

APPENDIX A

Emerging Technologies

A.1 SUMMARY

The Emerging Technologies Task Team was charged with the unique task of investigating the entire underground damage prevention process to determine how current or emerging technologies could be used to improve the best practices developed in each of the following Task Teams:

1. Planning and Design
2. One-Call Center
3. Locating and Marking
4. Excavation
5. Mapping
6. Compliance
7. Public Education and Awareness
8. Reporting and Evaluation

As this Appendix is multi-focused, the information for each of the eight Task Teams is addressed under separate headings.

Based upon current knowledge of evolving technologies, the Emerging Technology Task Team considered the anticipated impact upon or improvement to current best practices associated with damage prevention. The information provided in this section, therefore, offers the reader possible opportunities for the development of a utopian underground damage prevention process.

A.2 BACKGROUND AND MOTIVATION

The following mission statement was adopted by the Team:

While performing the study of best practices in preventing damage to underground facilities, the Emerging Technologies Task Team will consider and evaluate technologies used in current practices from all aspects of the excavation process: planning and design, mapping, one-call, locating and marking, excavation, reporting and evaluation, compliance, and public education. The Task Team will evaluate how the application of existing, promising, or breakthrough technologies might affect and improve upon current practices. We will use our imaginations and venture outside of our current realms to develop ideas for potential, new technologies that will assist in a global plan to construct and maintain uninterrupted underground facility services with absolute safety in our working environment. Only after developing an understanding of what a totally uninterrupted

facility system incorporates technologically, can we define “perfection” in the workplace, enabling the industry to gauge its progress toward achieving it.

With imagination as our inspiration, an absolute safe working environment as our motivation, total availability of facility services will be our achievement.

A.3 TEAM MEMBERS

The Emerging Technologies Task Team members are listed below. A brief biographical sketch of each Team member, that serves to validate his or her participation in the Study effort, is included in Appendix F, “Common Ground Study Team Member Biographies.”

Team Member	Representing²³	Employer
John Archambeault	NULCA	
Jack Arseneau	ARTBA	Wisconsin Transportation Builders Association
Rick Canaday	Network Reliability Steering Committee-Facilities Solution Team	AT&T
Catherine Carver, Co-Chairperson	Public Education Research	Center for Construction Technology and Integration
Chuck Cohen	NUCA	Tires N’ Tracks
Sandra Daziani, Co-Chairperson	OCSI	Arizona Blue Stake, Inc.
Ziyad Doany	Private Industry Research	3M Telecom Systems Division
Ben Heise	NTDPC	AT&T
George Ragula	AGA	Public Service Electric & Gas Company
Angela Wallace	OCSI	Utilities Protection Center, Inc. of Georgia

Others that participated in the Task Team’s discussions but did not participate in the consensus decision process include:

Team Participant	Representing	Employer
Ken Naquin, Linking Team Liaison	AGC	AGC
Perly Schoville	AAR	Union Pacific Railroad

²³ See Appendix D for a detailed list of acronyms.

A.4 DATA COLLECTION AND EVALUATION PROCESS

1. Each Team member was assigned to one of the eight Task Teams as an Emerging Technologies Liaison.
2. Each Emerging Technologies Liaison attended scheduled meetings of the assigned Task Team to attain an understanding of the best practices being identified.
3. Best practices from each of the other task teams were brought to the monthly Emerging Technologies Team meetings to be discussed as a group.
4. Best practices that could effectively be enhanced with existing or emerging technologies were identified.
5. Team members performed research on existing technologies or investigated emerging technologies that might apply to improve current best practices.
6. Technologies were presented at monthly meetings of the Task Team and voted on for consensus by the Team as to how they could affect an existing best practice.

A.5 OPPORTUNITIES IDENTIFIED

The investigation and evaluation of the emerging technologies addressed below was for the purpose of providing an opportunity for improvement in each of the processes, *but no one process should be considered valid without having all of the other processes remain in place*. An example: an accurate map utilizing a standard mapping coordinate system and an excellent depiction of underground facilities should never replace the need for a locator to visit an excavation site to mark the location of such facilities.

The development of this Section was not intended to provide a thorough assessment of the value of a particular technology over another nor is it to predict their evolution and success. Hence, the focus was on identifying areas of importance as they relate to damage prevention in the hope of steering the direction of emerging technologies to ultimately provide a “better” solution.

A.6 FINDINGS

A.6.1 Planning & Design

Introduction

It is important for damage prevention that the engineer involved in planning and designing new projects have access to reliable and complete information on existing buried facilities in the early project stages. Identification of the facility owner/operator in a given area could be obtained from the one-call centers. The designer could then communicate directly with a succinct list of affected facility owners/operators to

obtain maps and/or physical markings on the proposed project site to determine the location of underground facilities.

Furthermore, the design specification could include the means to provide for the future prevention of damage to buried facilities especially when the materials used are non-metallic, such as plastic, which has traditionally been difficult to locate.

Finally, as-built drawings that reflect the actual route of the new facility instead of the planned route could be generated in order to improve accuracy.

