Feasibility of Mapping and Marking Underground Utilities by State Transportation Departments

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FOREWORD

The Federal Highway Administration conducted research from 2012 to 2015 to document issues associated with State transportation departments asserting their responsibility to manage utility installations within the highway right-of-way. The research focused on the use of three-dimensional (3D) techniques by State transportation departments. The research addressed the following topics: (1) feasibility of State transportation departments as the central repository of utility data within the State highway right-of-way; (2) benefits of having reliable, accurate utility data available during project delivery; (3) barriers for collecting and managing utility location data as well as strategies to overcome those barriers; and (4) cost to manage 3D utility location data and mark utilities with radio frequency identification (RFID) technology.

The analysis concluded that developing and maintaining reliable inventories of utility facilities within the State highway right-of-way is feasible and provides significant benefits. The research outlined 10 implementable strategies to achieve this goal along with 6 strategies that need development work. The return on investment (ROI) for preparing 3D inventories of utilities could be of the same order of magnitude as the ROI for conventional utility investigations. The application of RFID technology to mark utility installations at the Virginia Department of Transportation (VDOT) is unique among State transportation departments. VDOT started its RFID program as a damage prevention strategy to protect relocated utility installations during highway construction. The average cost of installing RFID markers at VDOT is $0.65/ft of utility line, assuming RFID markers every 25 ft.

The audience for this report includes State transportation departments, utility owners, one-call notification centers, consultants, and contractors.

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16. Abstract

A critical factor that contributes to inefficiencies in the management of utility issues in highway projects is the lack of accurate, complete information about utility facilities that might be in conflict with the project. Barriers that transportation agencies must overcome before collecting and storing utility location data include, but are not limited to, liability in connection with data accuracy, visualization of data reliability and accuracy, long-term storage and maintenance of the electronic data, access to the data, and homeland security issues. The objective of the research was to document issues associated with State transportation departments asserting their responsibility for managing utility installations within the highway right-of-way. The research focused on the use of three-dimensional (3D) techniques by State transportation departments. Activities completed to meet this objective included the following: (1) a literature review on the use of 3D technology; (2) outreach to State transportation departments to document business practices and lessons learned from a review of selected case studies; (3) an analysis of strategies, barriers for implementation, and return on investment; and (4) a review of the use of radio frequency identification technology to mark and manage underground utility installations, along with a discussion of benefits and costs. The audience for this report includes State transportation departments, utility owners, one-call notification centers, consultants, and contractors.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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LIST OF ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
4D	four-dimensional
5D	five-dimensional
6D	six-dimensional
AASHTO	American Association of State Highway and Transportation Officials
ACRP	Airport Cooperative Research Program
AGC	Associated General Contractors of America
agcXML	Associated General Contractors of America Markup Language
AMG	automated machine guidance
ARTBA	American Road and Transportation Builders Association
ASCE	American Society of Civil Engineers
BIM	building information modeling
BIMXML	Building Information Model Extensible Markup Language
CAD	computer-aided design
Caltrans	California Department of Transportation
CDA	comprehensive development agreement
CFR	Code of Federal Regulations
CGA	Common Ground Alliance
CI	Construction Institute
CIM	civil integrated management
CTDOT	Connecticut Department of Transportation
DelDOT	Delaware Department of Transportation
DSM	digital surface model
DTM	digital terrain model
EDC	Every Day Counts
EMI	electromagnetic induction
EPSRC	Engineering and Physical Sciences Research Council
FDEMI	frequency domain electromagnetic induction
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GHz	gigahertz
GIS	geographic information system
GPR	ground penetrating radar
GPS	Global Positioning System
GUIDE	Geospatial Utility Infrastructure Data Exchange
HVAC	heating, ventilation, and air conditioning
Hz	hertz
ID	identification
ifcXML	Industry Foundation Classes Extensible Markup Language
IFC	Industry Foundation Classes
Iowa DOT	Iowa Department of Transportation
IT	information technology
ITS	intelligent transportation systems

kHz	kilohertz
LFEM	low-frequency electromagnetic field
LIDAR	light detection and ranging
MDOT	Michigan Department of Transportation
MDSHA	Maryland State Highway Administration
MHz	megahertz
MoDOT	Missouri Department of Transportation
MTU	Mapping the Underworld
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NHI	National Highway Institute
NURBS	nonuniform rational basis spline
ODOT	Oregon Department of Transportation
OGC	Open Geospatial Consortium
OS	Ordnance Survey
OXEMS	Oxford Electromagnetic Solutions Limited
PAS	publicly available specification
PDF	portable document format
PE	professional engineer
PennDOT	Pennsylvania Department of Transportation
PHMSA	Pipeline and Hazardous Materials Safety Administration
PMF	passive magnetic field
PS&E	plans, specifications, and estimates
QLA	quality level A
QLB	quality level B
QLC	quality level C
QLD	quality level D
QC	quality control
RFID	radio frequency identification
RIDOT	Rhode Island Department of Transportation
ROI	return on investment
SESI	Stanford Energy System Innovations
SHRP2	second Strategic Highway Research Program
STIC	State Transportation Innovation Council
SUE	subsurface utility engineering
TDEMI	time domain electromagnetic induction
TDOT	Tennessee Department of Transportation
TIN	triangulated irregular network
TRB	Transportation Research Board
TxDOT	Texas Department of Transportation
UACT	Utility Accommodation and Conflict Tracker
UAR	utility accommodation rules
UCM	utility conflict management
UDOT	Utah Department of Transportation
UIR	Utility Installation Review
UKWIR	United Kingdom Water Industry Research

VAULT	Scottish Community Apparatus Data Vault
VDOT	Virginia Department of Transportation
VISTA	Visualising Integrated Information on Buried Assets to Reduce Streetworks
W3DS	Web 3D Service
WisDOT	Wisconsin Department of Transportation
WSDOT	Washington State Department of Transportation
WVDOT	West Virginia Department of Transportation
XML	Extensible Markup Language

EXECUTIVE SUMMARY

RESEARCH OBJECTIVES AND ACTIVITIES

The Federal Highway Administration conducted research from 2012 to 2015 to document issues associated with State transportation departments asserting their responsibility to manage utility installations within the highway right-of-way. The research focused on the use of three-dimensional (3D) techniques by State transportation departments. More specifically, the research addressed the following topics: (1) feasibility of State transportation departments as the central repository of utility data within the State highway right-of-way; (2) benefits of having reliable, accurate utility data available during project delivery; (3) barriers for collecting and managing utility location data, as well as strategies to overcome those barriers; and (4) cost to manage 3D utility location data and mark utilities with radio frequency identification (RFID) technology. To address these topics, the research team (1) completed a literature review on the use of 3D technology; (2) analyzed and documented case studies; (3) conducted an analysis of strategies, barriers for implementation, and return on investment (ROI); and (4) reviewed the use, benefits, and costs of using RFID technology to mark underground utility installations.

RESEARCH FINDINGS

Benefits of Reliable Utility Inventories at State Transportation Departments

State transportation departments must 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 the State transportation departments' goal to collect, map, and store utility facility data systematically and reliably. State transportation departments are typically interested in just a few utility data items they need to manage the right-of-way but 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 (primarily that State transportation departments manage the right-of-way, but external entities own the utility infrastructure), it is currently not feasible for State transportation departments to be the unique, centralized repository of all authoritative information that exists 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 allowing others to have 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 that 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.

A reliable inventory of utility facilities that includes using 3D techniques to assist in that effort would provide benefits such as availability of depth and elevation of utility facilities throughout the project, integration with aboveground 3D project data, and 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, lower 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 for monitoring the submission of utility data to maintain systemwide data accuracy standards. Additional issues include concerns about data security, access, and privacy; lack of interest by utility owners in participation; and accuracy of the data.

Barriers and Solutions for Collecting and Managing Utility Location Data

Although it is common to depict existing utility facilities on utility maps after collecting the data, this information is not necessarily shown on all relevant project files. 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 documented. It is common to use existing utility records and one-call markings to obtain information about existing utility installations. Although useful, this information is typically inadequate for design purposes. The Construction Institute/American Society of Civil Engineers 38-02 standard guideline provides information on how to collect and depict existing utility installations.[(1)] Unfortunately, many agencies still do not recognize the benefits of conducting thorough utility investigations.

