Utility Locating Technologies:
A Summary of Responses to a Statement of Need Distributed by the Federal Laboratory Consortium for Technology Transfer

A project partially funded by the
State and Local Government Committee of the
Federal Laboratory Consortium for Technology Transfer
Washington, DC

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February 2000

Federal Laboratory Consortium Special Reports Series No. 9
ISSN 1075-9492C

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Preface

The Federal Laboratory Consortium for Technology Transfer (FLC) is regularly involved in technology searches to solve problems that affect U.S. industry or public interests. The search process is intended to identify commercially available, emerging, and uncommercialized 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, universities, and the private sector. The first step is to develop a Statement of Need (SON) that contains an adequate definition of the criteria (e.g., most important range of applications, approximate range of acceptable costs for a commercialized technology, etc.) that technological improvements must meet in order to address the problem and provide a significant advance from the current practice. The SON helps to focus attention on the most applicable technologies rather than any potentially related technologies. The SON is developed with input from the affected industry and other interested parties.

Once completed, the SON is circulated to researchers in federal laboratories, universities, and the private sector 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. Once the SON has been distributed and responses received, the information is compiled into a summary report that analyzes the potential of the various technologies identified and serves as a starting point for further research, technology transfer, commercialization, and collaboration. Recommendations are then made concerning which technologies should be further investigated for possible commercialization and/or implementation, and a business opportunity statement is prepared that solicits interest from businesses in undertaking the technology development or commercialization process.

The search for technologies applicable to utility locating was initiated in 1998, and the SON was distributed in the summer of 1999. This report provides a summary of responses to the SON and an assessment of the extent to which the submitted technologies can meet the criteria identified in the SON. The next step in the process will be to bring the researchers involved in the technology development together with the agencies, institutions, and companies that have significant stakes in finding solutions to the utility location problem. The purpose of the meeting will be to seek partnerships through which the most promising technologies can be further developed and/or tested.

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Executive Summary

This project was conducted by the State and Local Government Committee of the Federal Laboratory Consortium for Technology Transfer (FLC), with assistance from the Technology Transfer Information Center of the National Agricultural Library, Agricultural Research Service, U.S. Department of Agriculture. The project addresses an issue of significant national importance—the current and increasing potential for damage to underground utility systems caused by utility installation/repair and other excavation activities. The project has searched for novel solutions to the problem of effective location of all types of underground utilities under the variety of site conditions found in urban areas through distribution of a Statement of Need (SON) in June 1999 and a summary of the responses in this report.

For some utilities, hits cause interruptions to daily life and commerce; for others, they can cause physical danger to workers, bystanders and nearby buildings. All result in expense that is borne by a combination of the contractor, the locating company, utility providers, insurance companies, the affected public, and business owners. Individual incidents can entail costs that are out of proportion with the cost of the work being undertaken, and the total of all utility damage costs is very significant and increasing. This report provides some incident examples and company statistics to illustrate the extent of economic and social consequences.

The SON detailed the desire for a single multisensor system that accurately locates all underground utilities under the variety of site conditions found in urban areas. Ideally, the method(s) would operate from the ground surface and not require prior knowledge of the location or access to the utility to introduce special signals for detection. Novel approaches, sensors, and/or a combination of technologies are needed to increase the reliability of utility detection in terms of the size, depth, and materials that can be detected and operate in the presence of utility congestion and the error-producing conditions present in urban rights-of-way.

A brief overview is presented of current state-of-the art technologies used for utility location detection and other subsurface site investigation. The description provides the general principles involved in the methods rather than the specifics of any particular methods.

The summary of responses to the SON focuses on general-purpose pipe and cable locators rather than equipment that is used to detect faults in operating systems (e.g., leak detectors for gas lines, insulation damage or faults in electric cables, etc.). The report is not comprehensive since it relies mainly on the responses to the Statement of Need. Also, many commercially available systems are not discussed since the emphasis in this report is on directions for the next generation of utility locating systems rather than existing systems.

The trends for future development and the possibility of developing systems that fully meet the criteria set forth in the SON are discussed as a series of responses to the following questions.

- *Were any relevant technologies uncovered that were not currently being applied to the utility locating problem?*
- *Is there a system under current development that will be capable of locating urban utilities as desired in the SON (e.g., multiple and close-spaced utilities beneath urban streets, all types of utilities, conducting and nonconducting, in all types of soil conditions)*?
- *Is there a system under development that will make it easy to locate plastic pipe?*
- *Is the current level of technology development mature?*
- *Can new utility locating technologies be cost-effective?*
- *What directions appear to offer the greatest long-term potential for improvements in the utility location problem?*
- *What are some of the advances that are anticipated in the processing and display of data?*
- *What steps are needed to continue the advancement of utility locating equipment?*
- *What else is needed in the industry to lower utility damage?*
- *What is planned as a continuation of this project?*

In short, all relevant technology developers had already identified utility location as a potential market, and there is no technology that has adequately demonstrated the potential to solve the problems outlined in the SON. However, the technology development is far from mature, and several ideas with significant promise could not be adequately researched regarding their potential effectiveness within the scope of this summary report.

To follow up on this report, the Federal Laboratory Consortium and the Technology Transfer Information Center plans to invite companies with promising technologies to participate in controlled field trials to establish/confirm the accuracy and range of applicability of the methods. These field trials will be followed by discussion sessions among the various stakeholder groups for better utility location. These sessions will be focused on establishing partnerships to help develop, commercialize, and spread the technologies.

Section 1
Introduction

The following introduction is taken primarily from the Statement of Need for Utility Locating Technologies issued in June 1999. It describes the need for utility locating technologies and some of the safety and economic hazards associated with inadequate utility locating technologies and procedures.

The Need for Utility Locating Technologies

Overhead utility lines are becoming a thing of the past, except in rural areas. The urban underground has become a spider's web of utility lines, including phones, electricity, gas, cable TV, fiber optics, traffic signals, street lighting circuits, drainage and flood control facilities, water mains, and wastewater pipes. In some locations, major oil and gas pipelines, national defense communication lines, mass transit, rail and road tunnels also compete for space underground. The deregulation of utility services is adding to the problem as multiple service providers seek to place their networks underground.

All of these lines are susceptible to damage as construction, renovation, and excavation occur in their vicinity. Utility records often contain inaccurate utility positions and/or depths. Some live services do not even show on utility plans. This means that the ability to physically determine on-site the location, nature, and depth of underground utility services is critical to reducing the risk and consequences of inadvertent damage during construction.

Utility companies, locator services, and contractors are searching for new excavating equipment and methods and ways to overcome unreliable utility locates, but they face huge obstacles. For instance, the conduits for these utilities range from steel, cast iron and ductile iron pipes to clay, polyethylene, polyvinyl chloride, and fiberglass-reinforced plastic pipes. Cable may be copper or fiber optic. The conduits have different shapes, compositions, densities and diameters, and they may be as little as 0 to 0.5 meter or more than 50 meters deep. Some lines (usually local telephone, electric, and gas) may be stacked vertically in a common trench. Multiple lines may be grouped in a single conduit or duct bank. Multiple utilities may be grouped in common utility tunnels often called utilidors. Figures 1, 2 and 3 show some recommended utility layouts within public rights-of-way; however, standard layouts are the exception rather than the norm. Utility layouts grow as a city grows and must accommodate to what is already underground. In older cities and, especially at street intersections, underground utilities can become extremely congested (see Figure 4).

