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Feasibility of Mapping and Marking Underground Utilities by State Transportation Departments

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FHWA Contact: Richard Duval, HRDI-20, (202) 493-3365,
richard.duval@dot.gov

This document is a technical summary of the Federal Highway Administration report *Feasibility of Mapping and Marking Underground Utilities by State Transportation Departments* (FHWA-HRT-16-019).

Introduction

The Federal Highway Administration (FHWA) conducted research to document issues associated with State transportation departments asserting their responsibility to manage utility installations within the highway right-of-way.⁽¹⁾ The research focused on the use of three-dimensional (3D) techniques by State transportation departments. More specifically, the research addressed the following topics:

- Feasibility of State transportation departments serving as the central repository of utility data within the State highway right-of-way.
- Benefits of having reliable, accurate utility data available during project delivery.
- Barriers to collecting and managing utility location data as well as strategies to overcome those barriers.
- Cost to manage 3D utility location data and mark utilities with radio frequency identification (RFID) technology.

To address these topics, the research team did the following:

- Completed a literature review on the use of 3D technology.
- Contacted State transportation departments to document business practices and learn lessons from a review of a sample of case studies.

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- Conducted an analysis of strategies, barriers for implementation, and return on investment (ROI).
 - Reviewed the use, benefits, and costs of using RFID technology to mark underground utility installations.

Research Findings

Feasibility of State Transportation Departments as the Central Repository of Utility Data

State transportation departments have to know what utility facilities are located within the highway right-of-way to manage that right-of-way effectively. Developing and maintaining reliable inventories of utility facilities within the State highway right-of-way is feasible, and an increasing number of State transportation departments are implementing initiatives to accomplish that goal. A common denominator of these initiatives is State transportation departments' goal to collect, map, and store utility facility data systematically and reliably. State transportation departments are typically interested in only a few utility data items they need to manage the right-of-way, and not the much larger datasets that include all kinds of operational data and other information that utility owners need to manage their infrastructure. Because of legal and operational hurdles (i.e., State transportation departments managing the right-of-way, but external entities owning the utility infrastructure), it is currently not feasible for State transportation departments to be the unique, centralized repository of all existing authoritative information about utility facilities within the State highway right-of-way.

Occupancy of the highway right-of-way by a utility facility is usually by permit, easement, lease, or some other legal instrument. With some exemptions, State damage prevention laws require utility owners

to provide utility facility information to one-call notification centers. However, there is no formal requirement for utility owners to provide accurate, comprehensive copies of their utility facility records to agencies that own or manage the right-of-way where the utility facilities are located. Utility owners are generally opposed to the idea of allowing others access to their records. Reasons include commercial concerns, homeland security concerns, and a lack of societal consensus on acceptable levels of data access by authorized stakeholders.

It is common for State transportation departments not to know the exact location of most underground utility facilities in the highway right-of-way. If information about those facilities is needed for a highway project, State transportation departments request the information from utility owners or perform some level of field investigation themselves or through consultants. However, the quality and completeness of the data depends on the field investigation procedures or the utility owner's standards and procedures for record generation and keeping, which are frequently inadequate for highway design and construction purposes.

Strategies to facilitate the development of reliable repositories of utility facilities at State transportation departments include the following (in addition to relevant strategies that are listed for other topical areas):

- Use a utility data model that meets most State transportation department needs for design, construction, operation, and maintenance applications throughout the lifecycle of both highway and utility facilities.
- Strengthen permitting requirements to require applicants to measure and submit accurate locations, including depth, on all new facilities

and facilities that are exposed for maintenance or repair activities. This strategy could also include enabling State transportation departments to assess utility permitting fees that take into consideration the actual cost to manage the accommodation of utility facilities within the highway right-of-way, including developing and maintaining accurate, comprehensive utility inventories.

