proposed road alignment, high-voltage transmission lines, and buried petroleum pipelines. The SUE study yielded a preliminary utility relocation cost estimate to quantify costs and to compare alternatives, such as redesign of the roadway alignment. As a result, the plans were sent back to design for realignment. The savings to VDOT were significant.

Case Study No. 33: Virginia DOT, Covington

On a subsurface utility engineering project in Covington, Virginia, a SUE study was able to locate and map a terra-cotta sewer dating from 1925. There were no access points, and records were sketchy. The investigation extended beyond records research to interviews with people who had helped build the system. Using a combination of sondes and exploratory vacuum excavation, the SUE company accurately mapped the horizontal and vertical location of utility conflicts with the proposed road construction.

Case Study No. 34: North Carolina DOT, Capital Boulevard, Wake County

The North Carolina DOT (NCDOT) requested 60 test holes based on previously furnished designating information. Many of the test-hole locations were in pavement along this heavily congested primary roadway. Traffic-control requirements were significant and, whenever possible, several utilities were documented in a single test hole. This resulted in considerable cost savings. Evaluation of the information indicated that the location of a nondesignated sanitary line differed from existing plan depictions, conflicting with proposed features. Other services included terrain conductivity and magnetic searches for anomalies, with subsequent air/vacuum excavation methods. This approach was successful in identifying the exact location and condition of a buried sanitary structure that was in conflict with a proposed retaining wall and temporary sheeting/pile operations. Had this main interceptor sewer been damaged, there would have been severe environmental consequences. Services were provided within the project's tight time schedule.

Case Study No. 35: North Carolina DOT, I-40 Rest Area, Haywood County

The study included designating and CCTV inspection services on water and sanitary facilities crossing I-40. Designating identified the location of the existing water line and enabled NCDOT personnel to confirm the existence of a useable casing pipe crossing I-40. CCTV inspection services revealed that the existing sanitary line under I-40 was structurally sound and identified several conditions contributing to flow problems.

Case Study No. 36: North Carolina DOT, Lenoir, Caldwell County

SUE was used early in the development of a project on the Southwest Loop Extension in Lenoir to identify utilities that needed to be relocated. About 58 test holes were selected at points of potential conflict. In addition, a geophysical investigation was conducted in 11 sites to search for unrecorded underground storage tanks. Based on the SUE data, the locations of 16 storm-drain boxes were changed to eliminate utility conflicts. The SUE contractor also detected underground storage tanks near the proposed right-of-way limits and constructed test holes to determine the precise position of the previously unrecorded storage tank locations.

Case Study No. 37: North Carolina DOT, Raleigh Beltline, Wake County

Many of the facilities on this site were made out of thermoplastic materials and, thus, required extensive record interpretation and correlation with field data. Additionally, some water and sanitary force mains were privately owned with no available records. The SUE consultant detected the presence of these facilities through sweeping procedures and by personal interviews with local residents to identify the private-facility owners.

Case Study No. 38: North Carolina DOT, NC 138, Currituck County

SUE was used on a highway project in North Carolina to locate a PVC water line along 18 mi of NC 168 in Currituck County. Location of the line was critical to determine conflicts with proposed pavement-widening and shoulder-excavation work. Using vacuum excavation, 40 holes were dug at a cost of less than \$10,000. From the resulting quality level A information, it was determined that about 21,280 ft of the water line could remain in place. The resulting saving to NCDOT was estimated at \$500,000, a benefit-to-cost ratio of 50 to 1.

Case Study No. 39: Pennsylvania DOT, Erie

A SUE consultant was asked to designate and map active and abandoned steam lines near the waterfront area in Erie, Pennsylvania. The city was undergoing major redevelopment of the waterfront area and was gradually phasing out a Pennsylvania Electric plant in the vicinity. In addition to providing electricity, the plant also provided steam for heating. The records on the location of the steam pipes were extremely poor. In addition, the pipes were insulated in asbestos, and there was a concern that disturbing the pipes would create an environmental hazard. The SUE consultant mapped the entire system (live and abandoned). It was found that the asbestos was encased in concrete or double piping and posed minimal environmental hazard. So-Deep performed about 65,000 ft of designating services and excavated 40 test holes.