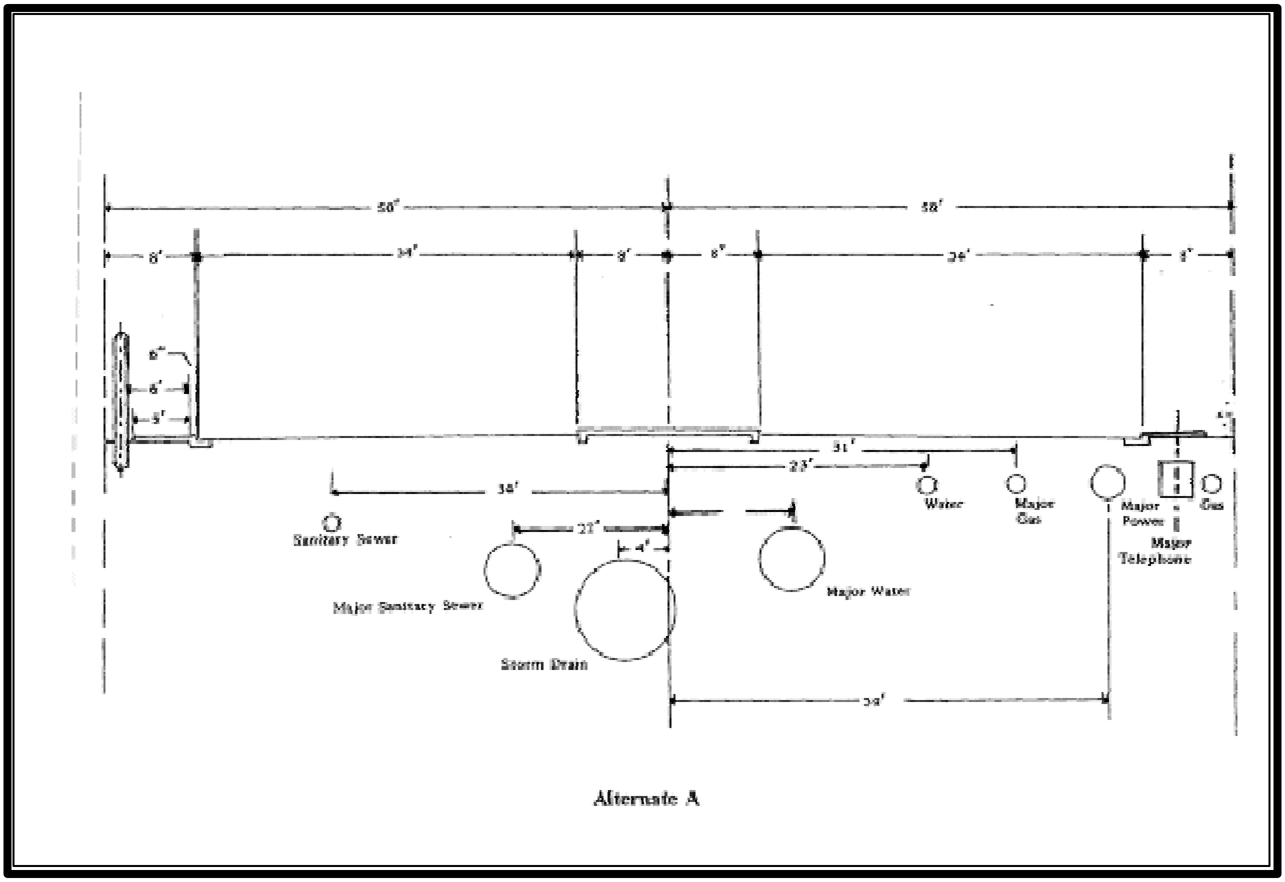

Figure 1 - Example Utility Layout A (APWA/ASCE, 1974)

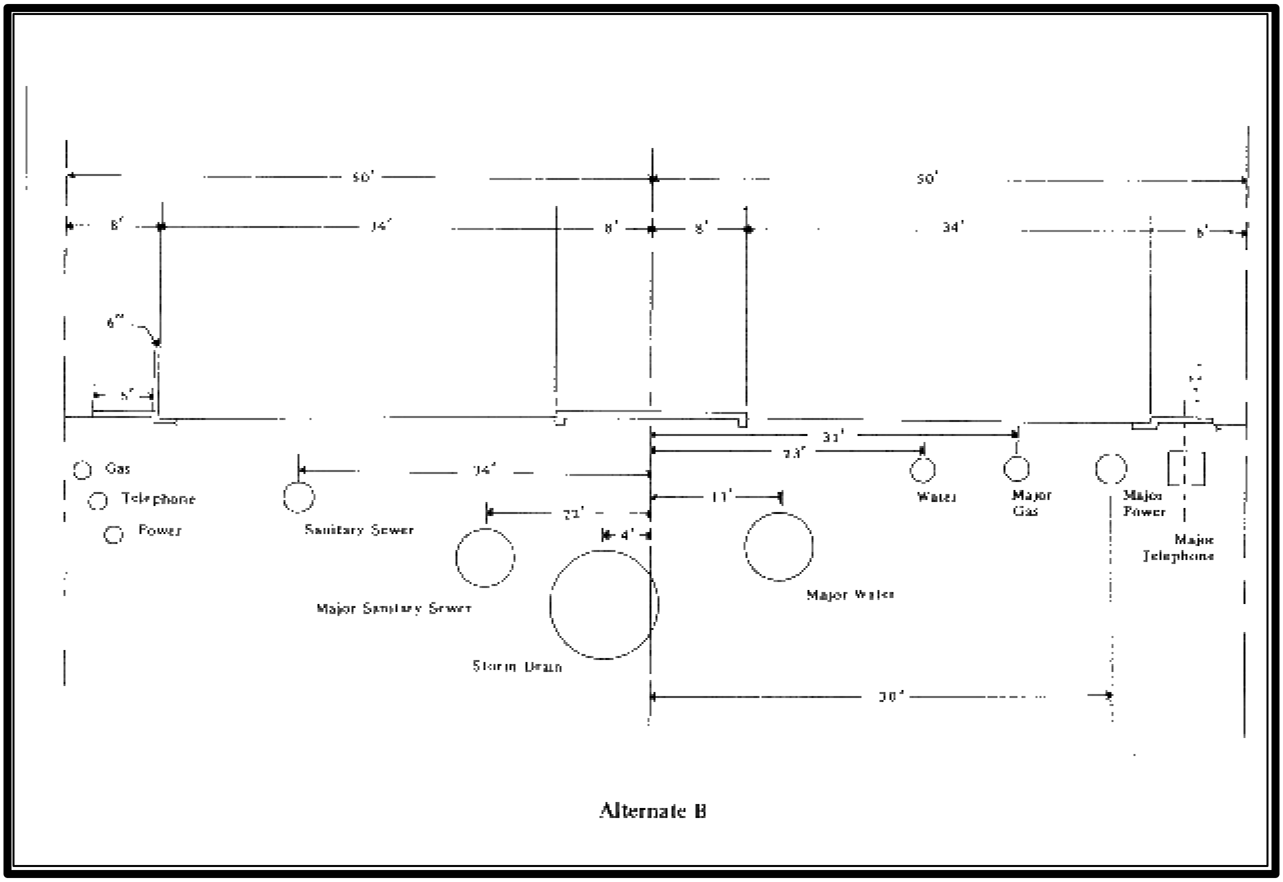

Figure 2 - Example Utility Layout B (APWA/ASCE, 1974)

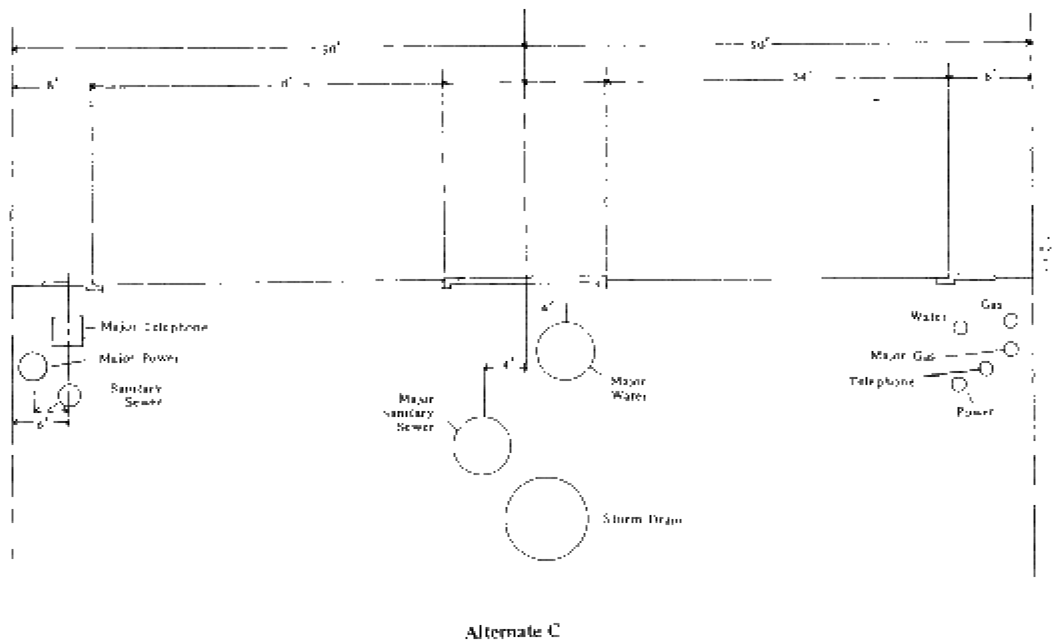

Figure 3 - Example Utility Layout C (APWA/ASCE, 1974)