Most 3D design and construction processes focus on grading and paving automated machine guidance (AMG) applications. However, data exchange standards that facilitate the AMG process, such as LandXML, provide very limited support for underground facilities. Further, existing 3D platforms provide support for LandXML import and export operations, but it is unknown whether data interoperability across platforms is achievable on a consistent basis.

A variety of geophysical methods are available to detect underground utilities, including electromagnetic induction (EMI) methods, ground penetrating radar (GPR) methods, optical methods, infrared (or thermal) methods, magnetic methods, inertial methods, and elastic wave methods. For any of these geophysical methods, there is more certainty about horizontal locations than about vertical locations. Rigorous protocols and engineering judgement 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 at the point where they 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 the second Strategic Highway Research Program R01A and R15B projects applies to a wide range of projects regardless of whether design and construction occurs in a two-dimensional or a 3D environment.[2–4] This research outlined additional activities that augment the generalized utility process for projects designed and constructed in a 3D environment, including activities that occur prior to building a 3D model of existing utility installations, activities for building and using a 3D model of utility installations, and activities for keeping the 3D utility information current throughout project design and construction.

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

Cost and ROI of Using 3D Models for Utility Investigations

The cost to develop 3D models is decreasing rapidly, making it difficult to separate this cost from other costs to develop and deliver projects. A strategy that State transportation departments use to control 3D modeling costs is focusing on basic 3D model functionality rather than the production of 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 building information modeling (BIM) resulted in a 75-percent reduction in the number of construction change orders.[5] 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 in 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 Arts Center at the Presidio National Park, San Francisco, CA, produced an estimated savings of more than $10 million (or almost 3 percent of the total project cost).[6] Using BIM for design and construction for the $165 million University of Southern California’s School of Cinematic Arts complex produced an estimated cost savings of $6.4 million (or almost 4 percent of the total cost of the project).[7]

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.[1] 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).[8,9] ROI estimates in the literature for conducting traditional QLB and QLA utility investigations 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.[8–10]

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, in most cases, trends suggest that the cost of using advanced geophysics is 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. Further, lessons learned from the use of BIM for vertical construction 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.

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

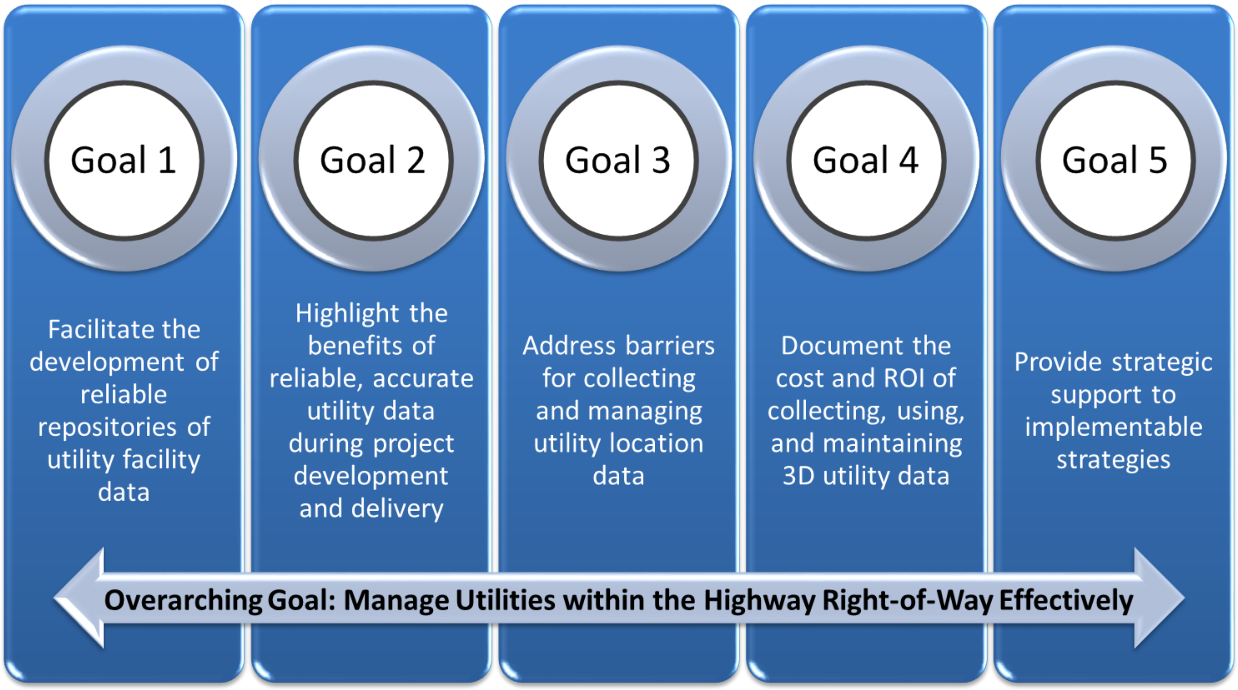
The application of RFID technology at the Virginia Department of Transportation (VDOT) is unique among State transportation departments. VDOT started the RFID program to mark utility installations that have been relocated as part of VDOT construction projects to reduce the level of uncertainty with respect to these facilities and, more specifically, as a damage prevention strategy.[(11)] 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 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 is 1.1 percent for a pipe that costs $60/ft to install.[(11)]

Program benefits range from the availability of georeferenced 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 because available project cost data, including change orders, are not sufficiently disaggregated. However, VDOT has realized damage prevention benefits. For example, VDOT installed RFID markers over an 8-inch gas line that was relocated near 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. Fortunately, VDOT was able to provide markings on the ground showing RFID marker locations where the gas main had been relocated.

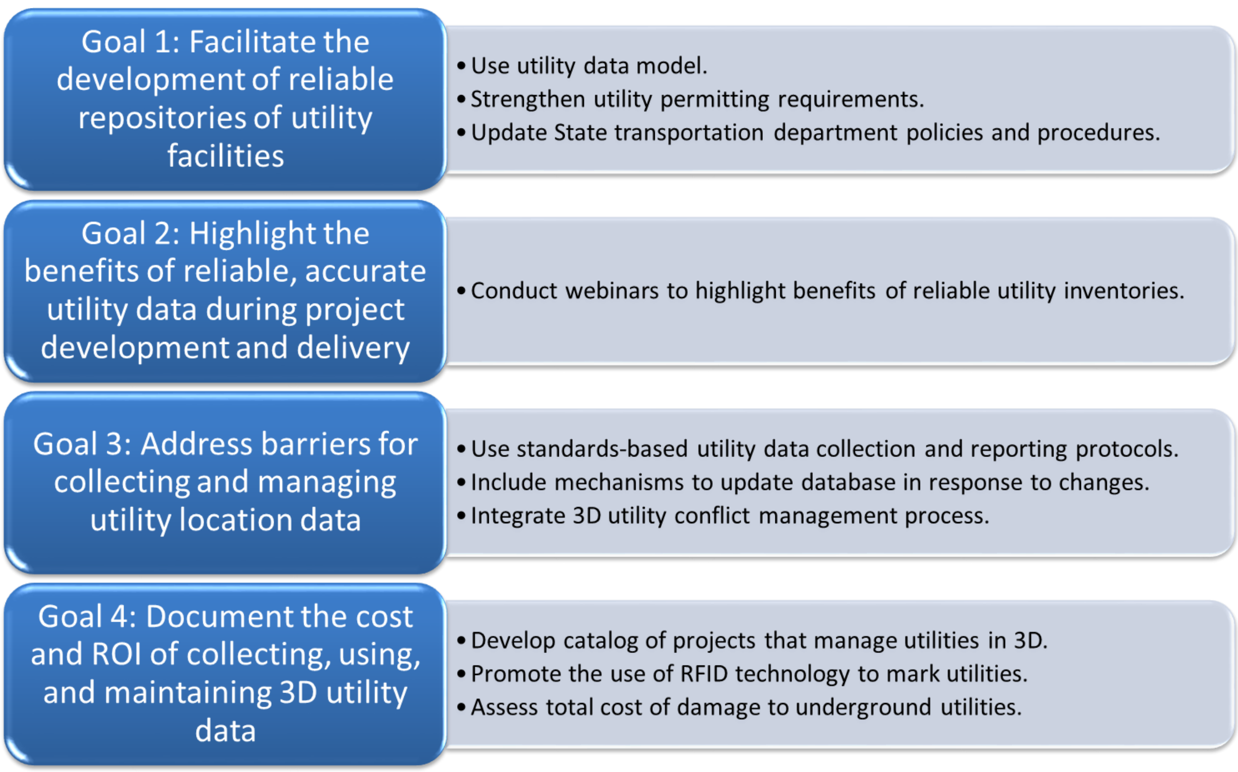
IMPLEMENTATION STRATEGIES

The research outlined 16 implementation strategies, including 10 strategies that are readily implementable and 6 strategies that need additional development or research work. These strategies are grouped according to five main implementation goals, as shown in figure 1 through figure 3. Some strategies could apply to multiple implementation goals.