- Update State transportation department policies and procedures to achieve the goal of managing the right-of-way effectively based upon the requirement to obtain accurate location of all the assets within that right-of-way. This includes requiring that utility owners provide accurate locations of both new and relocated utility assets located within the highway right-of-way. It also includes establishing reliable protocols to identify, map, and document recorded and non-recorded utility facilities within project boundaries throughout the highway project delivery process. Updating American Association of State and Highway Transportation Officials utility accommodation guidelines and FHWA utility regulations accordingly would also assist in promoting a uniform implementation of this strategy around the country.

Benefits of Having Reliable, Accurate Utility Data during Project Delivery

There is a growing demand at State transportation departments for the use of 3D modeling to support project design and construction. However, only a few agencies are using 3D technology for utility installations, clearly indicating that this area is new for most agencies. In most cases, agencies might collect 3D utility data but then develop two-dimensional (2D) plans

to document the existence of utility installations for inclusion in other aspects of project delivery (see figure 1). Anecdotal information suggests that 3D utility mapping is more common in Europe than in the United States. For many projects in Europe, it is relatively common to represent utility data in three dimensions throughout the entire project limits.

A reliable inventory of utility facilities that includes using 3D techniques to assist in the effort of developing the inventory would provide benefits such as the availability of depth and elevation of utility facilities throughout the project, integration with aboveground 3D project data, and the capability to generate cross sections at any desired location. Additional benefits include a 3D representation of subsurface environments with a high concentration of utility installations within a limited space, 3D design and analysis of utility conflicts, and acceleration of project delivery, and fewer delays. Other benefits include increased safety, less risk, and less damage to utilities, as well as less utility exposures for absolute proof of utility installation existence, location, and attributes.

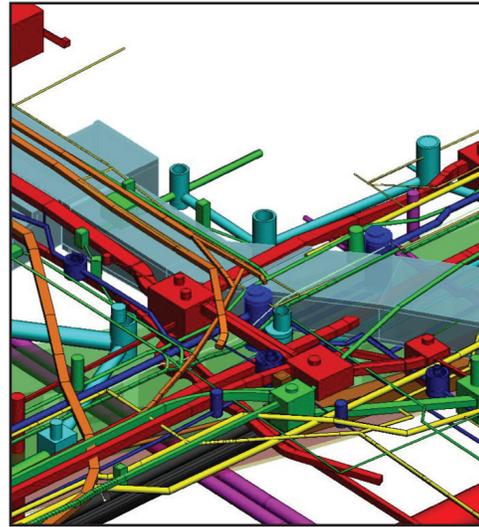
The main barrier preventing the implementation of utility data inventories at State transportation departments is the lack of funding and resources. State transportation departments also have concerns about the effort and cost to maintain and update the inventory and about monitoring the submission of utility data to maintain system-wide data accuracy standards. Additional issues include concerns about data security, access, and privacy; lack of staff and/or equipment to conduct an implementation; lack of interest by utility owners to participate; and accuracy of the data that would reside within the system. Strategies that highlight the benefits of having reliable, accurate utility data during project delivery

Figure 1. Illustrations. 2D plan view versus 3D model of underground infrastructure.



Courtesy of Hatch.

A. Traditional 2D plan view.



Courtesy of Hatch.

B. 3D model.

include conducting webinars, creating and maintaining blogs, and developing training materials. Because of the differences between 2D- and 3D-design environments, the outreach programs should focus on how a 3D-design environment actually works because this environment requires designers and coordinators to approach project delivery differently compared to a traditional 2D-design environment. Focus should also be on “just in time” training, which includes detailed training for when the agency is committed to start designing in 3D. Staff interest and effectiveness decreases substantially as the lag between training and implementation increases.

Barriers and Solutions for Collecting and Managing Utility Location Data

Currently, it is common to depict utility lines and appurtenances on certain project drawings right after collecting the data. However, this information is not necessarily shown or referenced on all relevant project design files or on plans, specifications, and estimates. Relocated utilities are also

frequently not shown on design or construction plans, or changes to the operational status of previously documented existing installations are not updated.