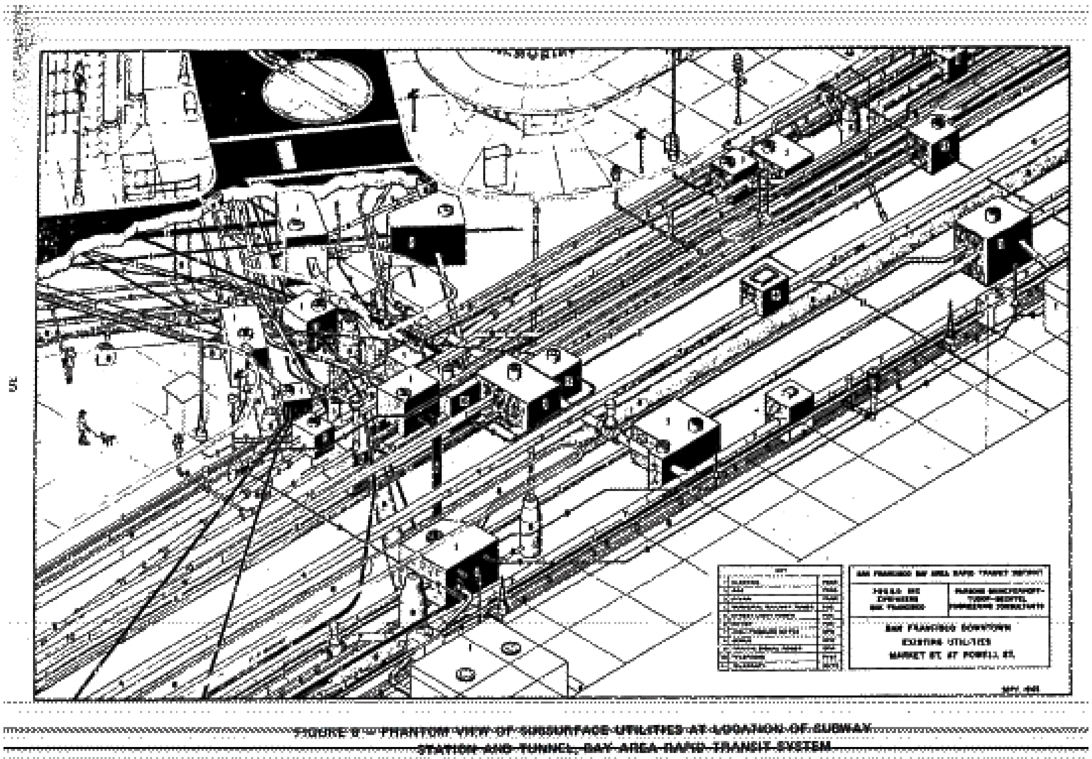

Figure 4 - Illustration of Subsurface Utilities at a Downtown Intersection in San Francisco (APWA 1971)

Some underground utilities at shallow depths can be located with relative ease using inexpensive equipment, but many types of utilities—especially smaller nonconducting utilities at greater depths—are extremely difficult to locate. The complex signal record produced by some types of current locating equipment requires expert interpretation, which raises costs and makes underground utility location an art as well as a science. This lack of definition is problematic, however; informed guessing about the location of utility lines is not good enough. Mistakes bring down vital 911 emergency services, electric cash registers cannot be opened, security alarms are inactivated, online stock transactions are lost, bank records cannot be accessed and, for people who work at home, business and many other comforts grind to a halt.

Improved Technologies Can Increase Safety and Reduce Economic Losses

For some utilities, hits cause interruptions to daily life and commerce; for others, they can cause physical danger to workers, bystanders and nearby buildings. All result in an expense that is borne by a combination of the contractor, the locating company, utility providers, insurance companies, the affected public, and business owners. Individual incidents can entail costs that are out of proportion with the cost of the work being undertaken, and the total of all utility damage costs is very significant and increasing. The following incident examples and company statistics illustrate the extent of the economic and social consequences:

- In 1998, Public Service Company of Colorado reported 300 primary feeder cable cuts in the state. Since a primary feeder carries power to 2,000 to 3,000 customers, 300 cuts affect 600,000 to 900,000 customers (*Rocky Mountain News*, March 14, 1999).
- Public Service Company of Colorado also reported that more than 3,000 underground lines were cut in 1998—an increase of 1,000 from the previous year (*Rocky Mountain News*, March 14, 1999).
- Damage to the U.S. West cable network can exceed 2,000 hits in one month and averages more than 1,000 per month (Nelson and Daly, 1998).
- A Colorado phone utility hit in March 1999 cut off service for 12,000 customers.
- A 36-fiber optic cable can carry up to 870,912 circuits and generate more than $175,000 per minute in revenue (Milliken ,1998).
- In 1993, there were more than 104,000 hits or third-party damage to gas pipelines, for a total cost of greater than $86 million (Doctor, et al., 1995).
- A construction crew driving piles for a new garage accidentally crushed a high-voltage underground electrical cable serving Newark International Airport's three passenger terminals. Several hundred passenger flights were canceled, and the travel plans of tens of thousands of people were ruined. (*Minneapolis Star Tribune,* January 10, 1995).
- In 1997, Memphis Light, Gas and Water paid $515,000 and collected $793,000 for utility damages (Stinson, 1998).

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 produce unexpected, severe safety consequences. For instance, a new gas line was inadvertently installed using horizontal directional drilling through a clay sewer service pipe. The sewer service pipe later plugged, and the sewage backed up into a home. A sewer cleaning firm was called to clean out the sewer line and unknowingly ruptured the gas line in the process. Gas from the sewer entered the house basement, causing an explosion that destroyed the house.

What Is Needed

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.

As evidenced by the following, a system that would significantly improve current locating capabilities at an acceptable cost would find a large market.

- In Colorado, there were more than 500,000 requests in 1998 to locate underground utilities. Because each request usually involves several utility lines, the total number of lines located was more than 2.5 million.
- U.S. West spent $3 million in 1998 to locate utility lines in the Denver area alone.

The extent of underground utility networks worldwide is enormous. In the U.S. in 1989, the approximate mileage of major elements of the existing U.S. underground utility network was as follows (Kramer, et al., 1992):

Electricity - 370,000 miles of underground distribution cables
Natural gas - 900,000 miles of distribution mains and 600,000 miles of distribution services
Sewers - 600,000 miles of collector sewers with 600,000 lateral connections
Telephone - 260,000 miles of direct buried cables and 300,000 miles of cable in conduit
Water - 450,000 miles of distribution pipe

In addition, in 1994 the Electric Power Research Institute (EPRI) estimated that 7,000 to 8,000 miles of electric transmission lines in the U.S. were located underground. These totals do not include the recent construction of new national fiber optic networks.

Underground utility networks are typically designed for lifetimes of 20 to 50 years; however, they are often used, with little maintenance, for much longer. As these utilities need to be replaced, rehabilitated and maintained, and as new lines are needed to serve new developments and new services, the potential for damage and the value of improved locating technologies grow.

Section 2
Problem Statement

The goal for improved utility location technology is to avoid third-party damage to existing underground utilities that is caused by the presence of unknown or mislocated utilities. To meet this goal will require radically improved location technologies and the integration of these technologies into the planning and execution of excavation work. While the Statement of Need for this project focused on location technologies, as discussed under technology constraints and specifications, technology advances relative to other aspects of this problem were of interest also.

What is desired is a single multisensor system that accurately locates all underground utilities under the variety of site conditions found in urban areas. Ideally, the method(s) would operate from the ground surface and not require prior knowledge of the location of or access to the utility to introduce special signals for detection. Novel approaches, sensors, and/or a combination of technologies are needed to increase the reliability of utility detection in terms of the size, depth, and utility materials that can be detected and operate in the presence of utility congestion and error-producing conditions present in urban rights-of-way.