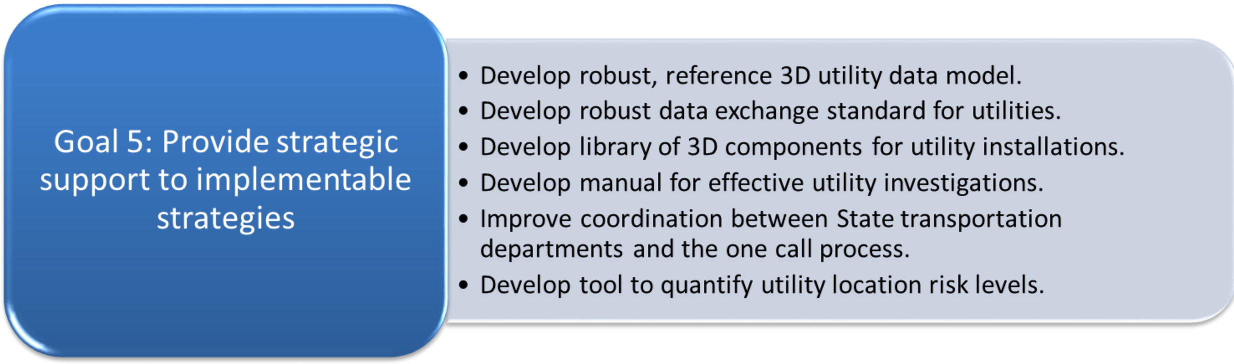
Source: FHWA.

Figure 1. Diagram. Implementation goals.



Source: FHWA.

Figure 2. Diagram. Readily implementable strategies.



Source: FHWA.

Figure 3. Diagram. Strategies that need development or research work.

CHAPTER 1. INTRODUCTION

Two critical factors that contribute to inefficiencies in the management of utility issues on transportation projects are (1) the lack of accurate, complete information about utility facilities that might conflict with the project and (2) the resolution and overall management of those conflicts. These inefficiencies can result in problems, such as the following:

- Disruptions to the construction site when utility installations are encountered unexpectedly, either because there was no previous information about those installations or because their stated location on the construction plans was incorrect. Disruptions could also occur because one-call markings that the contractor relied on during construction were in error or were not visible. In other cases, design plans may have been accurate, but some of the utility information changed during design or construction and was not updated on project plans or in one-call responders' records.

- Damage to utility installations that leads to disruptions in utility service, release of environmentally sensitive liquids and gases, and risks to the health and safety of construction workers and the public.

- Delays that can extend the period of project delivery and increase total project costs through higher bids, change orders and/or damage or delay claims, redesign, and litigation by utility owners or agencies. These delays also result in frustration for the traveling public and negative public perception about the project.

- Unnecessary utility relocations and project delivery inefficiencies that occur because adequate information about existing utility facilities was not available to enable stakeholders to apply alternative utility conflict resolution strategies, such as modifying the transportation project design or protecting existing utility facilities in place.

- Overdesign of structures or facilities because of the need for increased safety factors related to uncertainty in utility facility locations or characteristics.

Historically, research to address utility issues during project delivery has lagged compared with research in other transportation areas. Some utility research has been carried out by State transportation departments or the National Cooperative Highway Research Program (NCHRP). Recently, several utility-related projects received funding through the second Strategic Highway Research Program (SHRP2). Research to improve utility detection techniques has also been funded by the Pipeline and Hazardous Materials Safety Administration (PHMSA). Examples of relevant research topics include detecting utility installations at various depths, populating datasets that include a reliable determination of depths as well as utility condition and character, more effective utility mapping to decrease traffic and safety impacts, combining utility data with geotechnical and environmental data, and providing guidance on what tools would likely produce tangible results.

These research initiatives are a step in the right direction to address critical utility issues during project delivery. However, they are not enough. Barriers that transportation agencies must overcome before collecting and storing utility location data include liability associated with data accuracy, visualization of data reliability and accuracy, long-term storage and maintenance of the electronic data, access to the data, tracking and fusion of new data, and utility owner data security and homeland security issues. These issues are critical in any major transportation project. However, they are even more critical in situations that involve the use of three-dimensional (3D) data, particularly in light of the provisions in the 2012 Moving Ahead for Progress in the 21st Century Act encouraging the use of 3D modeling techniques to accelerate project delivery.[12]

The objective of the research was to document issues associated with State transportation departments asserting their responsibility for managing utility installations within the highway right-of-way, with a focus on the use of 3D techniques to assist in that management. More specifically, the research addressed the following topics:

- Feasibility of having State transportation departments as the central repository of utility data within the State highway right-of-way.
- Potential benefits of having accurate utility data available during the delivery of highway projects.
- Barriers that State transportation departments may encounter in collecting, storing, and maintaining utility location data as well as recommendations on how to overcome these barriers.
- Potential cost to State transportation departments to collect and maintain 3D utility location data, as well as to mark utilities with radio frequency identification (RFID) technology.

This report documents lessons learned during the research and is organized as follows:

- Chapter 1 is this introductory chapter.
- Chapter 2 provides a literature review on the use of 3D technology.
- Chapter 3 describes an outreach effort to State transportation departments and a summary of lessons learned from case studies.
- Chapter 4 summarizes issues, strategies, barriers, and a return on investment (ROI) analysis.
- Chapter 5 provides a literature review and analysis on the use of RFID technology.
- Chapter 6 includes conclusions and recommendations.
- The appendix includes an implementation guidance providing how-to steps and other information for the implementation of 16 strategies that resulted from the research.

CHAPTER 2. LITERATURE REVIEW—USE OF 3D TECHNOLOGY

USE OF 3D TECHNOLOGY DURING PROJECT DELIVERY

Basic Concepts and Terminology

A number of definitions exist for basic 3D modeling concepts. The current practice for developing and delivering transportation projects involves the use of computer-aided design (CAD) software that relies primarily on vector graphics (which use primitives such as points, lines, and curves, as well as shapes or polygons) as opposed to raster images (i.e., based on pixels) to design and build transportation facilities. For consistency with this practice, the following definitions are used in this report:

- **3D modeling**—3D modeling is the process to develop mathematical representations of surfaces or objects that exist in a 3D environment.

- **3D model**—A 3D model is an object in a database that contains 3D data (i.e., X, Y, Z coordinates) and topology (i.e., a structure that connects the points in 3D space using geometric elements such as lines, curves, and curved surfaces). The product of 3D modeling is a 3D model. Just because a file contains 3D data does not mean it contains a 3D model. For example, a light detection and ranging (LIDAR) point cloud without topology is not a 3D model. However, it may be possible to generate a 3D model by interpreting the LIDAR point cloud or by applying algorithms to extract features in vector format.

- **3D computer graphics**—3D computer graphics are graphics that provide a 3D representation of objects for rendering, visualization, and animation. Although 3D computer graphics are sometimes referred to as 3D models, a 3D model is a not a graphic until it is rendered and displayed.

- **3D rendering**—3D rendering is the process to display a 3D model on a two-dimensional (2D) image or surface (e.g., a computer screen) that conveys 3D information to the human brain, typically by using reflection, scattering, and shading techniques.

- **Raster graphics**—Raster graphics are grid or pixel representations of surfaces or objects. Raster images usually do not have topology, and their ability to represent objects depends on grid or pixel resolution. Raster files can be 2D or 3D, depending on the availability of Z data. A 3D raster image is not a 3D model. However, it may be possible to generate a 3D model by interpreting a 3D raster image or by applying algorithms to extract features in vector format.

- **3D imaging**—3D imaging is the process to render a 3D image on a 2D surface.