It is common to rely on existing utility records and one-call markings to obtain information about existing utility installations. Although useful, this information is typically not accurate or complete enough for design purposes. Questions about the completeness and quality of existing utility as-built information prompted the emergence of the Construction Institute (CI)/American Society for Civil Engineers (ASCE) 38-02, *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data*.⁽²⁾ Unfortunately, many agencies still do not recognize the benefits of conducting thorough utility investigations. One of the reasons is the lack of reliable tools to (1) determine the type of utility investigations to conduct at different quality levels as a function of project type, complexity, and other characteristics and (2) prepare quantitative assessments of the risk that an agency

assumes by not pursuing more detailed utility investigations. Other reasons include a tendency to consider that utility inventories are the responsibility of utility companies and the common practice of collecting utility data too late in the design phase.

Most 3D design and construction processes focus on grading and paving automated machine guidance (AMG) applications. Over the years, it has been possible to exchange 2D computer-aided design (CAD) files in their native formats as well as Extensible Markup Language (XML) formats. However, the same level of interoperability has not yet translated to the 3D environment. Data exchange standards to facilitate the AMG process, such as LandXML, provide very limited support for underground facilities. For example, LandXML includes a pipe network component that supports sanitary sewer, storm water, and water facilities. However, the level of attribution for underground facilities is very limited, which in turn, limits the ability to use LandXML to document existing or proposed utility installations in ways that could support both AMG applications and other utility-related applications at State transportation departments. Furthermore, existing 3D CAD platforms provide support for LandXML import and export operations, but it is unknown whether data interoperability across platforms is achievable on a consistent basis.

Commonly used 2D and 3D CAD applications handle objects as disconnected geometric elements that only make sense to the human brain. As opposed to traditional 3D modeling, building information modeling (BIM) involves representing the components of a facility as individual objects that have geometry, attributes, and relationship characteristics. BIM is increasingly used during design and construction, including project scheduling support, quantity and

cost management and control, and construction supply chain management.

A variety of geophysical methods are available to detect underground utilities, including electromagnetic induction (EMI), ground penetrating radar (GPR), optical, infrared (thermal), magnetic, inertial, and elastic wave methods. For any of these geophysical methods, there is more certainty about horizontal locations than about vertical locations. Rigorous protocols coupled with engineering judgement do enable the assessment of depth values, but the resulting data are rarely comprehensive. New GPR and EMI array technologies that use multiple sensors to produce 3D imagery of underground facilities are beginning to provide a backbone for preparing 3D deliverables when combined with all other available utility data sources and high-level technical expertise to interpret, analyze, and consolidate the data.

A generalized utility process that was developed as part of projects R15B and R15C of the second Strategic Highway Research Program applies to a wide range of projects regardless of whether design and construction occurs in a 2D or a 3D environment.^(3,4) This research outlined additional activities that augment the generalized utility process for projects designed and constructed in a 3D environment, including activities prior to building a 3D model of existing utility installations, activities for building and using a 3D model of utility installations, and activities for maintaining the 3D utility information current throughout project design and construction.

Strategies to address barriers for collecting and managing utility location data include the following (in addition to relevant strategies that are listed for other topical areas):

- Use standards-based, agency-wide utility data collection and reporting

protocols, including appropriate surveying, CAD, and geographic information system standards and specifications. Standards-based data collection protocols include referencing all spatial data to a common, easily retrievable datum and obtaining appropriate utility as-built information for existing, newly installed, or relocated utilities within the highway right-of-way. Recognizing the need for a national utility as-built data standard, ASCE started an initiative to develop a standard for recording and exchanging utility infrastructure data.

- Develop and implement a utility inventory system that includes appropriate mechanisms and protocols to update the database whenever there are changes (e.g., through the utility permitting process).
- Promote the use of a generalized process for utility conflict management that takes into account procedures to handle 3D utility data workflows with a heavy emphasis on interactive, hands-on training on the use of the UCM approach to link utility activities throughout the project delivery process.