Section 3
Literature Review and Related Activities

Literature Review

This project focused on identifying technologies that would be relevant to utility locating but perhaps had not yet been applied to the problem or sufficiently advanced to demonstrate their potential. However, an extensive computer search of engineering, science, and technology databases also was undertaken—identifying more than 650 papers, reports, and theses related to utility locating. The abstracts of these citations were reviewed, and the most recent and pertinent citations are in the bibliography. The literature review, which is not discussed in detail in this report, did not identify any new approaches or breakthroughs other than those included in the summary of responses.

Common Ground Study

A study of one-call systems and damage prevention best practices was 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), and a report was released in August 1999 (USDOT 1999). In addition to discussions of potential improvements in planning, communication and record-keeping practices relevant to avoiding utility damage, the report contains an appendix on emerging technologies relevant to the underground damage prevention process.

The emerging technologies are grouped in the report under the following headings:

- Planning and Design
- Mapping
- One-Call Center
- Locating and Marking Technologies
- Excavation
- Reporting and Evaluation
- Compliance
- Public Education

Key elements of the anticipated or emerging technologies outlined in the report include:

- The emerging use of global positioning systems (GPS) and geographic information systems (GIS) to facilitate the storage, updating, and retrieval of information about a particular excavation site and its associated utilities. This would result in quicker and more accurate identification of excavation sites, more cost-effective locates, elimination of many types of gross errors in utility location, and improved reporting of errors in utility location records.

- Locating and marking technologies are categorized in the report as follows:
- *Magnetic field-based locators or path tracers*. Emerging technologies may provide more robust performance under congestion, including consistent accuracy of depth estimates.
- *Buried electronic marker systems (EMS)*. Emerging technologies could provide digital identification of facilities and automatic marking of location on a digital map.
- *Ground penetration radar-based buried-structure detectors (GPR)*. Emerging technologies could enhance signal quality and reduce clutter and dependence on operator interpretation.
- *Acoustics-based plastic pipe locators*. Improvements in acoustic transmission and detection, coupled with a nonintrusive method of applying the signal to the buried pipe, would assist in damage prevention.
- *Active probes, beacons or sondes for nonmetallic pipes*. No emerging technologies were identified for improvements in this area.
- *Magnetic polyethylene (PE) pipe*. This emerging technology to make new polyethylene pipe more easily located when buried is under development by the Gas Research Institute (GRI).

Locating technologies are also divided in the report in terms of widely used (magnetic field detectors; passive/inductive magnetic field detectors; tracer wire/conductive tape; electronic marking system; active probes, beacons and sondes) and limited use (acoustic detector, ground penetrating radar, magnetically impregnated pipe, metal detectors). The distance and depth ranges for utility detection were listed as important requirements for emerging technologies.

1996 Federal Laboratory Research and Development Contest

A program to identify federal laboratory technology relevant to finding buried plastic pipe in gas distribution systems was carried out in 1996 by the Institute of Gas Technology for the Gas Research Institute (IGT 1997). Limited field evaluations of four federal and one commercial technologies were carried out and the results are described in the report, along with an evaluation of the most promising technologies. The systems comprised two GPR-based systems, one ground capacitance system, one passive marking system, and an acoustic pipe tracing system. GPR-based systems were not recommended for further development unless the underlying problem of signal penetration in wet clays could be overcome. The ground capacitance system worked well identifying pipes in the field trial, but it also is sensitive to other variations in ground capacitance caused by soil inhomogeneity, cracks in the street pavement, etc. The passive marking system tested was similar to other systems already in commercial use; however, it failed to operate well in wet clay. The acoustic pipe tracing system worked best in the field trials, but requires access to the pipe to allow a loudspeaker to inject sound directly into the gas in the piping.

Section 4
General Overview of Utility Locating Technologies

As an introduction to an analysis of the responses to the Statement of Need, the following discussion (from the SON) provides an overview of the current state-of-the art technologies used for utility location detection and other subsurface site investigation. Each description provides the general principles involved in the methods rather than the specifics of any particular method.

Destructive Methods

- **Soil borings** are the traditional method of determining the zonation and properties of subsurface materials. Since underground utilities can be damaged if struck, borings must be used carefully in the vicinity of existing utilities. The hole created by the boring operation can be used for other nondestructive site investigation methods (described below).
- **Test pits** can be excavated by a combination of machine and hand excavation methods. They create a sufficiently large hole for the direct physical examination of the in-place soil materials and any exposed utilities. Care must be taken not to damage utilities during the excavation process, and the cost of a test pit rises rapidly as the hole becomes deeper, the soil becomes weaker or the excavation extends below the water table.
- **Hand excavation** is normally used near existing utilities. However, even shovels can easily damage unprotected cables. Many cases of damage occur because the utility is not in the expected location and before the contractor switches to hand excavation.
- **Vacuum excavation (potholing)** is used to create 0.3- to 0.5-m diameter holes to physically confirm the position and depth of an underground utility. A hole is cut in the road pavement using a rotary core drill, and then the excavation is advanced using **compressed air jets** and/or **high-pressure water jets**. This excavation process does not normally damage an existing utility, and the hole in the street pavement is kept to a minimum and easily repaired. This procedure can only be used to confirm the position of known utilities or previously located utilities.

Nondestructive/Geophysical Methods

Geophysical methods of locating underground objects typically utilize a wave/signal that is introduced into the ground and/or a physical property of the object to be located that is different from the surrounding ground. An instrument is then used to measure the ground response and, based on this response, information is inferred about the position of the object below ground and/or soil properties. Many of the methods can be used in several different arrangements that vary in terms of what can be detected, depths of penetration, sizes and types of objects that can be resolved, and implementation cost.

Listed below are some of the basic types of waves or field properties:

- **Seismic waves** are ground vibrations that travel through soil and rock. They can be introduced into the ground via explosives, hammers, vibrating elements, and acoustic signals in buried pipes. Seismic waves travel at different velocities in different materials and also will be reflected at discontinuities below ground, e.g., embedded objects and geological layers. Different types of seismic waves are used for different purposes: compression waves (p-waves), shear waves (s-waves) and surface waves (Rayleigh waves and Love waves).
- **GPR** uses radio frequency signals to penetrate the ground. These signals are introduced to the ground with antennas that determine the frequency of the wave introduced. As with seismic waves, the signals are reflected (reradiated) at the interfaces of dissimilar materials.
- **Magnetic field** variations can be used to determine the position of magnetic materials below ground or cables/pipes that either create or can be induced to create their own electromagnetic field.
- **Electrical field** properties are also used by measuring the AC resistivity between different points within the soil or on the ground surface. Either electric or magnetic dipoles may be used. The variation of resistivity seen between different points reflects the nature of the materials along the path of current flow between the points.
- **Gravitational field** variations can be used to locate objects or voids that exhibit substantial density variations from surrounding material. Since the changes in gravitational field are very small, the method is usually referred to as a microgravity method.
- **Temperature field** variations are used to identify objects that disturb the normal ground temperature field—either because of the function of the object (e.g., steam pipe) or because the object has different thermal characteristics than the surrounding ground. Changes in solar radiation input to the ground surface or surface air temperature variations may provide sufficient changes in the thermal field for shallow buried objects.
- **Nuclear methods** typically introduce a form of radiation into the ground and measure the response of the ground with appropriate detectors. Common forms of radiation used are gamma and neutron rays. Naturally occurring radiation such as cosmic radiation has also been used to detect underground voids.
- **Gas detection** may be used to locate objects such as plastics that outgas during their lifetime. The gas diffuses through the ground and, if in detectable concentrations, can indicate the presence and approximate location of the object. Such methods are used to detect plastic mines.

Most of the above methods can be applied in several configurations or types of applications that are described below:

- **Airborne** methods allow wide area coverage at low cost. They are typically used for magnetic surveys, infrared surface temperature surveys, and photographic observation of surface features that provide evidence of subsurface conditions.
- **Surface** methods may be truck- or cart-mounted or be small enough to be carried by an individual.

No excavation is necessary but, in street rights-of-way, there may be interference with normal traffic flow. In utility applications, the method must be capable of working through the discontinuities and material properties provided by the surface pavement layers. Surface methods may use a single location for both emitter and receiver or multiple locations for both emitters and receivers.