Common techniques to develop 3D models include the following:

- **Polygonal modeling**—With this technique, a 3D surface is modeled by using polygons (i.e., by connecting line segments through points on the 3D surface). Triangular irregular networks (TINs) are a common example of a polygonal modeling technique. Polygonal models are flexible and can be rendered quickly. However, depending on the situation, they can be inefficient for developing realistic representations of the 3D objects being modeled. For Earth surface modeling, commonly used techniques include TINs and regularly spaced grids. Common terms include digital terrain models (DTMs), which depict the bare surface of the Earth, and digital surface models (DSMs), which represent the Earth's surface and objects on it, including vegetation and cultural features such as roads and buildings. The term digital elevation model is frequently used as a generic term that covers both DTMs and DSMs.

- **Nonuniform rational basis spline (NURBS) modeling**—With this technique, a 3D object is modeled by using control points on the 3D surface, splines (i.e., smooth curves that pass through two or more points), and surfaces that connect points and splines. NURBS modeling is common in 2D and 3D modeling, as well as animation applications. Complex 3D objects frequently require the use of several NURBS surfaces (also called "patches").

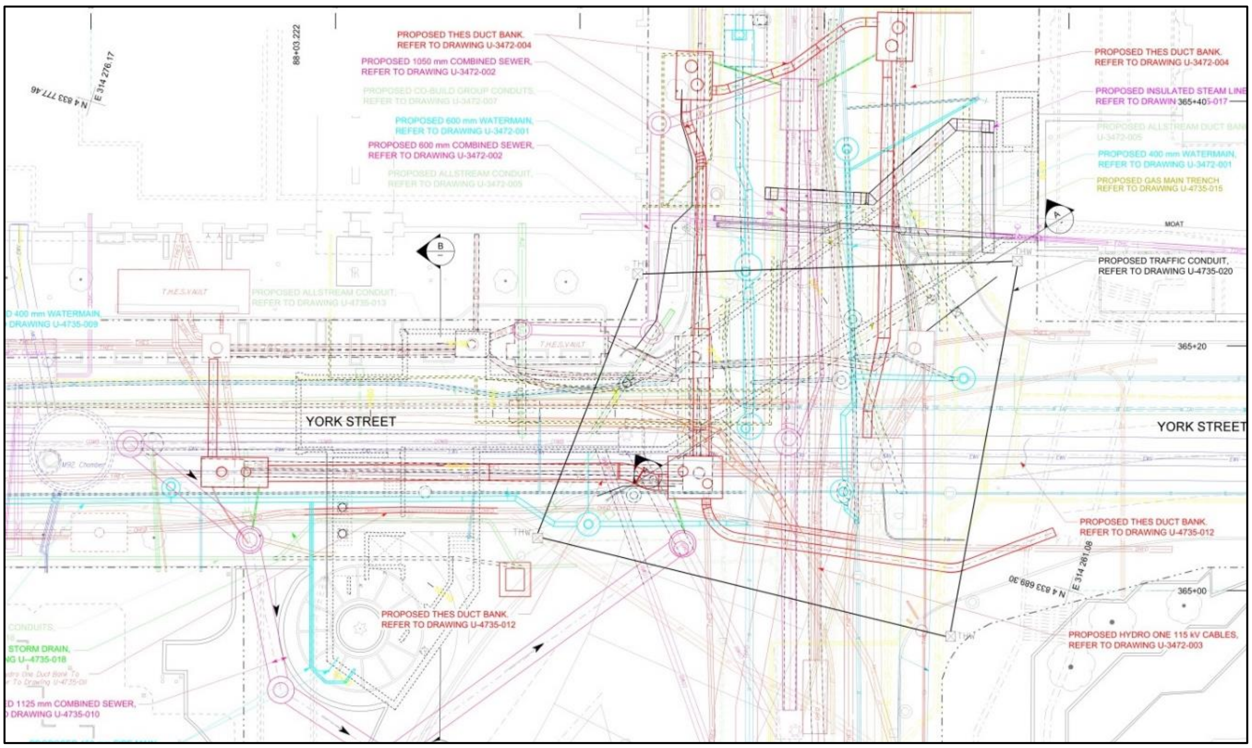
- **Primitive modeling**—With this technique, a 3D object is modeled by using geometric primitives such as cylinders, cones, cubes, and spheres. This method is easily scalable and works well in situations where 3D objects can be defined geometrically with accuracy and precision. However, it is less useful for complex or irregular geometry objects.

In addition to 2D and 3D modeling, it is common to hear about four-dimensional (4D) modeling and, increasingly, five-dimensional (5D) and six-dimensional (6D) modeling. In general, 4D modeling refers to 3D data plus time, where the time component enables the development of views or animations that describe a specific business process (e.g., critical path method scheduling or supply chain management). 5D modeling refers to 3D data plus time and cost. 6D modeling refers to the linkage of 3D data to project lifecycle management data, which is intended to assist owners in the operation and management of a facility throughout its lifecycle.

Building Information Modeling

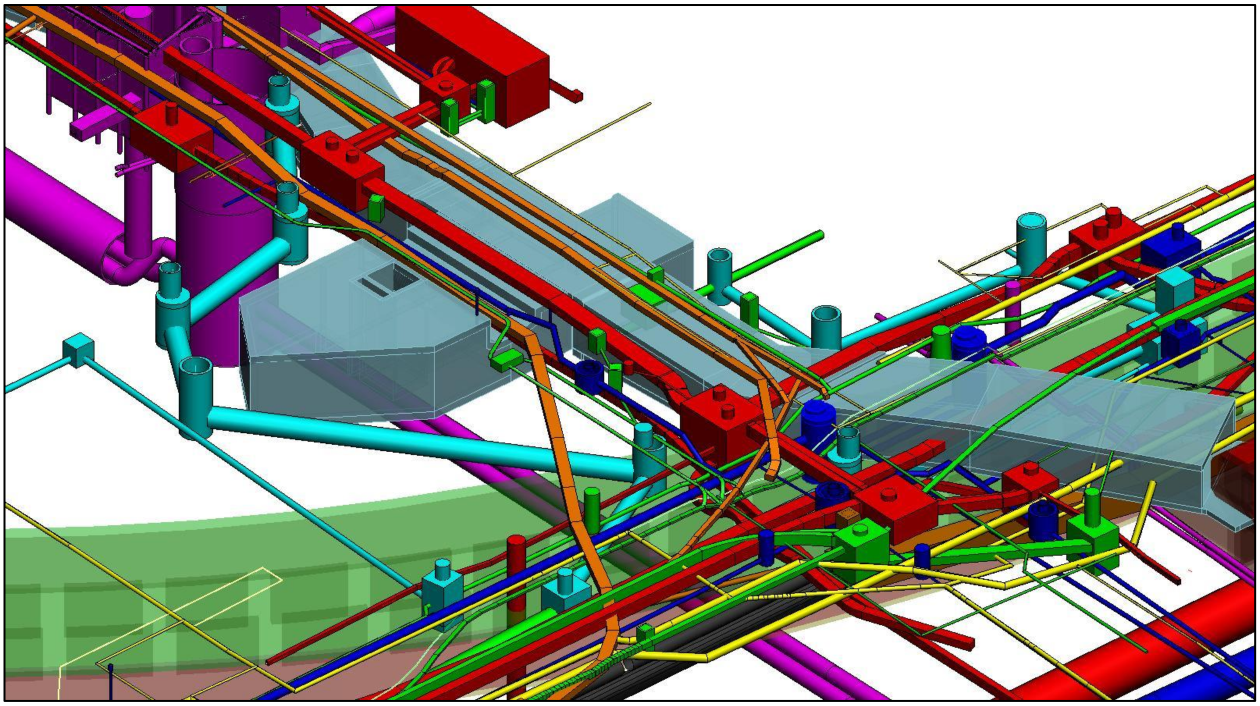
The National Building Information Model Standard Project Committee of the National Institute of Building Sciences defines building information modeling (BIM) as "a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle, defined as existing from earliest conception to demolition."[(13)] As opposed to traditional 3D modeling, BIM involves representing the components of a facility as individual objects that have geometry, attributes, and relationships. In BIM, it is common to define objects in terms of parameters that define the geometry of the object and parameters that define relationships among objects. Full parametric definition facilitates object updates because of the capability to trigger changes to other related objects by following a predefined set of rules. The rules could be simple (e.g., if a wall that has a window is moved, the window moves with the wall) or more complex. Increasingly, BIM is used during design and construction, particularly in the case of vertical construction projects, including support for project scheduling, quantity and cost management and control, and construction supply chain management (e.g., by tracking RFID tags for individual construction components or equipment).