Cost to Collect and Maintain 3D Utility Data and Mark Utilities with RFID Technology

Cost and ROI of Using 3D Models for Utility Investigations

Although direct, comprehensive information about the cost to develop 3D utility inventories is generally not available, the analysis indicates that the cost to develop 3D utility inventories is primarily a function of the cost to collect the data in the field because the cost to develop the 3D model is relatively minor once the data have been

collected. In general, 3D modeling has reached the point where the cost to develop 3D models is a normal component of the cost of doing business. Because the cost to develop 3D models is relatively minor, it is difficult to separate this cost from other business costs. In general, State transportation departments control 3D modeling costs by focusing on basic 3D model functionality, not on sophisticated renderings (which tend to increase costs dramatically).

ROI information on the use of 3D modeling for horizontal construction at State transportation departments is generally not available. Nevertheless, a few numbers are beginning to appear in the literature. For example, the Norwegian Public Roads Administration noticed that using BIM resulted in a 75-percent reduction in the number of construction change orders. Construction change order amounts also decreased significantly from 18 percent of the construction contract amount to 4 to 10 percent of the construction contract amount. Overall, using BIM resulted in 8- to 14-percent project cost savings.

Examples documenting economic benefits from the use of 3D modeling and BIM for vertical construction are also beginning to appear in the literature. For example, using BIM to identify and resolve design and construction conflicts for the \$350 million Letterman Digital and New Media Arts Center at the Presidio of San Francisco, CA, produced an estimated savings of over \$10 million (or almost 3 percent of the total project cost). Using BIM for design and construction for the \$165 million University of Southern California School of Cinematic Arts complex in Los Angeles, CA, produced an estimated cost savings of \$6.4 million (or almost 4 percent of the total cost of the project).

There is a lack of reliable data to develop a generalized estimate of the cost to

map utilities in 3D. For traditional utility investigations, a rule of thumb is to assume 1 percent of the total design and construction cost for a project to gather quality level B (QLB) data throughout the project and quality level A (QLA) data in sufficient locations to identify important utility conflicts. There could be significant variations (e.g., 2 percent estimated in North Carolina in the late 1990s and 0.22 to 2.8 percent in Pennsylvania in the mid-2000s). ROI estimates for conducting traditional QLB and QLA utility investigations in the literature range from 3.42:1 (Ontario, Canada, study), to 4.62:1 (Purdue University study), to 22:1 (Pennsylvania Department of Transportation study), with most ROI values fluctuating between 3:1 and 6:1.⁽⁵⁻⁷⁾ Assuming, for simplicity, an ROI of 4:1 and 1 percent of the total project design and construction cost spent on a utility investigation at QLB for the entire project and QLA at strategic or critical locations, the result would be savings of about 4 percent of the total project cost.

Using GPR or EMI arrays adds to the cost of conducting utility investigations. There is a lack of reliable statistics on the cost of using advanced geophysics due, in part, to the tendency to use these techniques at high-stakes locations characterized by particularly complex utility infrastructure, which makes it difficult to develop typical estimates on a cost-per-linear-foot basis. However, trends suggest that the cost of using advanced geophysics is likely to be lower than (although in some cases of the same order of magnitude as) the cost of conventional QLB and QLA utility investigations. Given these values, adding advanced geophysics to the menu of options for conducting utility investigations will still likely result in positive ROI values for projects that use those additional techniques. Furthermore, lessons learned from the use of BIM strongly suggest that the use of 3D