- **Downhole** (well logging) methods use a drilled borehole to insert signal emitters and sensors that provide information about ground conditions or objects in the vicinity of the borehole. This may allow retrieval of information about conditions at much greater depth than the equivalent surface method, but only near the borehole. Downhole methods rely on local material properties or reflected/re-emitted signals.
- **Surface/downhole** methods combine emitters on the surface with receivers at depth in a borehole (or vice versa). These methods allow direct path information to be collected.
- **Cross-hole** methods use two or more different boreholes with emitters and/or sensors. Direct path information between pairs of boreholes can be collected.
- **Reflection/back scatter** methods rely on reflection or re-emission of signals at interfaces of dissimilar materials. Since the reflections may be weak and the total path length is twice the distance to the object to be detected, signal attenuation is more important than in direct path methods.
- **Direct path** methods use information on field properties or travel time between two points to infer the presence of objects along the travel path or variations in subsurface layering. Attenuation is less of a problem than with reflected signal methods, but creating information from multiple signal paths is usually required. For example, seismic refraction uses seismic wave travel time between varying spacings of surface emitters and receivers to distinguish geological layering. AC resistivity methods use the resistivity information between different surface and/or borehole locations to detect the position and nature of inhomogeneities in the subsurface.
- **Normal-operation signal emission** methods use the normal operating conditions of a cable or pipe for detection. For example, an electric cable can be located by its electromagnetic field, and this is made easier by the known frequency of the signal. A steam pipe may be located by its disturbance of the ground temperature field.
- **Direct-induced signal emission** methods introduce signals into pipes, cables or fluids with pipes that are then radiated from the utility to aid in detection and location. For example, a metal pipe may be used to complete an AC circuit and the resulting electromagnetic field used to locate the pipe or compression waves introduced into a water-filled pipe for seismic position detection. These methods require advance knowledge of the utility and its accessibility at various locations so that the signals can be introduced into the line.
- **Portable direct-signal emission** methods use signal generators that can be moved along a pipeline for location purposes. For example, radio frequency emitters (sondes) can be towed along a plastic pipeline generating a signal that can be interpreted for location at the ground surface. These methods require that the utility be known about in advance, that the utility is accessible for the introduction and retrieval of the emitter, and that the pipe is sufficiently unblocked to allow the passage of the emitter.

- **Surface-induced signal emission** methods generate signals on the surface that induce a response in the underground cable or pipe. For example, the creation of a fluctuating electromagnetic field in the ground will induce a current in a metal pipe and the field due to the induced current can be used to locate the pipe. Unknown pipes can be identified using this technique, and no direct connection to the pipe is required. Signal strengths are, however, lower than those of direct signals.

Once the various signals have been collected, the information must be processed or inspected to infer the position and/or nature of the buried object or subsurface inhomogeneity. This is done in a variety of ways, including:

- Interpretation of pattern in plots of **reflected signal** data. For example, in either seismic reflection methods or surface GPR surveys, the plots showing signal traces versus horizontal position indicate reflections from surface interfaces as lines on the plot and reflections from localized objects as inverted hyperbolae. Spatial location and orientation can be inferred and the approximate depth estimated if the wave's speed of travel in the subsurface material is known. Complex underground conditions and local interference sources can make interpreting the plots very difficult.
- Interpretation of **dispersion curves** for direct path signals. Dispersion curves indicate the change of a property with the wavelength of the emitted signal. For example, in the spectral analysis of seismic waves (SASW) method, the apparent wave velocity between two surface points usually changes with the signal wavelength. This change reflects the fact that higher frequency waves depend more on near surface layers due to the attenuation of the higher frequencies at greater depths. The dispersion curves can be interpreted by computer analysis to infer the actual layering of soils and pavement.
- The use of **tomography** that has been highly developed in medical imaging allows the recreation of 3D images of objects from spatially correlated sensor data.
- The use of **inverse methods** of analysis. These are computational analysis methods that allow the spatial and property data of an object to be inferred from field measurements taken. These are computationally intensive and may not have unique solutions.
- **Data filtering** and other data processing or **image enhancement** techniques that improve the ability to interpret field data. For example, when looking for electric cables, signals at frequencies at other than 60 Hz may be filtered to enhance the signal-to-noise ratio for cable detection.
- **Neural networks** and other **pattern matching** methods may be used to interpret raw or processed field measurements. **Expert systems** may also be used to reduce the need for a trained expert in interpretation of results.

Technology Constraints and Specifications

All of the above current state-of-the-art methods have one or more of the following problems:

- They cannot locate all types of utilities.
- They cannot be used in all types of soils.
- They are affected by interference from nearby objects.
- They cannot penetrate to required depths.
- They cannot resolve smaller utilities at the required depths.
- They use hazardous materials that increase cost and risk.
- When used in normal practice, their cost exceeds what the market is willing to pay.

The goal for improved utility location technology is to avoid third-party damage to existing underground utilities. This has several facets, and significant improvements in any area of locating technology or in the linking of investigation data to field information or warnings will assist in meeting that goal. The objective for the location technologies themselves is to make locating utilities foolproof in all types of soil and site conditions and for all types of utilities at all depths of interest. Utility location sensors may be used as part of a site investigation process before excavation and/or they may be used during the excavation process, attached to a backhoe excavation bucket or drill bit. Although addressing only part of the problem, methods of manufacturing new nonmetallic pipes/cables so that they are easily locatable and adding foolproof marking systems to existing pipes and cables are also important in improving future location abilities. The objective for the total system is combining locating data with existing utility records and providing a real-time information/warning transfer to the equipment operator who is planning to excavate or already is excavating. While improvement is possible in many different areas, critical improvements that would significantly reduce current damage hazards include:

- Novel or improved methods of locating nonmetallic pipes and cables, e.g., plastic and clay pipes and fiber optic cables.
- Novel or improved methods of marking new or existing utilities for easy location in the future.
- Novel or improved methods of detection/warning systems on excavation/drilling equipment that respond to the presence of other utilities before contact is made.
- Multisensor technologies that compensate for weaknesses or potential interference with any individual locating method.
- Improved analysis methods that allow the resolution of objects at greater depth or in the presence of higher levels of interference.
- Data management methods that allow rapid interface between a field crew and a multi-utility database.
- Easy updating of utility records with new locating information.
- Field alerts about discrepancies between expected utility positions and field measurements.
- Graphical displays of utility layouts available onsite in real time and based on current database information.

Most Important Application Criteria

Although the eventual goal may be foolproof location and elimination of third-party utility damage from poor utility location information under all conditions, this is likely an unattainable goal in the foreseeable future. The main constraints and application criteria for novel or improved methods are as follows:

- Methods must be applicable in urban right-of-way settings as well as in an open-ground, uniform soil condition.
- Can operate through asphalt or reinforced concrete road pavements.
- Can tolerate interference from metallic objects nearby.
- Can provide useful information in crowded utility settings.
- Do not require long-term street occupance or large areas of street occupance that would interfere significantly with traffic flows on major routes.
- Methods should be readily portable, rugged enough for field use, and able to be powered by generators or batteries, as appropriate.
- Truck-mounted units, units on wheeled carts, and units that can be carried in a walkover mode are applicable for different survey conditions.
- Exposed sensor suites must be capable of operating effectively under normal exterior temperature, moisture, dust and other urban environmental conditions.
- Equipment must withstand long-term use in field conditions.
- Equipment and sensors to be used in boreholes and/or utility pipes must be able to withstand immersion in water and exposure to the potentially corrosive fluids/gases that may be present.
- Methods should be able to be operated by a technician. The extent of training would depend on the comprehensiveness of the equipment.
- Methods ideally should be able to identify utilities with a depth-to-diameter ratio of 30:1 or better, i.e., a 25-mm pipe or cable at a 0.75-m depth or a 1-m diameter pipe at a 30-m depth.
- Methods ideally should be able to resolve the depth and horizontal position of utilities at a depth-to-accuracy ratio of 20:1 or better, i.e., an error in depth or horizontal position of "50 mm at 1-m depth or "1 m at 20-m depth.
- Methods or combinations of methods are more desirable if they improve detection of all types of pipe or cable in all soil conditions; however, the cost of multisensor technologies must remain realistic.
- Methods capable of greater depths are better, but the following depth ranges are most important:
  - Cables: up to 2 m (greater depths becoming more important as trenchless technologies are more widely used)
  - Pipes: up to 5 m most common, up to 10 m important, over 10 m uncommon.

Current Industry Accuracy and Cost Parameters

Although many existing methods can give more precise information under favorable conditions, the following information is considered the normal precision of utility location information (not including mislocates):

- Typical surface-only utility "locates"
  - Horizontal location within 24 inches of either side of location markings
  - Vertical location not provided

- Typical surface survey with vacuum excavation potholes for confirmation (subsurface utility engineering [SUE] provider):
  - Horizontal location within 0.5 ft.
  - Vertical location within 0.05 ft.