Emerging Technologies

Emerging technologies that could enhance the communication between the stakeholders involved in the planning and design of a project, and facilitate the exchange of information in an efficient manner would have an important role in the damage prevention process.

Technologies that are used in mapping, locating, and one-call centers, which are described in detail in separate sections A.6.2, A.6.3, and A.6.4, could combine to benefit the engineer in the planning and design phase of a project.

A.6.2 Mapping

Introduction

The emerging technologies for enhanced mapping is represented by the integration of the detailed data gathered at each and every facility location and or installation with surface mapping that utilizes a standard mapping coordinate system. This information needs to be distributed through an open platform that provides the subscriber with the ability to define the level of detail provided to the various users.

Currently, the data gathered during the performance of routine locating of underground facilities are used to mark the buried facility. This information may be gathered and provided back to the facility owner/operator for the correction of blatant errors in facility drawings. It is not, however, routinely collected and transmitted back to the facility owner/operator for the purpose of correcting errors of less than a dramatic nature.

Locate equipment capable of collecting and storing all of the data from many locating operations is available today. The information may include, but not be limited to, signal strength, electrical current direction, depth estimate, type of locate, latitude/longitude and date/time. This emerging technology provides the opportunity to collect and transfer these data sets to a central database. The database can serve to enhance the overall knowledge of the embedded infrastructure utilizing a common mapping platform that could deliver the database in a cost-effective manner. The development required would include the implementation of a standard format for interchanging the information, the platform for transmitting and receiving it, and a vehicle for indexing the information to an open platform mapping system. Various manufacturers currently marketing locating equipment were contacted during the Study. Although none of those contacted were rigorously pursuing this mapping and storage capability, a few felt that the technology was easily within reach.

The following tasks and practices were considered before recommending the characteristics for the new technologies:

- Mapping is generally defined by the requirements of the user. Methods from using directions on the back of a napkin to using all the latest technology will need to live hand in hand for years to come. Emerging technologies will allow these extremes, and many combinations in between, to merge into a damage prevention methodology that allows users to upgrade their databases without losing their most important asset, accurate maps and databases.
- For damage prevention, the various users will define the level and indeed the requirements of their maps. Certainly, a facility owner/operator or right-of-way owner/landowner will always want their facility maps to be as accurate as possible. Typically, this requirement is passed on to their respective locator, when necessary. However, there is information that the owner/operator may not wish to pass on, and the ability to be selective can be just as important to damage prevention. Certainly, an effort to link mapping data to marketing and sales is a competitive issue that can make mapping data sensitive. A company may want its facility location known to a qualified excavator but not which customers might be served by that facility. One-call centers will be provided the level of information each facility owner/operator feels safe in providing, but that will undoubtedly be less than what the owner/operator will maintain. Emerging technologies has the ability to move past these issues to bring greater reliability and accuracy to all stakeholders involved.

Emerging Technologies

More than a mere mention of each mapping technology is difficult. However, since they exist, it is important that users explore the respective possibilities in their quest for maps that serve their existing needs, and will serve them tomorrow.

1. Global Positioning System (GPS)

Much has been made of this exciting technology already. Satellite locations can provide data from the type used in survey to general “where am I” requests. Using software that can force a match to an existing geocoded database allows the user to not worry about differential corrections, thereby allowing the use of cheaper units. A satisfactory geocoded or standard mapping coordinate database allows the user an ability to “find” a location with or without satellite communication. However, a few issues should be pointed out with respect to mapping. While the latitude and longitude with the associated elevation locations on the earth are empirical, the methods to determine and reflect these locations on the earth are not empirical. The ellipsoid definition for the earth, the respective projection and even the differential software used to correct the satellite data can produce a “different answer” for a satellite location. Even with SA turned off, the use of differential corrections will be a requirement if accuracy less than 10 feet is expected. The exciting part is that virtually all receivers will be standardizing and allowing users access to

previously proprietary code. Certainly, emerging technologies must be able to handle satellite GPS data.

2. Video technology

Video technology provides an ability to enhance damage prevention in some very obvious and perhaps not-so-obvious ways. The ability to generate text on video has always been available using title generators linked to computer generated text. The “Close Caption” option, used primarily for the hearing impaired, provides an ability to enhance mapping. Stationing in feet or meters, has long been an engineering standard used by most mapping concerns. These distances, along with a milepost value, allow each facility along a highway or railroad to have a unique stationing identifier. Video or pictures without some sort of identifier renders the video or pictures difficult to associate with GIS-type databases or maps in general. There are a couple of pieces of technology that offer potential in each of these cases. Specifically, one is the use of the “Vertical Interval” used in video for the “Close Captioning.” This area can be shown or not shown by selecting a toggle on a monitor or television set. With a “Close Captioned Card,” a user can generate text, such as stationing or milepost value, at each facility or as a video is operated while a vehicle traverses the area of interest. The distance can be edited by programming the “Close Captioned Card.” This will allow the user to select a milepost value and the video will find the location and then display the video at that site. Loading these images to a GIS platform allows the user to see the ground that is of interest.