Case Study No. 40: Pennsylvania DOT, Lackawanna Industrial Highway, Lackawanna County

The SUE consultant performed designating and locating services on a fast-track basis for Lackawanna Industrial Highway. It coordinated with five different consultants to provide the Pennsylvania DOT (PennDOT) with accurate design information. These projects presented substantial technical difficulties. The terrain provided obstacles for crews because the utility ran cross-country through coal fields. Existing survey control was sporadic throughout the project and very few surface structures existed. Consequently, considerable survey work was necessary to document utility information.

Case Study No. 41: Delaware DOT, S. Madison Street Connector

This project sought to provide access to the proposed development of the Christiana Riverfront. The site was a former industrial park dating to the early 1900s. While providing subsurface utility engineering services on this project, the SUE consultant found significant discrepancies between utilities indicated on records and those that actually existed. About 15,500 ft of underground utilities were designated and 72 test holes excavated.

Case Study No. 42: Maryland State Highway Administration, Columbia

A highway project in Columbia, Maryland, involved the realignment and widening of the roadway from two to six lanes. Maryland State Highway Administration (MSHA) contracted a SUE study to support the relocation of water, sewer, gas, telephone, electric, and cable television (CATV) facilities along Route 29 in Columbia, Maryland. This project involved both arterial/collector road and interstate/expressway requirement options for both overhead and underground utilities. MSHA engaged the SUE consultant in the relocation design for a gravity sanitary sewer that was in conflict with a proposed storm retention pond. The use of SUE enabled MSHA to redesign the hydraulics system to minimize conflicts with utilities. Instead of affecting about 5,000 ft each of gas, water, and sanitary utility, conflicts were reduced to about 400 ft of each. The cost for SUE was $56,000. Cost savings to MSHA and the utilities amounted to $1,340,000. The benefit-to-cost ratio equals 23.9 to 1.

Case Study No. 43: Maryland SHA, Montgomery County

MSHA hired a SUE consultant to perform an estimate of utility congestion and a dollar estimate for utility relocation on a project in Montgomery County on MD Route 355. The consultant designated about 80,000 ft of utilities, located 125 utilities and points of conflict, and provided a determination of septic systems and wells and underground storage tanks that might affect right-of-way acquisition, highway design, and construction.

Case Study No. 44: Maryland SHA, New Hampshire Avenue

About 60 homes and businesses along 10 miles of this urban/rural stretch had no records of their septic systems, wells, or underground storage tanks. Previous construction on a different section of the road was delayed, property was purchased at a premium price, temporary housing and cleanup costs were incurred, and extra orders promulgated when the excavator discovered such buried structures within the construction zone. The SUE study included a review of septic system, well, and underground storage tank installation practices, as well as a review of surface geophysics and nondestructive testing techniques to identify the drainage fields, wells, and underground storage tanks.

Case Study No. 45: Maryland SHA

On another project in Maryland that involved widening an interstate highway from four to six lanes with full shoulders, retaining walls, and barriers, the use of SUE enabled MSHA to redesign the barriers and change the grading and ditches to minimize conflicts with gas, water, and telephone utilities. The cost for SUE was $5,000. Cost savings to MSHA and the utilities amounted to $300,000, and the relocation time was reduced by 46 months.

Case Study No. 46: Ohio DOT, Chagrin Boulevard, Cleveland

The Ohio DOT (ODOT) acquired designating and locating services to assist in the design of the widening of Chagrin Boulevard. The study revealed many discrepancies between the utility records and the actual utility positions. In one case, a sewer line that was recorded as being on the south side of Chagrin Boulevard was actually on the north side. In another case, a pipe that was recorded as carrying telephone lines was actually a gas line. An ODOT representative stated to the *Chagrin Herald Sun,* "This should help us avoid any delays once the project begins. We are spending more money up-front, but saving time and money in the long run."