The cost range for typical current practice for utility location is as follows:

- $0 to $50 for one-call notification and locates at an excavation location
- $150 to $500 for SUE service at an excavation location
- $0.20 to $2.00 per foot for utility designation service (may include records research, paint markings, traffic control, field sketches, surveying, CAD mapping, and signing and sealing by a professional engineer or professional land surveyor).

Section 5
Summary of Responses to
Statement of Need for Innovative Systems

This section summarizes the responses to the SON, together with other identified technologies with significant potential for further development in addressing utility location problems. The discussion focuses on general purpose pipe and cable locators rather than equipment used to detect faults in operating systems (e.g., leak detectors for gas lines, insulation damage or faults in electric cables, etc.). The report is not comprehensive since it relies mainly on the responses to the SON. Also, many commercially available systems are not discussed since this report focuses on directions for the next generation of utility locating systems rather than existing ones.

The systems are described alphabetically by the responding or identified developer of the technology. This is followed in Section 6 by a discussion of the trends in technology development grouped by area of technology.

Technologies Identified

USA

1. Bakhtar Associates

Features:	GPR, step frequency approach, low power (average transmitted power less than 0.1 watt), image processing and tomography. Developed for detection of unexploded ordnance.
Description:	Bakhtar Associates has been working with the Air Force Research Laboratory and Eglin Air Force Base for six years to improve techniques for locating unexploded ordnance. The most innovative aspect of the hardware and software developments is its use of relatively narrow frequency bands of ground penetrating radar pulses to perform a step-frequency-based interrogation of the subsurface. This provides a much better signal-to-noise ratio than conventional methods. The improved detection capability has been shown in several military demonstration projects.
Innovation:	Step frequency approach and associated analytical techniques.
Questions:	Subject to general limitations of GPR.

2. Ball Subterranean Systems

Features: GPR broad band antennas, downhole use for horizontal directional drilling (HDD) applications.

Description: Ball Subterranean Systems is a spinoff of the Ball Aerospace Technology Company and is applying its aerospace radar expertise to utility location applications. It is cooperating with three partners in South Africa to develop "see ahead" downhole systems (see description under South Africa).

Innovation: Use of polarimetry to improve data interpretation, low-power compact systems for use downhole with HDD.

Questions: General limitations of GPR, what is downhole "see ahead" range.

3. Environmental Investigations Corporation/CTC/NASA

Features: Acoustic resonance approach, use of ambient vibrations, use of frequency domain.

Description: The Resonance Acoustical Profiling (RAP) System has been developed by Igor V. Zuikov and is being commercialized by Environmental Investigations Corporation with the assistance of the NASA Center for Technology Commercialization. The method uses signals collected by piezoelectric sensors in contact with the ground surface. These signals are amplified and digitized and then converted from the time domain to the frequency domain using a version of the Fourier transform. Positional and dimensional information is then extracted using special algorithms.

Innovation: Ability to extract information from ambient ground vibrations, frequency domain approach.

Questions: Use of ambient vibration levels to provide information, new approach with little documented effectiveness as yet.

4. Geophysical Survey Systems, Inc. (GSSI)

Features: GPR, multifrequency antennas, GPS positioning.

Description: Pulse GPR systems tailored to specific applications. A wide range of antennas is available, as well as interpretation software.

Innovation: Real-time, onsite interpretation of utility position.

Questions: General limitations of GPR.

5. GeoRadar, Inc.

Features: Stepped-FM GPR.

Description: The system uses stepped-FM GPR that emits a continuous sine wave at each of a number of frequencies rather than a narrow pulse. This allows better signal interpretation and resolution of closely spaced objects. Stepped-FM GPR is less subject to interference caused by nearby metal objects and radio transmitters than pulse GPR. Work has also been carried out at Lockheed-Martin Corporation on 3-D imaging of utilities using proprietary algorithms, synthetic aperture processing, and a two-directional linear filter (example uses a 10-cm surface grid spacing).

Innovation: Use of stepped-FM, 3-D image processing.

Questions: General limitations of GPR, required grid frequency for 3-D imaging.

6. Johns Hopkins University, Applied Physics Laboratory

Features: Electrical conductivity object locator (ECOL), magnetometers for corrosion sensing, xylophone magnetometer for detection of small magnetic objects, and TerraHertz imaging system.

Description: Several approaches to the detection and monitoring of buried objects are being pursued by the Applied Physics Laboratory at Johns Hopkins University. Determination of anomalies in electrical conductivity, sensing of impressed currents in a pipeline or tracer wire, and multifrequency approaches are being pursued.

Innovation: Algorithms for interpretation.

Questions: Applicability for mapping close, vertical spaced utilities; processing power and time required.

7. NSA Engineering, Inc.

Features: Seismic reflection tomography; imaging ahead of tunnels.

Description: The method uses seismic signals generated by normal mining and tunneling equipment together with an array of piezoelectric cells and accelerometers positioned within the tunnel and back from the face. It produces a three-dimensional image of the rock mass ahead of the tunnel face.

Innovation: Use of vibrations generated during a normal tunnel cycle, receiver array design, and signal processing.

Questions: Diameter of tunnel/drill hole required to resolve ground conditions ahead of the bore.

8. Penn State University/Cold Regions Research and Engineering Laboratory (CRREL)

Features: GPR, signal processing, forward modeling, migration.

Description: This work examines the process determining the position of shallow buried pipes in complex configurations using GPR. Both forward modeling (generating synthetic GPR data for comparison with field data) and migration analysis using a 3-D Kirchhoff integral migration method are pursued.

Innovation: Signal processing, prediction-comparison algorithms for field use.

Questions: General limitations of GPR.

9. SC&A, Inc.

Features: Magnetometer and electromagnetic induction, multisensor arrays, coupling to GIS.

Description: Application of techniques developed for detecting unexploded ordnance at military bases. Use of multisensor arrays and post-processing of sensor data to form an image map of the measured fields and the anomalies present. Use of GPS for array positioning and coupling to GIS systems for output.

Innovation: Multisensor arrays, signal processing.

Questions: Relative effectiveness compared to other systems.

10. Sequel Research Corporation/Ventus, Inc.

Features: Advanced impulse electromagnetic radar (AIR) controls frequency, pulse duration, and power to enhance penetration of signals.

Description: Significant increases in penetration of electromagnetic signals into difficult materials are said to occur by using ultra-narrow impulse radar (on the order of nanoseconds)

Innovation: Enhanced penetration through barrier to normal GPR.

Questions: No scientific papers or independent reports provided to document the phenomenon described.

CANADA

11. Computing Devices Canada

Features: Electrical impedance tomography (EIT).

Description: EIT uses low-level electrical currents to probe a conductive medium and produce an image of its conductivity distribution. An array of electrodes (current configuration approximately 1 m2 with 64 electrodes) is placed on the ground surface to provide an image of the conductivity distribution below the surface. The EIT technology detects objects buried in the ground by detecting ground conductivity anomalies. The presence of a metal or plastic object disturbs conductivity distribution in the soil. The signal signature is based on the size, shape, conductivity, and depth of the buried object. The image reconstruction algorithm uses the difference between the measured potentials and the ones predicted from a homogeneous model to solve for the conductivity perturbations of the medium with respect to the homogeneous model. This is calculated over an arbitrary grid defined underneath the array. The calculations are done with a linearized version of Laplace's equation, which allows a fast reconstruction of the conductivity distributions.

Innovation: Fast interpretation of conductivity anomalies.

Questions: Not expected to work through asphalt and concrete.

12. Sensors and Software

Features: Selectable frequency GPR, signal processing, and user-oriented display software.

Description: High fidelity, digital, commercially available GPR survey units and integrated control, signal processing and display software. Antenna frequencies from 12.5 to 1200 MHz.

Innovation: Increased signal-to-noise performance, ease of use, enhanced processing and display capabilities.

Questions: General limitations of GPR.

ITALY

13. IDS

Features: GPR, multifrequency, multiantenna arrays, advanced processing and display.

Description: Highly integrated GPR system using multiple antenna arrays and multiple frequencies. Computer-assisted data interpretation and conversion of output to maps of utility position.

Innovation: Multifrequency, multiantenna arrays, system integration, and graphical output.