3. Video Mapping System (VMS)

The video mapping system, which lets you create interactive maps on your PC with links to video or still images taken with a camcorder, has also recently been developed. An example would be if you go to Paris and shoot a video of the Eiffel Tower. You could automatically create a map on your PC with a marker for the tower's exact location. Then, when you click on the marker, the video clip you took at the Tower will display on your monitor. First, you connect the video mapping system's black box/GPS receiver to your camcorder via a standard stereo cable and shoot the video just as you would ordinarily. The GPS data is collected from an internal receiver and recorded on an audio track of the videotape. Next, you connect the camcorder and the box to your PC's parallel port. When you press the play button on your camcorder, the VMS software creates a map on your PC of the GPS data stored on the videotape. Place a marker on any spot on the map (such as the Eiffel Tower) and the VMS system will find any segments of the tape that were shot at that location. Using the included video capture card, you can create video clips or still images and link them to the map or display the video directly off the camcorder onto your PC monitor. The VMS software also includes an HTML export format, allowing you to send your interactive maps to others for viewing via their Internet web browser.

4. Satellite and Digital Orthographic Imagery

Satellite and Digital Orthographic Imagery offers the damage prevention industry a range of opportunity. The low cost of this technology and the steady availability of data through USGS are making seamless Satellite and Digital Orthographic Imagery a real benefit. In

areas where the data has been flown at a low altitude, the benefits grow enormously. The low cost is attributed to the general fact that the data is not given digital attributes. The display becomes a background, properly projected so software can obtain measurements, but the user needs to digitize or observe in order to add information to their database.

5. Video Imagery

Numerous vendors with varied applications are using vehicles, such as trucks, for video stereo mapping and/or highway surface analysis. These vehicles use rectified imagery with stereo photography to collect and geocode information. The ability to simply record the information and then digitize or view the information at a later date at a level desired by the end user offers one more technology that should be taken into account. There are companies that offer the ability to load a digital image with a geocoded location to a database for mapping use.

6. Surface Survey Vehicles

Surface Survey Vehicles can range from a helicopter to a hy-rail track vehicle. Using helicopter laser imagery employs laser scanners along with video to build and enhance the digitizing process while creating mapping data. This is a post-processing application and allows the user to determine the level of processing for viewing or building a smart database. The uniquely equipped hy-rail has a real-time digital data collecting process that collects and defines the attribute data while providing geocoded data. Video is interfaced to allow linking and searching to geocoded data points by using mileposts, latitude/longitude, or stationing. The sophisticated hy-rail uses Global Positioning System receivers integrated to optical sensors, encoders, range finders, lasers and video. The resulting mapping database has attributed facility data created during the time of travel.

7. Existing Paper or Hard Copy Maps

There is existing software that allows existing paper or hard copy maps to be scanned and projected so that crude geocoding can occur. In addition, follow-up digitizing can add intelligence without forcing a complete re-survey of the data set.

8. Software

Software is perhaps the main focus for a mapping provision. Users will typically opt to use a type of GIS for their mapping applications. This is most evident by various one-call centers that may or may not need visual maps to accomplish this goal. GIS typically offers poor graphic capability but shines when it comes to manipulating attributed data for producing thematic maps and forced matching to geocoded data. For existing data sets, merging various projects with massive coverages, this offers a great solution. Other users require accurate maps using software by graphic vendors that provide highly versatile graphic capabilities but generally offer poor thematic map capabilities. Technology that must be considered includes the ability to take any mapping system, and virtually upgrade or transfer to any other system without translating data sets. This open architecture is imperative. The days of selecting or building a database, using proprietary software that creates a closed data set requiring modifications or upgrades only through that vendor, are over. Open architecture allows users to transfer only pertinent information to the end user

in a seamless method. The advice to users to consider this when building their system cannot be stressed enough. If Damage Prevention is to require that various facilities and right-of-way owners provide mapping data to multiple one-call centers, the one-call center should be able to handle data without going through a laborious or extensive translation process. This open architecture is available now, with numerous vendors providing this capability, to allow a company to use the package that best fits its requirements, provide timely updates and data sets to the one-call, continue protecting proprietary information, and still give accurate facility mapping data to the end user.

A.6.3 One-Call Center

Introduction

The one-call center continues to be the central hub of communications between all stakeholders involved in the damage prevention process. The opportunity exists to improve the damage prevention process at the one-call center by deploying an openly architected system using common, integrated communication devices and a standard mapping coordinate system. This system could provide continuous, seamless communication between all stakeholders involved in the design, placement, location & marking, maintenance, and excavation around underground facilities. Benefits that can be derived from the implementation of such a system are as follows:

1. Designer

The damage prevention process begins at the time an excavation project is designed. When the designer has the ability to identify the magnitude of facility conflicts early in the design process, the opportunity exists to either avoid them altogether or indicate, within the design, the appropriate methods of working around them.