In traditional engineering practice, the project plan-of-record is a set of 2D drawings representing plan views, profiles, and cross sections. These drawings are typically stored and archived on paper, although scanned images and portable document format (PDF) documents are increasingly used. However, 2D drawings have several limitations, including (1) the need for multiple views to depict real-world objects in adequate detail; (2) lack of connectivity between those views and the different elements within the views, making edits more difficult and increasing the risk of errors and redundancy; and (3) difficulty associating attribute data with graphical features. As an illustration, figure 4 and figure 5 provide a comparison between a traditional 2D plan view and the result of developing a 3D model to represent the same set of objects.



Courtesy of Hatch Ltd.

Figure 4. Diagram. 2D plan view of the Northwest PATH Pedestrian Tunnel, Toronto, Canada.



Courtesy of Hatch Ltd.

Figure 5. Diagram. 3D model of the Northwest PATH Pedestrian Tunnel, Toronto, Canada.

Commonly used CAD software can assist in addressing some of these limitations. However, most CAD applications handle objects as disconnected geometric elements that make sense to the human brain only because of the human brain's ability to extract information by recognizing spatial relationships and patterns. As a result, it is common to have CAD files that appear to contain all the necessary information (at least to the naked eye), but a close analysis reveals problems such as overlapping or disconnected graphical elements, inconsistent use of levels or design libraries, or inability to link business process databases to features in the files.

The National CAD Standard, also managed by the National Institute of Building Sciences, provides guidance and outlines general requirements for the preparation of CAD-based deliverables.[(14)] This standard covers topics such as organization of drawing sets, CAD layers, and graphic symbols and conventions.

Using the concept of maturity levels for software applications, which has been in use for years and is now migrating to other areas such as data management, four BIM maturity levels have been proposed in the United Kingdom as a tool to characterize BIM implementations:[(15–17)]

- **Level 0**—Unmanaged CAD (probably 2D) with paper or electronic deliverable as the most likely data exchange mechanism.
- **Level 1**—Managed CAD in 2D or 3D format using an industry CAD standard with a file collaboration tool that provides a common data environment.

- **Level 2**—Managed 3D environment with a file collaboration tool and library management capabilities. This level would enable 4D and 5D capabilities.

- **Level 3**—Fully open process and data integration enabled by Web services that are compliant with emerging Industry Foundation Classes (IFC)/International Framework for Dictionaries standards.

3D Engineered Models and Civil Integrated Management

The Federal Highway Administration (FHWA) is promoting the use of "3D engineered models for construction" (or simply 3D models) through the Every Day Counts (EDC) Program.(18) Focal areas of this initiative include the following:

- **Surveying and scanning**—This area includes topics such as satellite systems, stationary and mobile laser scanning, infrared sensing, low-distortion coordinate systems, projects, and survey control for automated machine guidance (AMG) applications.

- **3D data and design**—This area includes topics such as design visualization, electronic data and CAD, mechanistic analysis, and specifications and standards.

- **Construction and automation**—This area includes topics such as AMG, remote sensing, response analysis, earthwork, paving, and construction and equipment costs.

- **Post-construction and mapping**—This area includes topics such as mapping, intelligent compaction, and lifecycle costs.

To accomplish program goals, FHWA is relying on Web-based training, workshops, webinars, and field demonstrations.

FHWA and three national associations (American Association of State Highway and Transportation Officials (AASHTO), American Road and Transportation Builders Association (ARTBA), and Associated General Contractors of America (AGC)) are promoting the concept of civil integrated management (CIM) as a framework based on emerging technologies to facilitate a fast, efficient, and safe delivery of projects. Within this context, CIM has been defined as the "collection, organization, and managed accessibility to accurate data and information related to a highway facility."(19) Examples of topics in the realm of CIM include the following:

- **Project management systems**—Electronic document approval, transmittal, and storage; online real-time status of materials sampling and testing; electronic wage rate verification; and public relations.

- **Surveying**—LIDAR and laser total stations.

- **Information modeling**—Public outreach; software applications; optimization of construction means and methods; earthwork balancing; equipment automatic guidance control systems; and 3D, 4D, 5D, and higher D modeling.

- **Real-time verification**—Intelligent compaction, pavement thermal imaging, RFID for materials quantity and certification transmittal, in-cab weight scales, and video surveillance for remote construction inspection and recording.

- **Utilities**—3D mapping and data storage and RFID subsurface marking.

- **Legal**—Liability of plan and survey data and long-term liability with as-built information.

FHWA's promotion of 3D engineered models for construction is part of the second group of EDC innovations (also called EDC-2).(20) In 2014, FHWA announced a third group of EDC innovations (also called EDC-3), which include seven innovations in the area of project delivery. Two of these innovations are relevant to this research: 3D models (with a focus on schedule, cost, and post-construction) and e-Construction.(20)

Through the State Transportation Innovation Council (STIC) Incentive Program, FHWA provides funding to help State transportation departments standardize innovative practices.(21) In 2014, FHWA provided funding to 12 3D-related projects at 10 State transportation departments, most of them focusing on the development of standards, specifications, and procedures to support 3D modeling applications for design and construction. As follows, 2 of the 12 funded projects focused specifically on utilities, and a third one could be related to the identification and resolution of utility conflicts:

- **Michigan**—Pilot Application of Geospatial Utility Infrastructure Data Exchange (GUIDE).(22)

- **Utah**—Development of a 3D Utility Database.(23)

- **Alabama**—Development of Procedures and Best Practices for Utilizing 3D Data for Survey, Design, Visualization, and Clash Detection Analysis.(24)

The GUIDE program in Michigan is a joint effort of the Michigan Utility Coordination Committee. This program includes the Michigan Department of Transportation (MDOT), the one-call notification center, three major utility owners, and the contractor's trade association.(22) The goal of the pilot application was to develop a concept and requirements for the collection, presentation, analysis, and management of as-built data identifying the location of permitted utility facilities within the State highway right-of-way. The requirements include positional accuracy (0.16 ft horizontally and 0.33 ft vertically), required observations, and attribute data such as utility type, installation method, feature type, traceability method, and material.

Data Exchange Standards

A significant issue affecting the implementation of 3D applications is data exchange. Over the years, it has been possible to exchange 2D CAD data in formats such as AutoCAD® .dwg format and MicroStation® .dgn format. Several CAD software vendors' products enable users to export proprietary data files in Extensible Markup Language (XML), and some save all data in XML format directly.

The same level of interoperability has not yet translated to the 3D environment, although some attempts at developing XML schemas have been made. Relevant XML development efforts include the following:

- **ifcXML**[25]—IFC is an open, standardized specification for BIM, which is developed and maintained by buildingSMART and is registered as International Organization for Standardization 16739:2013.[26] It was developed to facilitate data exchange among stakeholders involved in the design and construction of buildings. The IFC specification architecture includes four main conceptual layers (domain layer, interoperability layer, core layer, and resource layer) that enable the development of 3D models for building design and construction in a BIM environment. The domain layer contains entity definitions for a large number of components that are typical in a building (e.g., structural elements, plumbing and fire protection, architecture, electrical, ventilation and air conditioning, building controls, and construction management). The interoperability layer contains entity definitions for shared elements in a building, including, but not limited to, services such as water, electrical, and communications. The IFC specification provides limited support for horizontal construction applications.

- **BIMXML**[27]—BIMXML is a standard for describing building data in a simplified spatial data model that uses extruded shapes and areas to facilitate data exchange through Web services. A typical BIMXML document includes four nodes: site, building, floor, and area or space.

- **LandXML**[28]—LandXML is a nonproprietary data exchange format for civil engineering and land surveying applications. LandXML is also supported by a number of machine control systems. LandXML provides support for features such as alignments, monuments, grade, parcels, plan features, pipe networks, roadways, surfaces, and survey data. The current support in LandXML for utility installations is very limited. Pipe network subtypes supported by the standard include sanitary, storm, water, and other. Pipe types include circular, elliptical, and rectangular. Each pipe type includes a basic set of attributes such as diameter, height, width, span, description, friction factor, material, and thickness. Existing 3D CAD platforms (see following 3D Software Platforms section) provide support for LandXML import and export operations, but the degree to which data interoperability across platforms is achievable on a consistent basis is unknown.