Case Study No. 47: Mapping Requirements for Permit Applications, Greenwood Village, Colorado, 2002

In 2002, the City of Greenwood Village, Colorado, instituted new mapping requirements for its permit applications for companies seeking to install new lines within its boundaries. Applicants are required to determine the location—both vertical and horizontal—of all existing utilities within the permit area and to provide the city with a map in a GIS format of their findings. This information is available to all underground-utility owners and contractors. The city mandated two levels of permits. For projects less than 500 ft, the applicants are required to pothole every 100 ft on either side of the proposed new utility as well as at line crossing. For projects longer than 500 ft, the entire right-of-way must be mapped.

Case Study No. 48: Florida DOT, District 4, West Palm Beach, 2003

In late fall 2003, the West Palm Beach Operations Center of District Four, Florida Department of Transportation (FDOT), decided to undertake a test of computer-aided radar tomography. Radar tomography (RT) is a technology that employs a radar array to penetrate soil to locate subsurface structures or other anomalies. As the array was set up, signal strength of 200 MHz was attained by arrays of 9 transmitting and 8 receiving antennae. Witten Technologies, Inc., was the vendor hired to conduct the tests. The objective of the study was to determine if RT technology was capable of giving better information regarding subsoil conflicts for buried utilities and foreign anomalies, such as buried rock or concrete, building pads, and walls, compared with traditional SUE methods. The technology was tested on two FDOT projects in the West Palm Beach area. It was found in the Olive Avenue project that Witten Technologies was able to locate about 50% of the existing utilities drawn and identified by the designers. Recommendations from the FDOT report included: (a) radar data interpreters should be more cognizant of the specific needs and procedures of the FDOT; and (b) better communication was needed between the service provider and the DOT as to expectations and abilities. While this particular evaluation of computer-aided radar tomography technology was not as successful as had been hoped, overall, Florida has a good experience with SUE technology. For example, Florida DOT analyzed the use of SUE on two major projects in Tallahassee and Miami and concluded that it saved $3 in contractor construction delay claims for every $1 spent for SUE.

Case Study No. 49: Columbus Southern Power Company, Columbus, Ohio

On a utility project in Columbus, Ohio, the Columbus Southern Power Company designed and installed almost 1.24 miles of underground 138 kV electric line through the downtown area at lower cost, reduced risk, and ahead of schedule by including SUE in its design. The increased quality of the utility information presented at the pre-bid meeting increased the bidder's confidence in the construction plans, resulting in a bid that was $400,000 less than anticipated. The cost of SUE was less than $100,000, with a benefit-to-cost ratio of 4.00 to 1. Additionally, there were no change orders as a result of utilities not correctly depicted on the plans, no utility relocations, no utility damages on the project, and no contractor claims.

Case Study No. 50: SR 4013-002, Pennsylvania DOT Engineering District 9-0, Hollidaysburg

The Seventh Street Bridge replacement, City of Altoona, project took place in an urban area and involved replacing an existing bridge, widening traffic lanes, and constructing new bridge approaches. A large underground phone system had been relocated near the project site two years prior to the project. The project length was about 0.5 mi. Available information revealed a 16-in. gas line, a 12-in. water and sewer line, three underground fiber-optic lines in different conduit runs, and a buried telephone and vault, as well as some unknown lines, in the project area. However, the exact location and direction of the existing lines were unknown. For quality level B SUE investigation, electromagnetic equipment was used in coordination with the utilities to introduce a sonde into the pipelines. For quality level A, the vacuum excavation method was conducted at 44 different locations. As a result of the SUE investigation, the roadway drainage facilities were successfully designed to save time and relocation expenses, and the potential impact of bridge pier construction on the existing lines was avoided.

The total project cost was $11.6 million, including design and construction cost, of which design cost was $2.0 million. SUE cost was $50,000 (designating $23,000; locating $27,000). The cost saving from using SUE was $1,515,000 (utility relocation $500,000; design and construction $1.0 million; information gathering and verification $15,000). Thus, the benefit-to-cost ratio was 30.3:1.