Questions: General limitations of GPR.

SOUTH AFRICA

14. Univ. of Cape Town/University of Stellenbosch/Halamahir
In cooperation with Ball Subterranean Systems (see description no. 2 under USA)

Features: Stepped frequency GPR, polarization, signal processing, antenna modeling, development for downhole use in horizontal directional drilling equipment (HDD).

Description: A collaboration of four partners in South Africa and the USA to develop systems for utility location, including downhole applications in conjunction with HDD. They are developing compact, low-power technology and a flexible signal processing framework. Polarimetry is used to improve data interpretation. Work is also conducted on antenna and propagation design using theoretical and computational electromagnetics. Compact, rugged, broadband antennas have been developed for use during directional drilling.

Innovation: Use of polarimetry to improve data interpretation, low-power compact systems for use downhole with HDD.

Questions: General limitations of GPR, what is downhole “see ahead” range.

Section 6
Trends for the Future Development of Utility Locating Systems

The following is based on a review of the technologies submitted in response to the SON, discussions with faculty involved in geophysics-related research, discussions with manufacturers and users of utility locating systems, and a literature review. Individuals and companies that responded to the SON were given the opportunity to review this summary report for errors and omissions and to comment on the discussion of future directions.

The trends for future development and the possibility of developing systems that fully meet the criteria stipulated in the SON are discussed as a series of responses to the following questions.

Were any relevant technologies uncovered that were not currently being applied to the utility locating problem?

The responses did not indicate any relevant technologies that had not been considered for application to the utility location problem. National laboratories and defense agencies have been involved in subsurface investigation work relative to unexploded ordnance, unmarked tunnels, environmental contamination, etc., and the potential application to other subsurface investigation problems seems to have been well identified.

Is there a system under current development that will be capable of locating urban utilities as desired in the Statement of Need (e.g. multiple and closely spaced utilities beneath urban streets, all types of utilities—conducting and nonconducting—in all types of soil conditions)?

None of the identified technologies is capabile of providing a complete solution to the utility location problem. GPR is the most promising single area of technology development since it can identify nonconducting pipes and cables. There are severe limitations on depth penetration of signals in conducting soils, however. Signal frequencies that allow the resolution of small diameter pipes may be attenuated within one meter of the surface in wet clays. Conducting or nonconducting utilities with tracer wires, conducting sheaths, passive markers or other means of electromagnetic identification are comparatively easy to find. Nonconducting utilities of small diameter at more than one meter below the ground surface present the greatest challenge. This problem will become more acute as directional drilling techniques place new, small, nonconducting utilities in nonlinear paths that extend below existing utilities. One submittal indicated that ultra-short electromagnetic pulses can penetrate materials farther than conventional pulses; however, there were insufficient data to validate this assertion. If correct, this may remove one key limitation of a universal GPR-based system.

Is there a system under development that will make plastic pipe easy to locate?

The *Common Ground* study reports that magnetic polyethylene (PE) pipe is currently being developed as part of a Gas Research Institute project for the gas industry. It does have application in other industries wherever standard PE pipe is used. It is not commercially available at this time, but is expected to be available sometime in 2001. The technology imparts a unique magnetic signature to PE pipe using a magnetic dopant (strontium ferrite). Its advantages are that it eliminates the need for tracer wire, simplifies installation, and provides a unique magnetic signature that aids locatability in cluttered environments. An existing system for wireless, passive marking of utilities is manufactured by 3M Company. The marking systems are buried immediately above key points of underground utility systems and require no external source of power. A portable, hand-held locator transmits a pulsed radio frequency signal to a buried marker, and the signal is reflected back from the marker. Markers can be tuned to different frequencies, thus allowing closely spaced, different utilities to be identified.

Is the current level of technology development mature?

While there are physical limitations on the range of applications of the various methods employed in finding underground utilities, there is still considerable potential for improvement in most of the techniques employed. Research and development is still occurring in both government and university laboratories and in commercial companies that manufacture locating equipment. These improvements will allow faster collection of field data with more automated data collection functions, more extensive data collection suitable for 3-D tomographic displays of utility positions, real-time display of survey information and comparison with utility records, enhanced signal processing, use of redundant data to increase accuracy, and enhanced graphical display functions that allow rapid updating of utility maps. These changes will greatly improve the effectiveness of utility locating activities.

Can new technologies in utility locating be cost-effective?

The complexity of utility locating equipment and systems will increase, but the higher costs associated with this complexity will be offset by the reduced level of training needed to operate the equipment and interpret the results, by the ability to collect substantially more data in less time during field operations, and by anticipated reductions in the cost of computing power and sensor hardware. The other aspect of cost-effectiveness is the cost of failing to locate utilities effectively before excavation or drilling/tunneling. The cost and safety implications of utility damage are very high and will directly or indirectly impact the cost of new utility installations. If the insurance industry, utility owners and contractors can properly assess the cost and risk of better utility locating surveys versus the cost and risk of damage to poorly located utilities, improved technologies can be cost-effective over current technologies, even at the higher implementation cost.

What directions appear to offer the greatest long-term potential for improvements in the utility location problem?

It is the author's opinion that multisensor (e.g., GPR, plus acoustic, plus electromagnetic) and multifrequency approaches offer the greatest potential for stand-alone utility location in the future. Multisensor approaches will compensate for the weaknesses of any one method (range of application or susceptibility to errors) and provide greater confidence in a utility locate for utilities that can be identified by more than one method. Multifrequency approaches can reduce signal-to-noise ratios and allow use of the frequency domain in signal processing; this typically has the capability to extract more information from field data than analysis solely in the time domain. The willingness of owners to pay for the cost of multisensor equipment will be a significant impediment, and substantial work will be required to develop intelligent sensor fusion software to extract the most information from the field data. Nevertheless, in the absence of better penetration of GPR in all soil conditions, this option is the only one that seems to provide most of the ideal criteria for utility location equipment.

What are some of the advances that are anticipated in the processing and display of data?

Based on responses to the SON, the following areas will be important:

- Computer manipulation and display of multiple radargrams and tomographic views to allow easy identification of pipes.
- Interactive display of the position of pipes and direct export to CAD software for utility maps.
- User-friendly software that operates on standard PCs with standard operating systems such as Windows.
- Automatic identification of the position of objects represented by hyperbolas in the GPR data together with a rating of the likelihood of the object being present.
- Comparison of field and synthetic pipe configuration data for rapid identification of anomalies during construction.

What steps are needed to continue the advancement of utility locating equipment?

The public, as served by its public and private utilities, has the most to gain from better utility locating practices that would lower the costs of damage, increase safety, and lower the cost of service outages. Companies that manufacture utility locating equipment or provide utility locating services must have a relatively short-term market for their equipment or services in order to develop or purchase advanced systems.

Further development of multisensor equipment would be enhanced by partnerships among utility owners, technology developers, and equipment manufacturers. Such partnerships could include funding of prototype systems, documentation of system capabilities in a variety of urban conditions, and guaranteed markets for systems that perform adequately. The Gas Research Institute has conducted a number of such programs, for example, developing locatable plastic pipe, as described above.

Multisensor fusion and advanced signal processing could benefit from similar work done for military applications. Generic software that could be used by various hardware manufacturers also may lower future development costs.

What else is needed in the industry to lower utility damage?

Many existing problems dealing with utility damage are organizational in nature. These problems are extensively described in the *Common Ground* study identified in Chapter 3. Building on the cooperation established during the preparation of this report, a nonprofit group has been established to create the *Path Forward* program, which will seek to mitigate utility marking problems through one-call systems and design and excavation practices. Key organizational problems that exist even in well-functioning systems include: depth information on utilities often is not provided from utility records to avoid potential liability and positional information on sensitive utilities may not be readily available when planning the route for a new service.

This report focused on utility locating equipment that is operated from the ground surface before excavation or drilling. Closer attention also needs to be placed on “see ahead” technologies that will sense utilities in the path of the bore before they are damaged by drilling, boring, or tunneling operations. This approach overcomes some limitations in depth penetration of utility location methods since protection against damage can be provided even if the utility is sensed within one meter of the excavation face. “See ahead” methods would not replace surface based methods for planning purposes, but they could provide an important second line of defense against utility damage.

What is planned as a continuation of this project?