A designer's ability to apply the above mentioned system to remotely register a proposed project with the one-call center's database offers the opportunity to identify, without guesswork, a succinct list of underground facility owners/operators specifically affected by the proposed project. Without having to waste valuable resources unnecessarily coordinating with facility owners/operators that are not involved, the designer's ability to focus on the inclusion of such additional information regarding existing facilities for use by future excavators on the project increases.

Once the designer has registered a proposed project with the one-call center, the opportunity further exists for the designer to receive electronic notifications of excavation activity or the placement of new facilities, that may occur within the geographic scope of the proposed project. With this additional knowledge, the designer/project owner has the opportunity to communicate and coordinate with the owner/operator of the new facility to possibly re-design the project to completely avoid the new facility before discovering its existence at the time of construction.

2. Excavator

The ability to utilize the above mentioned system offers the excavator an opportunity to:

- C Control and track one-call notifications by virtually communicating directly with the affected underground facility owner/operator's locators, through the one-call center's database.
- C Provide pertinent job site details, including the attachment of digital files such as voice, job site plans, and digital photographs to assist the facility owner/operator's locate personnel in the determination of which facilities are in conflict and need to be located and marked.
- C Receive pertinent information (e.g., positive responses) directly from the facility owner/operator's locator personnel, through the one-call center's database, without unnecessarily requiring them to spend valuable time meeting on the job site.
- C Process the one-call notifications at any time of the day or night (24 hours a day/7 days a week) that is most convenient to them without having to be dependent on the availability of the one-call center's personnel.

3. Underground Facility Owner/Operator's Locating Personnel:

The ability to utilize the above mentioned system offers the facility owner/operator's locating personnel an opportunity to:

- C Receive, from the excavator through the one-call center's database, pertinent job site details, including the attachment of digital files (voice, job site plans, and photographs), which could assist in the locating and marking of buried facilities.
- C Automatically and positively respond electronically to the excavator regarding the status of their markings for each and every excavation notification received from the one-call center.
- C Control, track, and maintain digital information regarding the geographic area within which they wish to receive notifications from the one-call center. This digital information could include the capability of coordinating with the diverse systems used by various facility owners/operators and cross-referencing or merging data from various systems (i.e., latitude/longitude and/or highway/railroad mile markers).

A.6.4 Locating & Marking Technologies

Introduction

The field of locating buried facilities has always been referred to as an "Art" rather than an exact "Science." Perhaps this is true since there are rarely two instances that are the same, and that the locator has to get information from drawings and notes where available, and most of all the locator has to use training, experience, and common sense. One purpose of this section is to give a brief overview of the current technologies used in determining the approximate position and depth of buried facilities, as they relate to damage prevention. Another purpose is to identify critical areas that are currently deficient or could be improved by emerging and new technologies for reducing damage.

Considerations made in this section are as follows:

- **Existing Facilities vs. New Installations:** It is important to keep in mind that some of the methods and systems mentioned below must be planned for and applied at the time of facility installation. Hence, these methods may be applicable to new installations more than existing ones. However, if these methods are used consistently on new installations, they may provide an increasing future value.
- **Metallic vs. Non-Metallic (or Plastic):** In general, metallic facilities are easier to locate than non-metallic facilities. Where plastic or non-metallic facility is buried, a tracer wire or an electronic marker is typically used for future detection. Where such means are not provided, great difficulties are encountered in determining and identifying the location of non-metallic facilities.
- **Directional Drilling:** Directional drilling has created new challenges for locating technologies. One such challenge relates to improving the accuracy of estimating the depth of existing buried facilities under varying conditions. Another challenge is the ability to place facilities using directional drilling to very deep depths, which has a negative effect on location and depth accuracy for future locates.

Locating methods can be categorized as follows:

1. Magnetic Field Based Locators or Path Tracers
2. Buried Electronic Marker Systems (EMS)
3. Ground Penetration Radar Based buried-structure detectors (GPR)
4. Acoustics Based Plastic Pipe locators
5. Active Probes, Beacons, or Sondes for Non-Metallic Pipes
6. Magnetic Polyethylene (PE) Pipe

1. Magnetic Field Based Locators or Path Tracers:

General Description:

The most common technology used to determine the location and depth of a buried conductor (cable, pipe, or tracer wire with an electrically conductive element) is based on magnetic fields. When electrical current flows in a straight conductor, a vector magnetic field is generated around that conductor in the form of concentric cylinders. Magnetic Field (MF) based path tracers work on the principle of detecting the amplitude and/or direction of the magnetic field in order to approximate the location of the current carrying source. This current is usually actively induced or injected by a transmitter, which causes a loop current to flow in the conductor and return through the ground.

In the case of energized and loaded power cables, there is usually enough current at power frequency harmonics that can be detected. Also, all cables that are grounded on both ends carry

some circulating and induced power frequency currents from power cables, and low-frequency radio signals from powerful short wave transmitters operating between 15-30 kHz.