Case Study No. 51: SR 0022-024, Pennsylvania DOT Engineering District 9-0, Hollidaysburg

The Third Ave. Bridge project was a replacement of an entire existing bridge located in an urban area with high traffic volume. Three water authorities crossed at this bridge. Two lines were 12 in. in diameter. There was also a telephone conduit system and vault near the bridge, with 10 conduits attached to the existing bridge. Homes and businesses were adjacent to the bridge and allowed little or no room to relocate the facilities. The project length was about 0.25 mile. This was a time-sensitive project. The initial utility information was incorrect.

The SUE firm found that the utility-marked plans were wrong. The quality level B SUE investigation was conducted using electromagnetic equipment along with close coordination with the utilities. For quality level A, the vacuum excavation method was performed at nine different locations. As a result of the SUE investigation, it was possible to design shoring around existing telephone conduits, to design the bridge to accommodate the telephone facilities, and to positively identify the gas line and determine that it was not affected.

The total project cost was $2.6 million, including design and construction cost, of which design cost was $600,000. SUE cost was $50,000. The cost saving from using SUE was $265,000 (utility relocation $150,000; design and construction $100,000; information gathering and verification $15,000). Thus, the benefit-to-cost ratio was 5.3:1.

Case Study No. 52: SR 0036-25M, Pennsylvania DOT Engineering District 9-0, Hollidaysburg

The 18th St. Culvert, Blair County, project was to add drainage to an existing road and also to lower the roadways as much as possible to provide additional overhead clearance for trucks to go freely under a railway overpass. The available information revealed that there was a complex existing utility network at the project site. This included a 12-in. diameter gas line, a 16-in. diameter water pipeline, a large buried telephone system, an underground electric system, and an abandoned 36-in. sewer culvert along with a 72-in. sewer pipe, all within a 22-ft-wide roadway. For SUE quality level B investigation, electromagnetic equipment was used in close coordination with the utilities. For quality level A investigation, the vacuum excavation method was conducted at 15 different locations. Results of the SUE investigation indicated that many of the facilities were abandoned and that the proposed gas line relocation would not work. Also, SUE provided proper locations for the inlet and drainage facility. Time was the most valuable saving for this project. An additional benefit was that, based on the SUE results, the water authority was convinced to replace a 100-year old 24-in. diameter water line while the road was open.

The total project cost was $1.6 million, including design and construction cost, of which design cost was $200,000. The SUE cost was $44,804 (designating $15,000; locating $29,804). The cost saving from using SUE was $1,515,000 (utility relocation $275,000; project delay cost by utility relocation $50,000; redesign $75,000; design $5,000; construction $1,095,000; information gathering and verification $15,000). Thus, the benefit-to-cost ratio was 33.81:1.

Case Study No. 53: SR 2014-04M, Pennsylvania DOT Engineering District 9-0, Hollidaysburg

The Cresson Culvert, Cambria County, project was to rebuild a roadway under a railway overpass. The work involved complete reconstruction of a portion of the roadway and installation of drainage facilities. Preliminary information revealed a gas line parallel to the roadway, plus an underground telephone line and water pipeline within the project site. However, the exact location and depth of the pipelines were unknown. Quality level B investigation used electromagnetic equipment and close coordination with utilities. For quality level A, vacuum excavation was performed at 15 different locations. Based on the results of the SUE investigation, the drainage facilities were designed to avoid utilities at various locations. The results of SUE also allowed the gas company to better plan for relocation.