- **PipelineML**[29]—In 2014, the Open Geospatial Consortium (OGC) announced establishment of a PipelineML Standards Working Group in conjunction with the Pipeline Open Data Standard Association to develop an XML standard to enable the exchange of pipeline data among parties, systems, and software applications.

In 2005, OGC established a 3D Information Management Domain Working Group to promote the convergence of standards.[30] The group focuses on the development of standards for open interoperability 3D services, best practices, test beds, and partnerships.

Worth mentioning are the following XML development efforts that sometimes appear in connection with data exchange for planning, design, and construction applications:

- **agcXML**[31]—agcXML does not focus directly on BIM but on transactional data such as agreements, schedules, requests for proposals, supplemental instructions, change orders, change directives, submittals, and payment requests.

- **TransXML**[32]—TransXML is the result of NCHRP Project 20-64 in the form of XML schemas for the exchange of transportation data. This project was finalized in 2006. The project focused on four key business areas: survey and roadway design, construction materials, bridge structures, and safety. TransXML was not geared toward the exchange of 3D design or construction data. For the survey and roadway design business area, TransXML includes a subset of LandXML to allow for the exchange of roadway alignment, cross sections, and geometry data. It is not clear why TransXML did not include other LandXML components.

3D Software Platforms

Two CAD software platforms for civil engineering applications are Autodesk® and Bentley®. Most architectural and engineering firms in the United States use Autodesk®, while most State transportation departments use Bentley®. Although some State transportation departments accept Autodesk®-format files, many engineers complete their designs internally in Autodesk® and then convert the files to Bentley® format for submission to the State transportation department.

Relevant Autodesk® software includes AutoCAD®, AutoCAD® Civil 3D®, and Autodesk® Navisworks®.[33–35] AutoCAD® is a basic 2D and 3D modeling environment that provides surface, mesh, and solid modeling tools, as well as parametric drawing capabilities. Civil 3D is part of the Autodesk® Infrastructure Design Suite, which is used for civil engineering applications. It provides support for BIM and includes survey and roadway design tools. Navisworks® enables coordination, construction simulation (including 4D and 5D), and project analysis. One of the tools in Navisworks® enables clash detection for the determination of feature conflicts.

Relevant Bentley® software includes MicroStation®, OpenRoads®, and Bentley® Subsurface Utility Engineering.[36–38] MicroStation® is a basic 2D and 3D modeling environment that provides surface, mesh, and solid modeling tools as well as parametric drawing capabilities. OpenRoads® provides roadway design capabilities, including 3D parametric modeling and design rules. Although OpenRoads® design files operate in a 3D environment, many State transportation departments still produce or require 2D deliverables (i.e., the 2D construction plans). Bentley® Subsurface Utility Engineering provides a framework for developing 3D models of utility features from survey information, CAD and geographic information system (GIS) files.

Typical 3D CAD data capabilities include creating, rendering, and visualizing (including zoom, rotate, view from any angle, layering, navigation, and animation) 3D models. Nowadays, it is also possible to export interactive 3D models to PDF. After generating a 3D PDF file, a PDF reader can then be used to view, rotate, and navigate the 3D model interactively in the PDF file. The PDF reader can also be used to add notes, markups, redlines, and digital signatures.

It is increasingly common for 3D CAD platforms to provide functionality to extract data to produce quantity take-offs (which is important for the production of cost estimates and letting documents) and generate DTMs for design and for AMG applications during construction. Depending on the application, it is also possible to exchange data with project scheduling software.

Increasingly, CAD platforms include GIS capabilities either by including GIS functions within the CAD environment or by supporting file exchange (e.g., importing from or exporting files to commonly used GIS file formats such as Esri®'s shape .shp file format). Most State transportation departments use dedicated GIS software for planning, preliminary engineering, and asset inventories but rarely for design and construction. Interestingly, utility owners and municipalities are increasingly using GIS to develop utility facility inventories.

MANAGEMENT OF UTILITY DATA FOR TRANSPORTATION PROJECTS

A 2001 survey of State transportation departments, highway contractors, design consultants, and other user groups shed light on the most frequent causes of delays in highway projects.[39] Across all categories of respondents, the top five causes of delay mentioned were delays in utility relocations, differing site conditions (utility conflicts), environmental planning delays, permitting issues, and insufficient work effort by the contractor. Responses varied among different stakeholders, highlighting differences in perspective. For example, State transportation departments and contractors listed weather as one of the top causes of delay, but designers listed delays in environmental planning as one of the top causes of project delays. Overall, delays in utility relocations and differing site conditions (utility conflicts) were ranked first or second by all groups.

Two critical factors contributing to inefficiencies in the management of utility issues are (1) the lack of accurate, complete information about utility facilities that might conflict with the project and (2) the resolution and overall management of those conflicts. A number of approaches exist to manage utility conflicts. In the traditional approach, the transportation agency or its consultant coordinates activities with utility owners. However, it is also possible for a local public agency or another jurisdiction to assume utility coordination responsibilities. Likewise, design–build projects increasingly include requirements for the developer to coordinate utility-related activities. Depending on the type of project, type of installation, and other considerations, utility facilities can be relocated on the public right-of-way or be required to find a corridor elsewhere. Utility owners are usually responsible for acquiring their own easements or other property interests when moving their facilities outside the highway right-of-way. Under certain circumstances, some State transportation departments have the authority to acquire property on behalf of utility owners.

Collecting accurate utility data from utility owners can be challenging. Typically, agencies send project drawings to utility owners with a request to mark up those drawings with relevant utility information. In some cases, utility owners request electronic copies of those drawings in CAD format. Sometimes, utility owners provide electronic as-built files. In practice, these files are rarely scaled or georeferenced and follow a variety of formats, making it necessary to convert the files to a usable format and adjust their scale and alignment to match the project files.

State transportation departments normally do not maintain long-term repositories of utility information. Sharing of utility data within a project is also often limited and isolated. Typical examples that reflect current practices include the following:

- Utility lines and appurtenances are commonly depicted on utility maps right after collecting the data. These drawings are typically labeled utility drawings, files, or maps. However, this information is not necessarily shown or referenced on all relevant project design plan views or cross sections. As a result, critical design files frequently lack utility-related information (e.g., in the case of files showing intelligent transportation system (ITS) or signalized intersection infrastructure, noise walls, or structure foundations).

- Utility lines and appurtenances are frequently not included in plans, specifications, and estimates (PS&E), although it is common to include utility certifications in these assemblies listing utility relocations that are still pending.

- Utility installations that are relocated before or during the construction phase (and associated attribute data) do not appear on construction plans, or changes to the operational status of previously documented existing installations are not updated. In addition, if changes are made in the design phase, project task designers might not be aware of them.

In general, project-related information tends to follow paper-era guidelines for document retention. In some cases, State transportation departments have implemented procedures to scan as-built drawings into image files, which could then be stored as PDF file “plan-of-record” repositories. The as-built documents could be based on CAD files or paper drawings that were marked up during construction. Increasingly, State transportation departments are interested in exploring strategies to keep the original CAD files or to, at least, generate PDF files directly from the CAD environment instead of losing the wealth of project data by first generating an image representation of the as-built conditions.

Typical 2D Utility Data Collection Equipment

A variety of geophysical methods are available to detect underground utilities, including electromagnetic induction (EMI) methods, ground penetrating radar (GPR) methods, optical methods, infrared (or thermal) methods, magnetic methods, inertial methods, and elastic wave methods (figure 6 and figure 7). In general, 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. At the same time, no single technology is available to detect utility installations under all conditions. Owing to a range of factors, including variability in soil characteristics and moisture content, as well as utility facility material and other properties, a large toolbox of equipment and techniques is frequently necessary to identify and map utility installations in a reliable, comprehensive manner.

Courtesy of Cardno.

Figure 6. Photo. EMI pipe and cable locator.