The locator's magnetic field sensor or antenna is typically an air coil or ferrite coil. The received signal is greater for higher electrical currents flowing in the conductor, higher locator trace frequencies, and closer distances from the source. Finally, the received signal strength is dependent on the orientation of the locator sensor with respect to the conductor, since only the magnetic vector lines that cross the surface of the sensor at 90 degrees would be detected.

Orienting the coil vertically or horizontally from the conductor path, then sweeping across the surface of the earth over an electrical-current-carrying buried conductor, produces a *minima* (null response) or *maxima* (peak response) over the conductor, respectively. Since the magnetic field behavior above the conductor is known, it would be simple to calculate the approximate depth of the conductor by taking two measurements: one at ground level and one at a known distance above the surface.

Limitations of Magnetic Field (MF) based methods:

Although magnetic field based locating equipment is the most commonly used technology in determining the location and depth of buried facilities (having metallic conductors), they do not provide 100% accuracy in location or depth estimate. As mentioned above, the position and depth is indirectly determined from the detected magnetic field at the sensors assuming ideal conditions; hence, errors will occur when there is congestion or less than ideal conditions. In general, the depth estimate from MF locators is much more susceptible to congestion than the horizontal indication.

The limitations associated with using magnetic field based path tracers can be divided into two main categories: Signal quality and congestion.

Signal quality refers to signal-to-noise ratios that depend on available signal that flows in the conductor and the ambient noise signals. Signal quality is affected by the amount of signal that can be injected or induced onto the conductor given access limitation and inconsistency of far-end grounding. The amount of signal and the depth of the conductor also influence it.

Congestion refers to the distortion of the magnetic field lines or deviation from the ideal set up, which is highly predictable. The electrical current that is flowing in the conductor has to complete the circuit and return to the transmitter. The return of electrical current may flow near the surface or get on other conductors in the ground and would produce an interfering response. In addition to the ground return currents and especially when using high frequencies, some of the main signal could be induced or coupled onto adjacent conductors causing further congestion.

Frequency Choices:

Active Frequencies

Low frequencies usually require a far-end ground for the electrical current path, but do not attenuate significantly with distance. There is typically more noise from power harmonics at low frequencies.

Medium frequencies share some of the strengths and weaknesses of both the high and low frequencies depending on the soil's resistance, conductor length, type, and construction.

High frequencies are more efficient for applying the signal by general induction without accessing the cable, or by an inductive coupler which does not require a metallic connection to the conductor. High frequencies also attenuate faster with distance and can couple to adjacent conductors more easily. Finally, the sensitivity of the receiver is typically greater at higher frequencies.

Passive Frequencies

Passive frequencies rely on detecting magnetic field generated by electric currents already flowing in the buried facility. Although this method does not provide a positive identification of a particular facility, it may be effective in detecting the presence of it as part of a general sweep.

Advantages:

- May be used on all existing buried metallic facilities
- Capable of providing adequate horizontal and vertical location in most situations
- Good target identification when a signal is applied directly to a single facility
- Provides depth estimation

Disadvantages:

- Tracer wires need to be installed together with plastic pipes and non-metallic cables
- It is an "Art," requiring the skill of a trained technician, and is susceptible to congestion
- Requires access to the cable or pipe for accurate performance

Emerging Technologies:

Emerging technologies on Magnetic Field based instruments for damage prevention, may provide more robust performance under congestion, including consistent accuracy of depth estimates.

2. Buried Electronic Marker Systems (EMS):

General Description:

Electronic markers consist of a passive resonant magnetic circuit that is buried along with the facility at the time of construction. The presence of such a marker is detected by using a marker locator.

The marker locator generates a magnetic field that couples to the marker and causes it to generate its own magnetic field. The magnetic field from the marker is detected from the surface and the location is identified. The detectable range increases with the size of the marker.

These electronic markers are used for underground marking of special buried features, such as splices, valves, etc., as well as non-metallic facilities.

Advantages:

- Unique signature, excellent location accuracy, very low susceptibility to congestion
- Ideal for buried special features
- Different frequencies are used for different facilities
- No physical access to the facility is required

Disadvantages:

- Requires installation at construction
- Depth indication is to depth of marker instead of the facility
- Does not provide continuous indication of path

Emerging Technologies:

Emerging technologies that are used in electronic tags could provide means for digital identification of such buried EMS markers. This digital information could assist in identifying the buried facility and link the physical marker position to an electronic map.

3. Ground Penetration Radar Based Buried-Structure Detectors (GPR):

General Description:

Ground Penetrating Radar works on the principle of radiating electromagnetic waves into the ground and analyzing the reflections from all the anomalies in the signal path over time. The instrument is typically dragged or swept over an area, and the cumulative data is processed and displayed for interpretation by the operator.

Any object in the ground that causes a change in the characteristics of the surrounding medium will cause a reflection, which is typically greater for larger objects over smaller ones, and metallic over non-metallic. Deeper objects produce smaller reflections than shallow ones.

“Clutter” is a term used to describe unwanted indications, similar to congestion in magnetic field locators. The source of this clutter or noise is primarily from the irregularity and non-uniformity of the soil. Hence, where there is a lot of clutter, especially in situations where the reflections from the buried facilities are small, the interpretations of the GPR traces become more difficult.