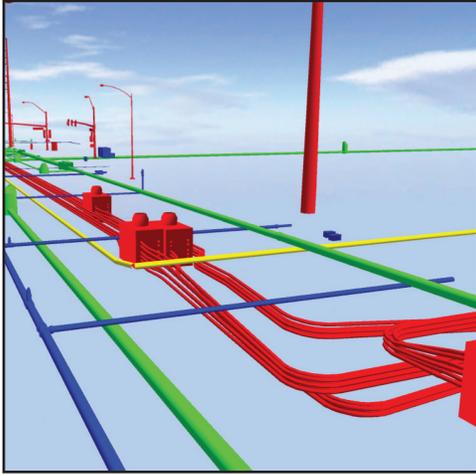
modeling for transportation projects will produce substantial economic benefits. As a result, it is reasonable to assume that the ROI for preparing 3D inventories of utilities could be at least of the same order of magnitude as the ROI for conventional QLB and QLA utility investigations.

In addition to relevant strategies that are listed for other topical areas, strategies to increase the ROI of using 3D models for utility investigations (see figure 2) include developing a catalog of projects that use 3D modeling techniques for utility facilities during project delivery to (1) quantify the cost to acquire and map utilities in 3D in a systematic way; (2) evaluate the impact of using 3D techniques on the State transportation department's capability to identify, resolve, and manage utility conflicts; and (3) document lessons learned and economic benefits. Assuming ROIs are positive, completing this activity for a sample of State transportation departments would result in documentation adding credibility to the idea of including utilities in plans to migrate design and construction practices from 2D to 3D throughout the country (see table 1).

Cost and ROI of Using RFID Technology to Mark and Manage Utility Installations

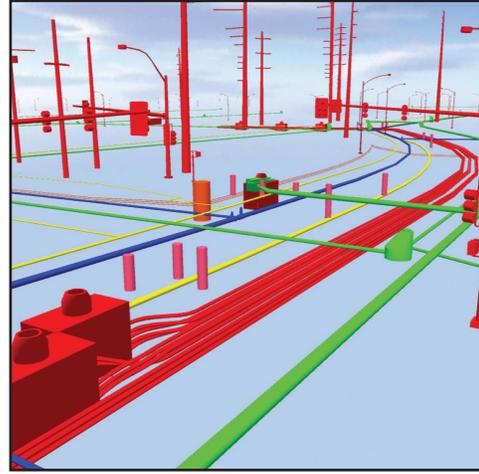
The application of RFID technology (see figure 3) at the Virginia Department of Transportation's (VDOT's) Northern Virginia District is unique among State transportation departments. VDOT started the RFID program to mark utility installations that had been relocated as part of VDOT construction projects to reduce the level of uncertainty with respect to these facilities and, more specifically, as a damage prevention strategy. The average cost in place for RFID markers at VDOT is \$16.22/marker, which translates to \$0.65/ft of utility line, assuming RFID markers every 25 ft. The relative increase in utility relocation cost

Figure 2. Illustrations. 3D models generated from 3D geophysical survey and other data sources.



Courtesy of VTN and Underground Imaging Technologies.

A. 3D model of project features (first view).



Courtesy of VTN and Underground Imaging Technologies.

B. 3D model of project features (second view).

Table 1. Project impacts associated with 3D modeling, BIM, traditional utility investigations, and 3D utility investigations.

Category	Topic	Project Impact
Cost of using 3D modeling/BIM for design and construction	Additional upfront costs during design	Minor project cost impact
Cost of using 3D modeling/BIM for design and construction	Difficulty in separating the cost to develop 3D models from other business costs	Minor project cost impact
Benefits of using 3D modeling/BIM for design and construction	Reduction in construction change orders	75 percent fewer change orders
Benefits of using 3D modeling/BIM for design and construction	Project cost savings	4–15 percent of total project cost
Cost of using conventional QLB and QLA utility investigations	Cost to gather QLB for the entire project and QLA at strategic or critical locations	0.2–3 percent of total project cost
Benefits of using conventional QLB and QLA utility investigations	Coverage and detection of underground of utility facilities	80–90 percent of utility facilities
Benefits of using conventional QLB and QLA utility investigations	Project cost savings	4 percent of total project cost
Cost of using advanced geophysics to develop a 3D inventory of utilities	Cost to gather utility data using advanced geophysics	0.1–2 percent of total project cost
Benefits of using advanced geophysics to develop a 3D inventory of utilities	Additional utility features detected and mapped	Depends on local conditions
Benefits of using advanced geophysics to develop a 3D inventory of utilities	Depth identification	Significant benefit
Benefits of using advanced geophysics to develop a 3D inventory of utilities	Project cost savings	Unknown but possibly up to 4 percent of total project cost