The FLC and the Technology Transfer Information Center plan to invite companies with promising technologies to participate in controlled field trials to establish/confirm the accuracy and range of applicability of the various methods. These field trials will be followed by discussions among the various stakeholder groups for better utility location and will focus on establishing partnerships to help develop, commercialize, and spread the technologies. For further information, contact Kate Hayes at the Agricultural Research Service (see page v for contact information).

Section 7
Contact Information for Institutions/Companies Included in Technologies Identified

1. **Bakhtar Associates/Air Force Research Laboratory**
   Development of stepped frequency GPR
   Dr. Khosrow Bakhtar
   Bakhtar Associates
   2429 West Coast Highway, Suite 201
   Newport Beach, CA 92663
   Phone: 714-642-3255

2. **Ball Subterranean Systems**
   Development of broadband GPR for downhole use
   Robert Wootten
   Ball Subterranean Systems
   P.O. Box 1235
   Broomfield, CO 80038-1235
   Phone: 303-533-4514
   Fax: 303-533-4514
   rwootten@ball.com

3. **Environmental Investigations Corporation/CTC/NASA**
   Development of acoustic resonance approach using ambient vibrations
   www.ctc.org
   Alex Martens
   Executive Director
   Upstate Center for Technology Commercialization (CTC)
   63 Winding Creek Lane
   Rochester, NY 14625
   Phone: 716-218-4260
   Fax: 716-218-4261
   amartens@eznet.net

4. **Geophysical Survey Systems, Inc. (GSSI)**
   Manufacturer of GPR systems and software
   http://www.geophysical.com

5. GeoRadar Inc.

Manufacturer of stepped-FM GPR

http://www.georadar.com

Doug Crice

GeoRadar, Inc.

19623 Via Escuela Drive

Saratoga, CA 95070

Phone: 408-867-3792

Fax: 408-867-4900

dcrice@georadar.com

6. Johns Hopkins University

Geophysics Research Group

http://www.jhuapl.edu/

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Applied Physics Laboratory

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Laurel, MD 20723-6099

Phone: 240-228-5826 or 443-778-5826

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joseph.suter@jhuaple.edu

7. **NSA Engineering, Inc.**
Seismic reflection tomography ahead of tunnels
David M. Neil, President and CEO
NSA Engineering, Inc.
Phone: 303-277-9920
dneil@nsaengineering.com

8. **Penn State University/Cold Regions Research and Engineering Laboratory (CRREL)**
GPR signal processing
Roy Greenfield
Professor of Geophysics
441 Deike Building
Penn State University
University Park, PA 16802
Phone: 814-865-5723
Fax: 770-209-1284
Roy@geosc.psu.edu

9. **SC&A**
Multisensor approach, including magnetometer use adapted from UXO investigations for the military
David Lieblich, Ph.D.
Chief Geophysicist
SC&A
97 Central Street, Suite 302
Lowell, MA 01852
Phone: 978-459-4411
Fax: 978-459-4488

10. **Sequel Research Corporation/Ventus Inc.**
Paul H. Geffert
Ventus Inc.
Phone: 301-229-3064
Fax: 301-229-3040
ventusinc@aol.com

CANADA

11. Computing Devices Canada

Dr. Philip Church
Computing Devices Canada
3785 Richmond Rd.
Nepean, ON K2H 5B7
Canada
Phone: 613-596-7083
Fax: 613-596-7392
philip.church@cdott.com

12. Sensors & Software

Manufacturer of GPR system and software
www.sensoft.on.ca
Louis Joubert, Product Manager
Sensors & Software
1091 Brevik Place
Mississauga, ON L4W 3R7
Canada
Phone: 905-624-8909
Fax: 905-624-9365
radar@sensoft.on.ca

ITALY

13. IDS

Manufacturer of GPR system and software
www.ids-spa.it
http://www.nodig.it/
Ing. Guido Manacorda
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SOUTH AFRICA

14. University of Cape Town
GPR research and system development
http://rrsg.ee.uct.ac.za
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Fax: +27 21 650 3465
http://rrsg.ee.uct.ac.za
http://rrsg.ee.uct.ac.za/URSI

Section 8
Other Contact Information

The following additional sources of information relative to utility location or utility defect identification are provided for further reference. This is not a comprehensive list, but it reflects sources identified by responses to the SON and products relevant to utility locating but not reviewed in detail.

AERVOE Corporation

Larry Rogers
AERVOE Corporation
Gardinerville, NV
Phone: 775-782-0100

Argonne National Laboratory

Shari Zussman
Manager, Information and Communications
Industrial Technology Development Center
Argonne National Laboratory, Bldg. 201
9700 S. Cass Ave.
Argonne, IL 60439
Phone: 630-252-5936
Fax: 630-252-5230
zussman@anl.gov

Brookhaven National Laboratory

Jim Higgins
Dept. of Advanced Technology
Brookhaven National Laboratory
Upton, NY 11973
Phone: 516-344-2432

Center for Technology Applications/NASA Kennedy Space Center
Cable scanner used to detect signal degradation or faults in an electrical cable
http://www.rti.org/technology

Jody Page
Research Engineer
Research Triangle Institute
Center for Technology Applications
P.O. Box 12194
Research Triangle Park, NC 27709
Phone: 919-541-6258
Fax: 919-541-6221
jody@rti.org
Or contact Dave Makufka, Tech Transfer Office, Kennedy Space Center, (407) 867-6227

NOVA R&D, Inc.
Hand-held fast neutron scattering device used to detect materials with a high hydrogen content. Currently used for narcotics detection behind steel plates, etc.

Bernie Pifer, General Manager
NOVA R&D, Inc.
1525 Third St., Suite C
Riverside, CA 92507
Phone: 909-781-7332
Fax: 909-781-0178

Department of Defense

Dr. Kenneth R. Parham
MOUT ACTD ACE Coordinator
Soldier Systems Center
ATTN: AMSSB-RSC-MA(N)
Natick, MA 01760
Phone: 508-233-4796 or DSN 256-4796
kparham@natick-amed02.army.mil

Interested in applications of techniques for locating voids beneath airfield pavements

L. Javier Malvar, Ph.D., CE, MBA
Research Materials/Structural Engineer
NFESC Code 63
1100 23rd Avenue
Port Hueneme, CA 93043-4370
Phone: 805-982-1447
Fax: 805-982-1074
malvarlj@nfesc.navy.mil

GPR and magnetometry sensors linked to GPS and map production

Tim Wittig
Army Research Laboratory
Phone: 301-394-1010
twittig@arl.mil

Dyebore

Pigmented/setting grout used as replacement for drilling mud during pullback of pipes and cables. Protects and identifies pipe or cable.

Jim Joyce
Jim2000@pipeline2000.freeserve.co.uk

"ESPAR" AIREC Engr. Corp./NTT Intl. Corp.

Japanese developers of utility locating equipment

AIREC Engr. Corp., phone: 81-3-3845-8185; fax: 81-3-3845-8189
NTT Intl. Corp., phone: 81-3-5956-9060; fax: 81-3-5956-9024

Gator Communicator

Hand-held digital mapping system (Gator Communicator) uses stereo digital cameras to obtain three-dimensional position, which is combined with GPS and heading/orientation data to perform high speed digitizing of utility facilities.

http://webresearch.geoplan.ufl.edu/

John F. Alexander, Ph.D., P.E.
Visiting Distinguished Professor and Director Applied Global Systems Lab
Department of Electrical Engineering
University of North Florida
4567 St. Johns Bluff Road South
Jacksonville FL 32224
Phone: 904-620-2970
Fax: 904-620-2975

Heath Consultants Incorporated
Manufacturer of multifrequency pipe and cable locators
9030 Monroe Road
Houston, TX 77061
Phone: 713-844-1300
Fax: 713-844-1309

Instrument Manufacturing Company (IMCORP)
Manufacturer of locating equipment for electrical cable faults
http://imcorp.uconn.edu
Matthew Mashikian
IMCORP
Mansfield, DE

Kolectric Research Limited
Manufacturer of locating equipment in the UK
David Fish
Kolectric Research Limited
Thame Station Industrial Estate
Thame Oxon OX9 3PY
England
Phone: 44-1844-261626
Fax: 44-1844-261600

National Institute of Standards and Technology (NIST)
Ultrasound device to detect flaws in underground gas transmission pipelines
Device developed by NIST. For more information, contact Fred McGehan, 303-497-3246, mcgehan@boulder.nist.gov

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Pipe Technologies

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Section 9
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