The depth of the object is inferred from the time that it takes the radiated wave to complete a round trip and the velocity of the wave in the soil. Since this propagation velocity depends on the soil characteristics, it is typically assumed or calibrated over a particular site, or calculated by using multiple readings across the buried facilities at known distances. Either method assumes uniform

soil, and hence an average velocity is used. Therefore, the depth accuracy would depend on the soil conditions.

The detection accuracy also depends on the resolution obtained which is a function of the frequency range of the instrument. Higher frequencies, or large bandwidths, would provide higher resolutions.

The detectable range into the ground depends on the frequency range used in the GPR instrument, the type of soil, and the moisture content. Some soils are almost opaque especially to higher frequencies, and would prevent very deep penetration of the signal for detecting deep objects.

Advantages:

- Capable of detecting plastic (non-metallic) and metallic buried objects under favorable soil conditions
- Does not require physical access to the pipes or cables for detecting them

Disadvantages:

- Very low penetration in other than favorable soil conditions
- Cannot be used to identify a specific facility
- Small cross sections are less detectable than large ones
- Deeper objects are less visible than shallow ones
- May be highly susceptible to clutter noise in areas with non-uniform soil
- Propagation velocity, which is used to determine depth, varies with soil type and condition
- Highly dependent on operator interpretation skill

Emerging Technologies:

GPR Technology provides some unique capabilities for locating non-metallic facilities. It is also useful for detecting unknown or abandoned facilities. However, GPR based instruments have traditionally been difficult to interpret. Emerging technologies and the application of software improvement could enhance signal quality and may reduce clutter and the dependence on operator interpretation.

4. Acoustics Based Plastic Pipe Locators:

General Description:

Acoustic based locators use sound waves to determine the location of a buried pipe. An active acoustic system utilizes an acoustic transducer that, when connected to an opening on a service or main line, applies a sound wave into the gas or water stream. The sound waves travel along the length of the pipe and attenuate through the pipe wall into the surrounding soil. Those sound waves that reach the surface may be detected using special sensors such as geophones or accelerometers.

The location of the buried facility is indirectly determined by monitoring the highest (peak) vibration amplitude at the surface.

Since the sound waves have to travel in the pipe and in the soil, the type of soil and its condition along with the size of the pipe and its content will affect the detection range at the surface from the acoustic transducer.

A particular difficulty arises when the sound waves from portions of the pipe that are at right angles interfere with each other. Along with reflected waves at certain points (valves, T's reducers, obstructions, etc.), the net result is analogous to congestion that is sometimes encountered when using magnetic field based locators. However, these interfering signals can also be a benefit to the locator if the above mentioned obstructions are the targets of the locate.

Finally, since the signals are detected by measuring small vibrations at the surface, it is important to assure good sensor-to-surface (soil or pavement) contact. The final determination of pipe location is based on the relative strength (amplitude) of the detected signal (compared to the adjacent measurements) and not on the absolute measurement.

Advantages:

- Effective on plastic pipes over limited distances and depths
- Provides identification of the facility
- No cross-over signals
- Works in all soils

Disadvantages:

- Requires physical connection to an open end of the facility
- Does not provide a depth estimate
- Signal attenuation varies in different soils
- Effective range decreases with the decrease of facility diameter

Emerging Technologies:

Improvements in the acoustic transmission and detection can increase locating accuracy and range under various soil conditions, along with a reliable depth estimate, and a non-intrusive means of applying the signal provided in an easy to use product would assist in damage prevention to buried plastic pipes.

5. Active Probes, Beacons, or Sondes for Non-Metallic Pipes:

General Description:

These devices typically consist of a battery-powered transmitter that is housed in a tubular enclosure, which is inserted in a pipe or conduit. These transmitters generate a magnetic field, at low frequencies (similar to magnetic field based locator frequencies) that may be detected at the surface.

Detecting the location of plastic pipe (and all non-metallic facilities) from the surface is achieved by inserting the active transmitter into the pipe and noting the located position at the surface. The device is then moved and relocated, until the whole path is marked. The device is pushed or pulled through the pipe, and cannot be steered.

The approximate depth is calculated using the detected signal levels at the surface.

Advantages:

- Can be used to determine the location of non-metallic pipe or conduit
- Excessive distance and depth with no signal loss

Disadvantages:

- Requires physical access to the internal pipe
- Can only locate over the sonde
- Limited capability
- No steering capability

Emerging Technologies:

None identified at this time.

6. Magnetic Polyethylene (PE) Pipe:

General Description:

Magnetic 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 some time in 2001.

The technology depends upon inducing a unique magnetic signature to PE pipe using a magnetic dopant (strontium ferrite). The magnetic signature becomes an easily detectable intrinsic property of the pipe. To aid in distinguishing buried magnetic pipe from other buried magnetic objects (i.e., iron pipe, cable, etc.) a technique has been developed to induce a unique spiraling magnetic signature to the pipe. This signature has the potential to describe the pipe diameter and the product the pipe is carrying. The locator used for detecting this material can determine pipe depth.