The total project cost was $2.4 million, including design and construction cost, of which design cost was $710,000. The SUE cost was $34,243 (designating $11,000; locating $23,243). The cost saving from using SUE was $165,050 (utility relocation $5,050; design and construction $150,000; information gathering and verification $10,000). Thus, the benefit-to-cost ratio was 4.82:1

Case Study No. 54: Pennsylvania DOT Engineering District 3-0, Montoursville

The Towanda River Road, Bradford County, project was to construct a roadway to bypass the center of Towanda, thereby relieving traffic congestion. Preliminary information revealed many undocumented underground obstacles at the project site, including sanitary sewer, water, gas, telephone, TV, and electric lines for which there was no exact location information. Throughout the project site, there were also abandoned water and sewer lines without exact locations. Quality level B information was collected using pipe and cable locators. For quality level A information, vacuum excavation was performed at about 150 locations. Based on the results of the SUE investigation, a decision was made to place the drainage facilities at a location at the site that did not interfere with the existing underground utilities.

The total project cost was $13.0 million, including design and construction cost, of which design cost was $1.0 million. The SUE cost was $141,000 (designating $66,000; locating $75,000). The cost saving from using SUE was $4,210,000 (utility relocation $1.5 million; project delay by utility relocation $100,000; change orders and claims $75,000; restoration $35,000; project delay cost by the emergency $1.5 million; design $1.0 million). Thus, the benefit-to-cost ratio was 29.86:1.

Case Study No. 55: SR 0015-077, Pennsylvania DOT Engineering District 3-0, Montoursville

The Market St. River, Williamsport, project involved replacing a bridge into the city of Williamsport, installing traffic circles, and reconstructing state route SR 15. The main purpose of the project was to relieve traffic congestion and to replace an old bridge. The project site had a very complex network of underground utilities that included sanitary sewer, water, gas, telephone, TV cable, and electric lines in unknown locations. Quality level B information was gathered using existing maps, surface features, and pipe and cable locators. About 110 vacuum excavation tests were performed to determine quality level A information. The results of the SUE investigation resulted in locations for drainage facilities that had little interference with the existing underground utilities. Also, the utility companies were given the accurate location of their underground facilities in this area.

The total project cost was $63.0 million, including design and construction cost, of which design cost was $10.0 million. The SUE cost was $141,000 (designating $46,000; locating $95,000). The cost saving from using SUE was $4.5 million (utility relocation $3.0 million; redesign $500,000; design $1.0 million). Thus, the benefit-to-cost ratio was 31.91:1.

Case Study No. 56: SR 0054-014, Pennsylvania DOT Engineering District 3-0, Montoursville

The Danville River Bridge, Montour County, project was to replace an inefficient bridge, to improve traffic conditions, and to provide a railroad crossing in the Borough of Danville. At the project site, the sanitary sewer, water, gas, telephone, TV cable, and electric line locations were unknown. Very few maps of the existing pipelines were available. Quality level B information was determined using pipe and cable locators. About 25 vacuum excavation holes were performed to determine quality level A information. Based on the results of the SUE investigation, a decision was made to place the drainage facilities at locations that were least affected by existing underground utilities. Also, the utility companies were provided accurate locations of their underground facilities.

The total project cost was $9.0 million, including design and construction cost, of which design cost was $1.0 million. The SUE cost was $101,000 (designating $21,000; locating $80,000). The cost saving from using SUE was $2,650,000 (utility relocation $1.0 million; design $1.5 million; construction $150,000). Thus, the benefit-to-cost ratio was 26.23:1.

Case Study No. 57: SR 0061-079, Pennsylvania DOT Engineering District 3-0, Montoursville

The Cameron Bridge, Shamokin, project was to replace a bridge and to relieve traffic congestion in the city of Shamokin. At the project site, there existed a very complex, undocumented underground network of pipelines, including sanitary sewer, water, gas, telephone, TV cable, and electric lines. Also, there were over five water lines that needed to be temporarily, and then permanently, relocated. Quality level B information was determined using pipe and cable locators. For quality level A, about 30 vacuum excavation holes were used. The results of the SUE investigation provided locations for drainage facilities that were least affected by the existing underground utilities at the project site and that are now also documented.