Figure 3. Photo. RFID marker next to a trench.



Courtesy of TTI.

varies according to the type of utility installation. For example, the relative increase is 0.45 percent for a 24-inch water main that costs approximately \$145/ft to install, but it is 1.1 percent for a pipe that costs \$60/ft to install.

Program benefits range from the availability of geo-referenced utility segment data for establishing protection zones during construction to the development of a reliable inventory of utility features for asset management purposes and to facilitate future construction activities. Other benefits include a more effective utility inspection process and improved coordination with other VDOT officials, including highway construction inspectors.

Most of these benefits are difficult to quantify in terms of fewer delays or lower project costs. Available project cost data, including change orders, are not sufficiently disaggregated to enable a reliable determination of economic benefits. However, VDOT has realized damage prevention benefits. For example, VDOT installed RFID markers over approximately 700 ft of an 8-inch gas

line that was relocated for a project along Route 50. The relocated gas line was in proximity to street light foundations that had to be removed during construction. The one-call marks on the ground that the contractor requested before construction corresponded to the location of the old main. With this information, the contractor started removing the street light foundations. Fortunately, VDOT was able to provide markings on the ground identifying RFID marker locations that showed where the new gas main was actually located. In another instance, a VDOT environmental contractor was performing investigative borings along Gallows Road in Falls Church, VA, at a location where an 8-inch gas line had been relocated. One-call markings on the ground had indicated that the gas line was located along the existing sidewalk. VDOT proceeded to locate the RFID markers that showed the actual gas line location, which showed the contractor where not to perform the boring.

These are not isolated incidents, considering that some 10 percent of underground utility

damage events nationwide can be due to visible but incorrect markings. From VDOT's experience, it is reasonable to assume that using RFID markers to systematically mark the location of relocated utility facilities and develop utility inventories based on this information has the potential to substantially reduce the number of underground facility damage events that currently occur due to incorrect utility markings.

Strategies to measure the cost and ROI of using RFID technology to mark and manage utility installations include the following (in addition to relevant strategies that are listed for other topical areas):

- Promote the use of RFID markers at State transportation departments throughout the country to mark underground utilities; build reliable, comprehensive utility inventories; and assist in damage prevention programs (see figure 4). This strategy includes developing and disseminating training materials and programs to teach State transportation department officials such as project managers,

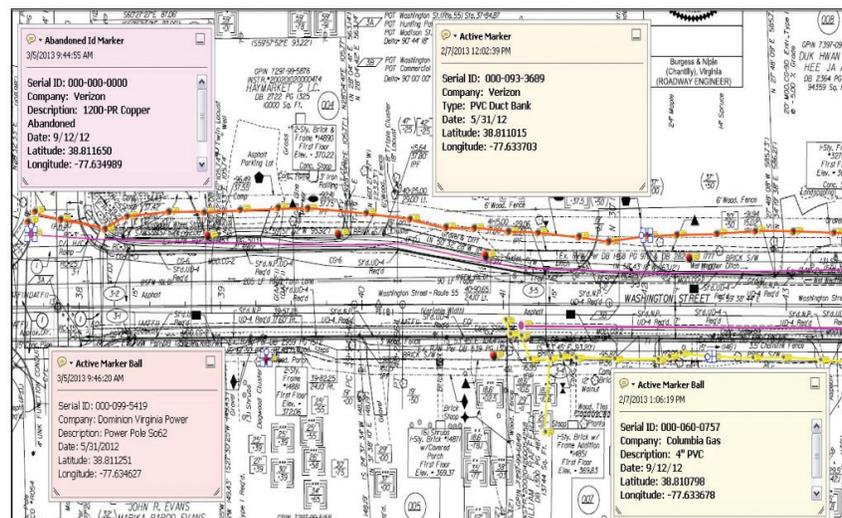
designers, inspectors, and surveyors on the techniques and protocols for using RFID markers. It also includes developing a compilation of standards and specifications for RFID markers to assist State transportation departments during the implementation phase.