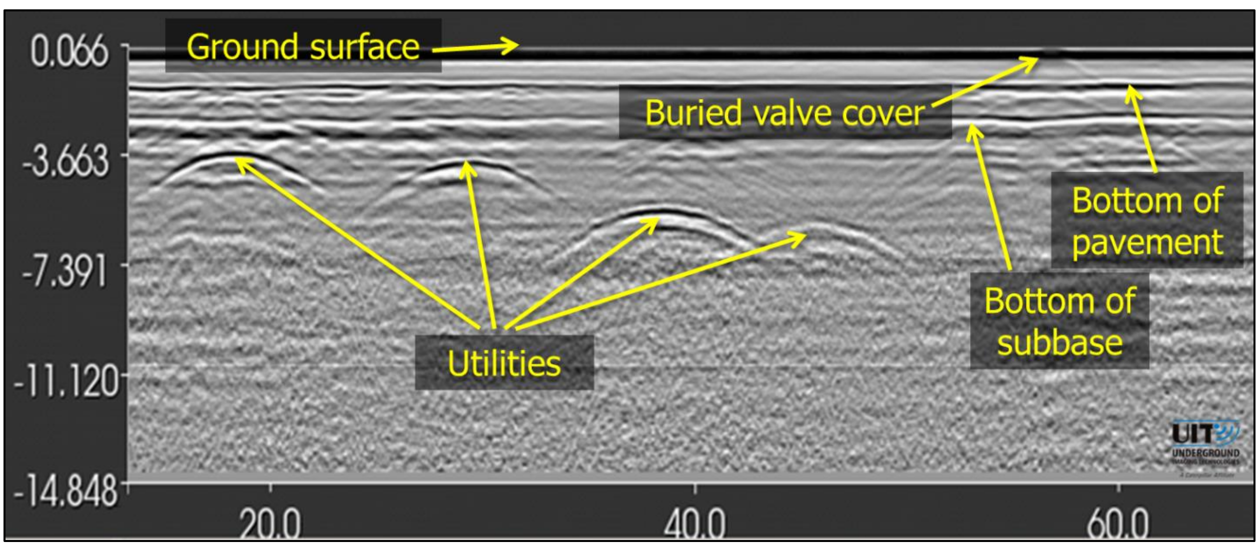
Courtesy of Cardno.

Figure 7. Photo. GPR equipment to detect underground facilities.

EMI typically works by inducing an electrical current along a metal pipe or cable and detecting the resulting magnetic field along the pipe. EMI methods are normally used to detect metal pipes (as well as plastic pipes equipped with metal detection wires or inserted sondes) and changes in rock and soil conductivity caused by drilling, trenching, and other construction operations. A wide range of frequencies (e.g., 50 to 480 kilohertz (kHz)) may be necessary to detect utilities. For example, a deep steel pipeline may need the 8-kHz frequency to find it and the 1-kHz frequency to trace it for any length of distance. However, a relatively shallow cast iron pipe with rubber or other nonmetallic joints might only be found using the high 480-kHz frequency. (However, this practice also increases the risk that the signal might "jump" to another nearby underground facility.)

There are two types of EMI: frequency domain electromagnetic induction (FDEMI) and time domain electromagnetic induction (TDEMI). FDEMI methods include a wide range of pipe and cable locators. TDEMI methods produce eddy currents and then measure the decay rate. As such, they require much higher skill levels. Usually the data cannot be easily interpreted in real-time and require post-processing.

GPR works by beaming a microwave pulse into the ground and measuring reflections received back at the ground surface (figure 8). Microwave frequency (10 to1,000 megahertz (MHz) are common), soil conductivity, and dielectric constants of the encountered molecules are prime factors that affect results. Lower frequencies can penetrate the ground deeper than higher frequencies. However, higher frequencies can resolve smaller size features better than lower frequencies. Highly conductive soils (e.g., those found in marine clays, tidal areas, and northern roadways—where salt is more commonly used for ice melting) and pavements with rebar tend to affect the depth of signal penetration. GPR can detect both metallic and nonmetallic utilities.



Courtesy of Underground Imaging Technologies.

Figure 8. Screen capture. 2D GPR imagery.

A rule of thumb is that, for up to 6 ft of depth and a combination of low conductivity and highly different impedances, it is possible to detect a round utility with a diameter in inches that does not exceed its depth in feet. For example, it would be possible to detect a 5 inch–diameter pipe up to 5 ft deep but not 6 ft deep. Beyond 6 ft, it becomes more difficult to detect pipes of any size. In general, GPR is more effective for detecting medium- to large-diameter pipes than small-diameter pipes or direct-buried cables. GPR can also be a useful tool to detect close-to-the-surface facilities, as well as underground storage tanks, construction debris, depth to bedrock and water table, paving thickness, and geologic features.

In the United States, the Federal Communications Commission limits the amount of power that can be used for GPR systems to prevent interference with other areas of the electromagnetic spectrum. Limiting the amount of power that GPR units are allowed to use decreases their soil penetrating capability to detect underground features. Anecdotal information suggests that GPR is apparently more effective in countries that are not subject to the same power limits as in the United States. (As a reference, in the European community, GPR is considered an "unintentional radiator," and the limitation on emissions is different from that in the United States.) If so, it might be advisable to compare practices to determine whether there are any grounds for potential policy changes that might increase the effectiveness of GPR applications in this country.

One-Call Systems

One-call systems started in the 1970s as a mechanism to prevent damage to underground utility installations by providing excavators with "marked-on-ground" information about utility facilities that might be located within the immediate vicinity of a proposed excavation site. Although systems vary from State to State, laws and regulations typically define membership requirements, purpose and application of system activities, and exemptions. Historically, State transportation departments were typically exempted from the requirement of membership in a one-call notification center. This is changing rapidly as the number of exemptions that State laws allow decreases over time due, in part, to PHMSA regulations that withhold grants to States that provide exemptions to municipalities, State agencies, or their contractors.(40)

Depending on the level of urgency, one-call notification centers often have different categories of job tickets (e.g., routine, priority, or emergency). Although most tickets are associated with imminent excavation activities, survey or design tickets are also possible. Most one-call systems do not allow designers or State transportation departments to call for information during the project design phase. For the few States that allow survey or designer tickets, there are significant shortcomings in getting utility installations marked accurately, comprehensively, and timely. In general, utility owners tend to respond slowly to low-priority survey tickets that originate from State transportation departments. In addition, there is no responsibility for markings to be correct in the case of design tickets, as there is for construction tickets. Another limitation is the search for unknown or out-of-service installations, or for installations whose owner is not a member of the one-call notification center. In other cases, it may be difficult to provide adequate traffic control or access structures within the traveled roadway, limiting the ability to complete the survey or design ticket.

Despite these shortcomings, many State transportation departments and other project owners try to use one-call notification centers to get information about existing utility installations because it is a "free" service to the State transportation departments (paid by ratepayers rather than taxpayers). Although the data provided through the one-call process are typically not accurate or complete enough to make design decisions, the data do provide valuable information about some utility installations at earlier stages of the project development process. However, agencies that rely exclusively on one-call information during project design often experience significant utility issues as projects progress.[41]

One-call notification centers maintain records of underground facilities as provided by their member organizations. Although underground facility owners are encouraged or required to provide up-to-date map information to the notification centers, in practice there is considerable variability in the coverage and quality of the information they provide to the notification centers. Some facility owners provide electronic copies of their facilities, while other facility owners provide only buffer area files. The centers use whatever information is provided to them to identify potentially affected utility installations by overlaying the proposed excavation location provided by callers. Depending on the system architecture, a notification center might use polygons of different shapes and sizes or a rectangular grid to conduct the spatial query.

Utility owners sometimes raise issues such as data security or data confidentiality when discussing the feasibility or need for centralized utility databases. Over time, utility owners in the United States have developed a level of comfort with one-call notification centers. However, as mentioned, they frequently provide "degraded" information to the notification centers (e.g., by providing buffer area maps instead of actual utility installation alignments).

The same level of comfort that utility owners have developed with one-call centers has not yet extended to State transportation departments. A frequent complaint by project designers or utility coordinators is that some utility owners only mark up paper copies of project drawings sent by the State transportation department (i.e., utility owners do not mark up CAD files or send a copy of their files to the State transportation departments).