The total project cost was $9.0 million, including design and construction cost, of which design cost was $1.0 million. The SUE cost was $66,000 (designating $20,000; locating $46,000). The cost saving from using SUE was $1,500,000 (utility relocation $250,000; redesign $1.0 million; restoration $50,000; construction $200,000). Thus, the benefit-to-cost ratio was 22.72:1.

Case Study No. 58: SR 0049-50M, Pennsylvania DOT Engineering District 3-0, Montoursville

The Reconstruct Main St., Elkland, project involved reconstruction of SR-49 and replacement of sanitary and storm sewers, sidewalks, and curbs. Preliminary information revealed sanitary sewer, water, and gas lines at the project site but without specific positions. Quality level B information was determined using pipe and cable locators. Quality level A information was determined by conducting vacuum excavation at about 75 different locations throughout the project site. From the results of the SUE investigation, the roadway drainage facilities were located at places posing the least interference to the existing underground utilities. The results of the SUE investigation also provided the utility companies with an accurate location for their underground pipelines.

The total project cost was $5.2 million, including design and construction cost, of which design cost was $700,000. The SUE cost was $56,000 (designating $26,000; locating $30,000). The cost saving from using SUE was $1.9 million (utility relocation $1.8 million; construction $100,000). Thus, the benefit-to-cost ratio was 33.92:1.

Case Study No. 59: SR 0865-002, Pennsylvania DOT Engineering District 9-0, Hollidaysburg

The Bellwood Road and Bridge, Blair County, project involved relocation of a roadway and reconstruction of a bridge in the rural area of Bellwood. The SUE process was used on the roadway portion to design drainage facilities. In the early project stage, there was some information concerning a gas line on one side of the existing road and a water line on the other side at the project site. Quality level B information was determined through basic electromagnetic equipment such as pipe and cable locators and metal detectors. For SUE quality level A, vacuum excavation was used at 15 different locations. Based on the results of the SUE investigation, the decision was made to place drainage facilities on the side of the road where the water line was located. On that side of the road, there was less conflict and more room for relocation; additionally, the work could be done by the department of transportation contractor.

The total project cost was $3.1 million, including design and construction costs, of which the design cost was $330,000. The SUE cost was $20,000 (designating $10,000; locating $10,000). The cost saving from using SUE was $65,000 (utility relocation $5,000; design and construction $50,000; information gathering and verification $10,000). Thus, the benefit-to-cost ratio was 3.25:1.

APPENDIX C

Organizations Contacted Relative to Buried-Utility Research

Industry Association Name	Web Site	Phone	Notes
American Concrete Pipe Association	concrete-pipe.org	972-506-7216	
American Congress on Surveying and Mapping (ASCM)	acsm.net	240-632-9716	Four organizations participate in the ACSM.
American Fence Association	americanfence association.com	630-942-6598	
American Gas Association	aga.org	202-824-7000	
American Petroleum Institute (API)	api-ec.api.org	202-682-8125	They work with the Pipeline Research Council International (PRCI) on research. Much of the current research is related to the prevention of mechanical damage to pipelines. They are also involved with the collection of spill and incident data in the pipeline performance tracking system (PPTS).
American Public Energy Agency	apea.org	800-476-3749	
American Public Gas Association	apga.org	202-464-2742	
American Public Power Association (APPA)	appanet.org	202-467-2900	Has conducted no research projects in this area in the past six years. APPA, located in Washington D.C., represents 2,000 municipals, most of which are small utility companies.
American Public Works Association (APWA)	apwa.net	816-472-6100	The Utilities and Public Rights of Way Committee has submitted a guidance statement for board approval that recommends the use of the SUE guidelines prepared by ASCE. There is active participation by APWA in CGA.
American Road & Transportation Builders Association	artba.org	202-289-4434	
American Society of Civil Engineers (ASCE)	asce.org	800-548-2723	Two groups within ASCE deal with utility locating issues. The ASCE CI 38-02 Standards Committee is specific to utility damage prevention through design procedures, and the Pipelines Division prepares design guidelines on various pipeline issues and sponsors an annual pipelines conference.
American Water Works Association (AWWA)	awwa.org	800-926-7337	See AWWARF.
American Water Works Association Research Foundation (AWWARF)	awwarf.org	303-347-6188	This is the research arm of AWWA. They have active research projects related to underground utility locating and past research projects in conjunction with UK Water Industry Research (UKWIR).