A high-power pulsing magnetizer has been developed to induce the spiraling magnetic signature to the pipe as it is manufactured. An advanced 3-axis locator based upon the use of a fluxgate gradiometer is used to locate the pipe. This locator enables both the magnitude and polarity of the pipe signature to be measured.

Advantages:

- Eliminates the need for tracer wire
- Simplified installation
- Unique magnetic signature aids locatability in cluttered environments

Disadvantages:

- Needs regulatory approval for use in gas distribution applications
- Needs special 3-axis locator

Comparison of Locating Technologies:

Widely-Used Technologies						Limited Use Technologies				Emerging Technologies Requirements	
	Magnetic Field Detectors	Passive/ Inductive Magnetic Field Detectors	Tracer Wire/ Conductive Tape	Electronic Marking System (EMS)	Active Probes, Beacons, Sondes	Acoustic Detector	Ground Penetrating Radar (GPR)	Magnetically Impregnated Pipe	Metal Detectors	Location & Identification	Detection
Existing Facility	Yes	Yes	Yes*	Yes*	Yes	Yes	Yes	No	Yes	Yes	Yes
New Facility	Yes	Yes	Yes*	Yes*	Yes	Yes	Yes	Yes*	Yes	Yes	Yes
Metallic	Yes	Yes	(N/A)	Yes*	(N/A)	(N/A)	Yes	(N/A)	Yes	Yes	Yes
Non-Metallic	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Access Required	Yes	No	Yes	No	Yes	Yes	No	No	No	Yes	No
Identification of Facility	Yes	No	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No
Depth Estimate	Yes	Yes	Yes**	No	Yes	No	Yes	Yes	Yes	Yes	Yes
Distance Range (low or high)	High	High	High	High	High	Low	High	High	High	High	Medium
Depth Range (low or high)	High	Low	High	Medium	High	Low/ Medium	Low/ Medium	Low/ Medium	Low	High	Medium
Detects/ Identify Special Features	No	No	No	Yes	No	No	Yes	No	Yes	Yes	Yes
Detects Facility Site	No	No	No	No	No	No	No	Yes	No	Yes	Yes

* Requires that tape, wire, electronic markers, or magnetized pipe be used at time of installation.

** Depth to conductor, which may not be the same as depth to the facility.

A.6.5 Excavation

Introduction

Excavation is the last step in the construction process that puts an existing facility at risk. Both new construction and restoration work are an integral part of damage prevention. Emerging technologies offers an opportunity to improve the process and prevent damages to underground facilities.

Excavation methods can be categorized as follows:

1. Excavation by Hand

- Hand Digging

2. Open Excavation by Machine

- Excavating by Backhoe
- Trenching
- Plowing/Planting
- Vacuum Excavating

3. Boring

- Directional Drilling
- Micro-tunneling
- Pipe-jacking
- Piercing

1. Excavation by Hand

Hand digging: A person excavates by hand using hand tools to remove earth without mechanized equipment.

Advantages:

- One of the least damaging excavation methods
- Easily and accurately controlled
- Excellent in confined areas
- One person operable
- Quiet

Disadvantages:

- Time consuming
- Risk of human injury
- Depth restrictions
- Limited to capacity of human strength
- Contingent on favorable weather conditions

2. Open Excavation by Machine

Excavating by Backhoe: Excavation as defined using backhoe machinery for material extraction and removal.

Advantages:

- Trench is open and exposed
- Time efficient
- One-person operable
- Good for large-scale projects
- Allows work to be customized to define width and depth
- Easily controlled
- Great capacity for strength
- Not limited by weather conditions

Disadvantages:

- Operator training is needed
- Limited to use in non-confined areas
- Not accurately controlled
- Depth restrictions
- History of damage to facilities

Trenching: Excavation as defined using trencher machinery for material extraction and removal.

Advantages:

- Time-efficient
- Trench is open and exposed
- Easily controlled
- Great capacity for strength
- Good for large-scale projects
- Not limited by weather conditions

Disadvantages:

- Two persons needed to properly operate
- Limited width and depth control
- Easily damage facilities
- Noisy

- Operator training required
- Limited to use in non-confined areas
- Requires additional planning time

Plowing/Planting: Horizontal excavation as defined using vibratory plowing equipment to displace material.

Advantages:

- Efficient
- Requires minimal clean-up
- One person operable

Disadvantages:

- Limited depth
- Limited by environmental obstacles
- Noisy
- Requires training
- Affected by weather conditions
- Easily damages facilities
- Cannot directly see equipment in operation underground
- Limited to use in non-confined areas
- Very difficult to control
- Application is limited to smaller diameter facilities

Vacuum Excavation: Excavating using an earth vacuum, which is hand controlled and is either hand-held or truck-mounted. Suction is used to remove material.