- Develop a systematic assessment of the total cost associated with the damage to underground utilities during project construction to complement the statistics that the Common Ground Alliance (CGA) compiles, which currently include the number of events that result in utility service interruptions and contractor downtime hours but do not include information about total costs to all affected stakeholders. CGA is an association that promotes effective damage prevention practices.

Additional Strategies

The research team also identified the following strategies that support the implementation of the previously listed strategies but need development or research work:

Figure 4. Illustration. VDOT RFID tag attributes.



Courtesy of VDOT.

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- Develop a robust reference 3D utility data model. Research could assist in the development of a robust reference data model for storing and managing 3D utility data (including related attribute data) to support all phases of project delivery from preliminary design to construction and production of as-built documentation.
 - Develop a robust data exchange standard for utilities. Data exchange standards such as LandXML facilitate the AMG process but do not provide adequate support for utility facilities. At the same time, data exchange standards such as ifcXML are very detailed, but it is not clear to what degree they support horizontal construction applications. Research and coordination with standards development organizations could assist in the development of updated versions of LandXML and other data exchange standards such as ifcXML to provide the support needed to manage utility installations at State transportation departments effectively.
 - Develop a library of 3D components for utility installations. A current issue for State transportation departments and consultants is the need to standardize and disseminate libraries of commonly used 3D objects to expedite the development of 3D models. In the current practice, individual practitioners develop their own libraries. Frequently, different consultants working for the same agency develop separate libraries to represent the same objects, which results in inefficiencies during project delivery. Coordination with the engineering community and trade organizations could assist in promoting the establishment of information warehouses to exchange libraries of commonly used 3D primitives, objects, and templates.
 - Develop a manual for effective utility investigations. Although the CI/ASCE 38-02 standard guideline provides information on how to collect and depict utility data for engineering applications, there is much confusion and lack of guidance on how to conduct utility investigations.⁽²⁾ Research and coordination with the engineering community could assist in the development of a manual to scope, procure, manage, and conduct utility investigations, with a specific focus on best practices for the collection and management of utility data, proper data attribution, and uncertainty levels. This manual would identify and provide guidance on effective technologies, standards, practices, and procedures for identifying and depicting utilities throughout project delivery.
 - Improve coordination between State transportation departments and the one-call process. The one-call process has been successful in promoting damage prevention practices and in decreasing the number of incidents and damage events affecting underground infrastructure during construction. However, what is working well for damage prevention is inadequate in addressing typical highway project delivery needs. Anecdotal information points to systematic issues related to accuracy and completeness of one-call markings in highway projects. Research could assist in documenting these issues and formulating recommendations to improve protocols and procedures that could result in more reliable data about existing utility installations within the highway right-of-way.
 - Develop a tool to quantify utility location risk levels. Research could assist in the development of a reliable methodology and prototype tool to

quantify utility location risk levels to improve current clash detection techniques. This tool is important because one of the main reasons that State transportation departments do not conduct thorough utility investigations is the lack of understanding of the risk and, therefore, the cost associated with not knowing where underground utility facilities are actually located.

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Researchers—This study was performed by Cesar Quiroga, Ph.D., P.E., and Edgar Kraus, P.E., at the Texas A&M Transportation Institute, and James Anspach, P.G., and Paul Scott, P.E., at Cardno.

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