Industry Association Name	Web Site	Phone	Notes
Associated General Contractors of America	agc.org	703-548-3118	They are actively involved in Common Ground Alliance.
Association of Metropolitan Water Agencies	amwa.net	202-331-2820	
Association of Oil Pipelines	aopl.org	202-408-7970	A small organization (approximately five staff members) working through committee member teams. They have a right-of-way team that deals with encroachment and damage prevention activities. They are involved in research projects and work jointly with API.
Canadian Gas Association	cga.ca	613-748-0057	
Canadian Public Works Association (CPWA)	cpwa.net	202-408-9541	CPWA and APWA cooperate closely on many issues.
Common Ground Alliance (CGA)	commonground alliance.com	703-836-1709	CGA has major initiatives in the area of underground damage prevention. They have a structured membership to represent a balanced approach to utility damage prevention issues and a research and development committee.
Distribution Contractors Association (DCA)	dca-online.org	972-680-0261	DCA has been strongly involved recently in the cross-bore/laterals issue and has proposed legislation. DCA is preparing an Emergency Crisis Management Notebook for companies and contractors dealing with utilities after a crisis event.
Edison Electric Institute	eei.org	202-508-5000	
Electric Power Research Institute (EPRI)	epri.com	973-467-0672	EPRI has carried out past research on underground utility locating but does not appear to have current research activities in this area.
Environmental Protection Agency (EPA)	epa.gov	202-272-0167	EPA is active in some areas of underground utility research but has no significant activities in the areas of utility location, characterization, or damage prevention.
The Fiber Optic Association	thefoa.org	760-451-3655	They do not have R&D activities, but they do have strong education and training activities. They monitor damage prevention issues but do not actively produce related materials. They have no projects on utility locating or characterizing or on interaction with transportation.
Gas Technology Institute (GTI)	gastechnology.org	847-768-0500	GTI has a number of ongoing research activities in conjunction with OPS, PHMSA, and others. GTI also participates in the CGA R&D Committee.
Geospatial Information & Technology Association (GITA)	gita.org	303-337-0513	GITA is active in the area of GIS mapping of utilities.
Infrastructure Security Partnership	tisp.org	703-295-6231	
Institute of Electrical and Electronics Engineers (IEEE)	ieee.org	212-419-7900	
International Right of Way Association	irwaonline.org	310-538-0233	Utility, survey, and pipeline committees deal with aspects of utility locating and damage prevention.
Interstate Natural Gas Association of America	ingaa.org	202-216-5900	They have an active interest in utility locating, characterization, and damage prevention issues. They work with PRCI, PHMSA, CGA, and other organizations.
Land Improvement Contractors of America	licanational.org	630-548-1984	