Advantages:

- One of the least damaging excavation methods
- Time efficient
- Good for use in confined spaces
- Minimal training required
- Not limited by weather conditions
- Easily and accurately controlled
- Minimizes excavation area

Disadvantages:

- Depth restrictions
- Noisy
- Not applicable for all soil conditions (i.e., rock or shale)

3. Boring

Directional Drilling: Horizontal excavation as defined using directional drilling equipment for displacement of material.

Advantages:

- Minimal clean-up and site disturbance
- Can achieve further distances at greater depths in a single equipment set-up
- Time-efficient
- Capable of precision accuracy
- Not limited by environmental or weather conditions
- Instrumentation available for locating and guiding boring head

Disadvantages:

- Requires a minimum of a two or three person crew
- Cannot directly see equipment in operations underground
- Easily damages facilities
- Requires extensive training
- Ability to place facility at depths which are difficult to locate and maintain
- Equipment has short life expectancy
- Machine must be properly sized for existing soil conditions and diameter of facility to be installed
- Fluid used in process can find a vein or fissure and seep to the surface

Micro-tunneling: The practice of closed excavation using a combination of vertical excavation to set-up for horizontal excavation for material removal.

Advantages:

- Wide range of diameter for facility installation
- Good for large scale projects
- Not limited by depth
- Not limited by weather conditions
- Not limited by soil conditions
- Capable of precision accuracy
- Ability to have extreme accuracy in line and grade
- Works well in high water table environments

Disadvantages:

- Very slow
- Not intended for projects of considerable length
- Very labor intensive
- Extensive vertical shaft work required
- Large amounts of spoil
- Requires extensive training

- Requires extensive planning and design
- Very equipment intensive

Pipe-jacking: A trenchless excavation method using a pneumatic hammer system to assist in forcing a rigid, large diameter, steel pipe through the ground, typically under a road.

Advantages:

- Limited soil displacement
- Generally approved method of boring

Disadvantages:

- Limited control
- Requires sending and receiving pits
- Typically requires shoring
- Easily damages underground facilities
- Limited to projects of short distances

Piercing: A trenchless excavation method for installing conduit or pipe using a bullet shaped tool containing an air assisted hammer action mechanism, which forces the piercing tool horizontally through the ground from sending pit to receiving pit.

Advantages:

- Minimal training required
- Good for short distances
- Quick set-up/breakdown

Disadvantages:

- Limited steering control
- Requires sending and receiving pits
- Limited to favorable soil conditions
- Easily damages underground facilities

Emerging Technology:

Currently in practice, laser equipment has been developed to attach to equipment to enable the operator to receive a more accurate line and grade. However, laser has no capability of identifying the presence of existing underground facilities.

Similarly, radar devices are being attached to equipment to detect existing facilities by scanning the ground prior to penetrating the earth.

In stages of Research and Development (R&D) are detection systems, which attach to the equipment and are designed to scan the area in front of the machine to detect any unidentified obstacles. Upon detection of the unidentified obstacles, the machine will be programmed to immediately shutdown.

Currently available for use is a software package, which enables the directional drilling machine to achieve Latitude/Longitude. In R&D is a device, which will enable equipment to sense obstacles in the bore path. It will signal the machine to shutdown automatically as a safety device.

A.6.6 Reporting and Evaluation

Emerging Technologies offer the opportunity for Reporting and Evaluating to construct a web site for the purpose of collecting information for an on-line survey, which can automatically update a central database. In addition, the information could then be extracted to create reports for all participants in the damage prevention process.

A.6.7 Compliance

Emerging Technologies offers opportunities for resolution when issues of compliance on a construction project arise. When damage occurs in the field, contracted companies may present recorded data from site videos, one-call ticket verifications, or even voice recorded request/call back information to determine whether or not a specific contracted company falls outside of the known best practices. It is thought that a well-documented job will reduce non-compliance. Therefore, the use of current and the integration of new emerging technologies by all involved in construction, will protect against accusation and validate a company's good work ethic.

A.6.8 Public Education

Emerging Technologies offers the opportunity for the education of all those involved in the construction or maintenance of the nation's buried infrastructure. The general public can be taught about the "Call Before You Dig" philosophy through a national campaign designed to target the complexity of the infrastructure that is buried in neighborhoods and on privately owned property. The high tech means for delivering the message is through interactive CD ROM software and the Internet. Training and education of the industry may fall into several phases of development. Initially, there is a need to educate the technicians in the field, whether it be a one-call system operator or a locate technician. These employees must stay abreast with the latest developments in technology. New technologies can be explored in such training programs and offer enhancements to current practices. Also, a curriculum of classes based on the industry's best practices needs to be offered at the high school or junior college level. It is believed that the earlier training and education begins, the safer our buried infrastructure will be against human/machine accidents.

A.7 CONCLUSION

Causes of underground facility damages are most attributed to incomplete information at the planning stage, excavation methods and techniques, lack of communication between stakeholders, and the accuracy of underground facility mapping, locating, and marking. The findings of the Emerging Technologies Task Team offer the industry information that will encourage and assist in the development of new software, better equipment, technologies and practices that can enhance the damage prevention process.