Industry Association Name	Web Site	Phone	Notes
Midwest Energy Association (MEA)	midwestenergy.org	952-832-9915	An operations committee deals with damage prevention issues and any new regulations. They also have a website, diggingsafely.com, that offers six free courses. MEA is active with CGA.
The National Association of Clean Water Agencies	amsa-cleanwater.org	202-833-2672	
National Association of Corrosion Engineers (NACE)	nace.org	281-228-6200	A buried utility corrosion report is downloadable from their website, but it is several years old. They have published several standards on direct assessment methodologies. A checklist of procedures for direct assessment of corrosion is also available on their website, and several reports are currently in process. Their guidelines can be adopted by PHMSA in some cases. There is a new NACE/IEEE joint committee addressing the corrosion of utility installations.
National Association of Counties	naco.org	202-393-6226	
National Association of County Engineers	countyengineers.org	202-393-5041	No committees or activities presently deal with buried utilities.
National Association of Pipeline Safety Representatives	napsr.org	303-894-2000	
National Association of Sewer Service Operators	nassco.org	410-486-3500	They are active in the standardization of utility characterization and condition assessment procedures.
National Cable Television Association	ncta.com	202-222-2300	
National Fire Protection Association (NFPA)	nfpa.org	617-770-3000	
National League of Cities	nlc.org	202-626-3000	The Finance, Administration, and Intergovernmental Relations section of their National Municipal Policy, section 1.03.B.2, deals with right-of-way.
National Propane Gas Association	npga.org	202-466-7200	Information on damage related to buried propane tanks is covered under NFPA 58. Pipeline issues are covered by U.S. DOT. The association's technology and standards committee provides input to NFPA 58. There is also a Propane Education and Research Council, www.propanecouncil.org.
National Rural Water Association	nrwa.org	580-252-0629	They have conference sessions dealing with damage prevention.
National Safety Council	nsc.org	630-775-2128	Their website has statistics about injuries and deaths across the U.S. from various causes. They refer to other organizations for specific buried-utility issues.
National Telecommunications Damage Prevention Council	ntdpc.com	904-230-9637	They are active in damage prevention issues and with other organizations, such as the CGA. They do not directly carry out or sponsor research.
National Telephone Cooperative Association	ntca.org	703-351-2000	
National Utility Contractors Association	nuca.com	703-358-9300	A special committee on damage prevention interacts closely with CGA. They also have a safety committee. They do not have separate activities on developing recommended procedures or carrying out research. They offer their members consulting services for dealing with claims related to utility damage.

Industry Association Name	Web Site	Phone	Notes
National Utility Locating Contractors Association	nulca.org	850-531-8352	
Natural Gas Supply Association	ngsa.org	202-326-9300	
North American Society for Trenchless Technologies	nastt.org	703-351-5252	They currently have an ad hoc committee looking at cross-bore problems. They also have ongoing education and training on all aspects of trenchless technology, including horizontal directional drilling, pipe jacking, and microtunneling. They do not have R&D activities related to buried-utility locating or characterization issues.
Pipeline Association for Public Awareness	pipelineawareness.org	720-876-5248	Their focus is on education, not technologies, and they own no assets. Their mission is educating public officials, emergency responders, excavators, and the general public.
Pipeline Contractors Association	plca.org	214-969-2700	They do not have committees or association-wide activities related to damage prevention.
Power and Communication Contractors Association	pccaweb.org	703-212-7734	They have a one-call locating committee, but it is for information sharing among members. Some of their members belong to CGA and they have had presentations from CGA at their meetings, but there is no formal relationship between the two organizations.
Society of Cable Television Engineers	scte.org	800-542-5040	
Southern Gas Association	southerngas.org	972-620-8505	
Underground Utility & Leak Locators Association	uulla.org	813-968-1092	
Uni-Bell PVC Pipe Association	uni-bell.org	972-243-3902	This association is interested in locating and characterization issues relative to buried plastic pipe, but they have no current research activities.
United States Telephone Association	usta.org	202-326-7300	
Urban and Regional Information Systems Association	urisa.org	847-824-6300	
Water Environment Federation	wef.org	800-666-0206	See WERF.
Water Environment Research Foundation (WERF)	werf.org	703-684-2470	WERF has a number of research activities related to utility characterization and asset management—especially for sanitary and storm sewer applications.
Western Energy Institute	westernenergy.org	503-231-1994	They have an underground/overhead committee and a damage prevention session in their annual conference.

Related SHRP 2 Research

NDT for Concrete Bridge Decks (R06-A)
Evaluating Field Spectroscopy Devices (R06-B)
GPR for Measuring Uniformity of New HMA Layers (R06-C)
NDT to Identify HMA Delamination (R06-D)
Real-Time Smoothness Measurements During Construction of PCC Pavements (R06-E)
Developing a Continuous Deflection Device (R06-F)
NDT for Mapping Tunnel Lining Defects (R06-G)

W W W . T R B . O R G / S H R P 2