Conventional Utility Investigation Practices

Until the early 1980s, the primary means of collecting subsurface utility data was through existing records, oral recollections, and invasive excavation using backhoes. The concept of conducting utility investigations using an engineering approach, frequently called subsurface utility engineering (SUE), began in the early 1980s with the combination of data collection techniques such as electromagnetic pipe and cable locators, sondes, magnetometers, elastic wave detectors, terrain conductivity, GPR, vacuum excavation, and professional surveying. The geophysics provided some indication that pipes or cables were present at some undetermined depth, and the nondestructive vacuum excavation uncovered those installations at limited point locations, usually where there was a potential conflict with design elements, so they could be surveyed and tied to the project ground control. In 1985, the Virginia Department of Transportation (VDOT) began using these techniques on projects, and in 1991, FHWA began encouraging State transportation departments throughout the country to use them.

Questions about the completeness and quality of existing underground utility as-built information as well as the potential liability of using this information by project designers prompted the emergence of the national Construction Institute (CI)/American Society of Civil Engineers (ASCE) 38-02 standard guideline.[1] This standard guideline outlines typical activities for conducting utility investigations and describes the following quality level attributes for individual utility features identified depending on the process used to gather and process the data:

- Quality level D (QLD) involves collecting data from existing utility records, verbal accounts, and one-call markings to determine the existence of major active utilities and their approximate locations.

- Quality level C (QLC) involves surveying and plotting visible utility appurtenances (e.g., valve covers, junction boxes, fire hydrants, and manhole covers) and making inferences about underground linear utility facilities that connect those appurtenances.

- Quality level B (QLB) involves the use of surface geophysical methods to determine the existence and approximate horizontal location of subsurface utilities, followed by survey and mapping of those locations. The geophysical methods involve using active or passive signals to detect underground installations and correlating this information with visible objects (QLC) and record data (QLD).

- Quality level A (QLA) involves the determination of accurate horizontal and vertical utility locations by exposing underground utility facilities at certain locations. Typical methods of exposure include air or water vacuum test holes as well as fixed access structures such as manhole, handhole, and valve covers.

For utility data to have one of these quality levels (QLD, QLC, QLB, or QLA), the standard requires the data to meet a set of requirements as described in the standard and be signed and sealed by a registered professional.

Collecting data from existing records, oral recollections, and one-call markings and surveying and plotting visible utility appurtenances is a routine practice at State transportation departments, although certifying the data as QLD or QLC is much less common. These investigations tend to miss a substantial number of underground installations, which is one of the reasons that QLB and QLA investigations become important. QLB and QLA utility investigations have been reported to find 80 to 90 percent of all underground utility installations that are suspected to exist in the area.(42) This level of performance is attainable provided the scope of the investigation includes “sweeping” the entire area rather than simply looking for specific utility facilities, in which case the success rate is likely to be much lower. In another application, QLB investigations identified, on average, 10 to 50 percent more utility installations than investigations at the QLD or QLC level.(8)

QLB utility investigation practices vary substantially across the country and even within the same State. Some agencies collect QLB data routinely, while other agencies collect QLB data sporadically, on a case-by-case basis, or not at all. Exposing underground utility facilities by using test holes is common. However, this method is usually performed on a case-by-case basis at the discretion of the project manager. Agencies frequently use test holes to expose and survey underground utility facilities at critical locations but do not certify the resulting utility facility data as QLA.

The CI/ASCE 38-02 standard guideline identifies typical tasks for project owners, engineers, and constructors to manage risks associated with the collection, depiction, and management of subsurface utility data.(1) This characteristic makes the ASCE guideline consistent with risk-based management approaches. However, the ASCE guideline does not provide a tool to quantify the risk that results from not capturing quality subsurface utility data. In addition, the guideline includes utility coordination during project delivery within the purview of SUE. In practice, most project owners, managers, and engineers associate SUE with utility investigations but not with utility coordination or the resolution of utility conflicts.

Utility investigation deliverables most often assume the form of a 2D CAD file depicting horizontal locations of designated utilities and test holes (figure 9). Test hole data sheets that accompany the CAD file typically include utility facility attributes determined through vacuum excavation of test holes, such as utility type, material, size, depth, and utility elevation (figure 10). Project owners then synthesize these data to their own specifications, which might include developing profiles and/or cross sections at required locations.

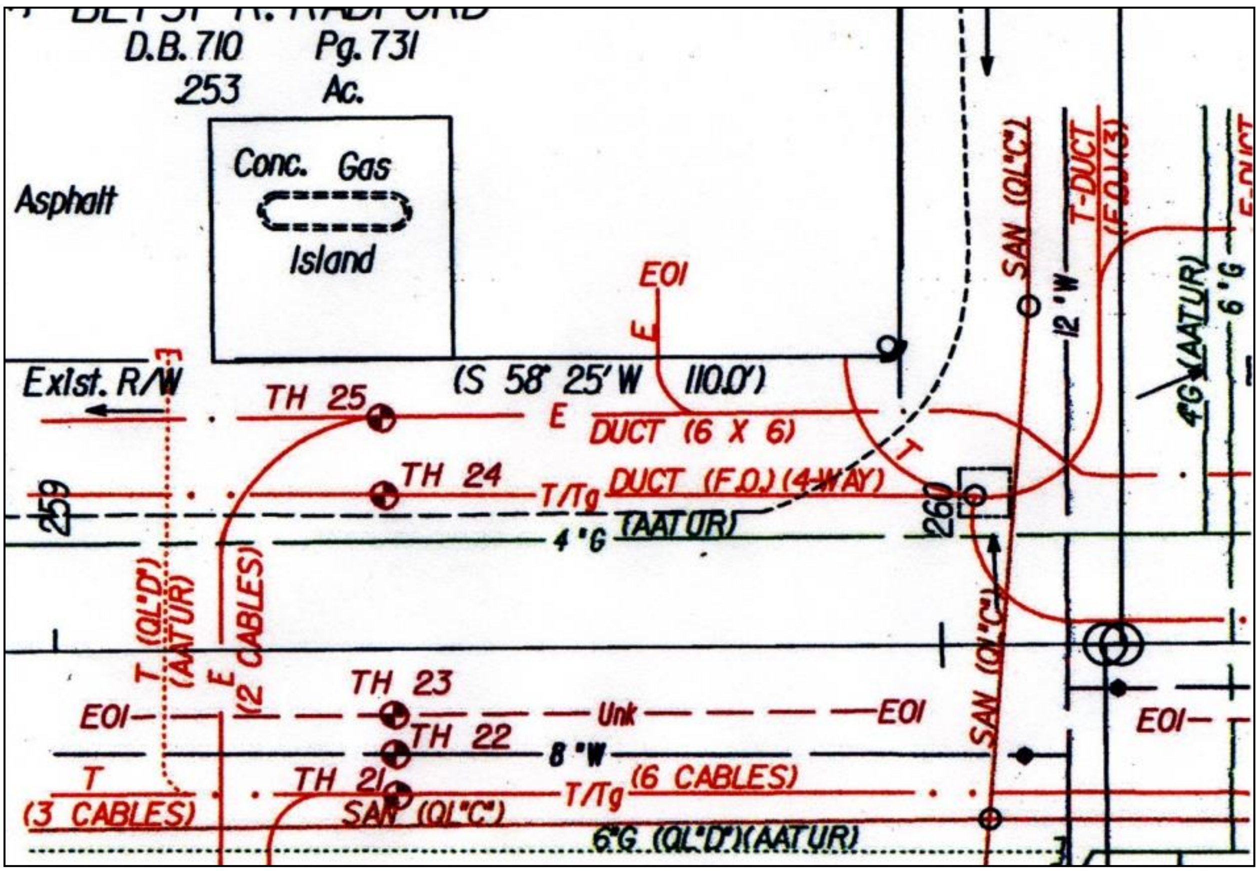


Figure 9. Diagram. Example utility investigation deliverable with identification of test holes.(1)

Test Hole Form

Utility Type		Utility Material	Offset Measured From	Identified By
E	Electrical	1 Steel	30 Edge of Pavement	20 Sleeve
G	Gas Line	2 PVC (Polyvinyl Chloride)	31 Baseline	21 Hub/Lathe
BT	Buried Telephone	3 DIP (Ductile Iron Pipe)	32 Right-of-Way	22 Nail/Disk
FOC	Fiber Optic Cable	4 VCP (Vitrified Clay Pipe)	33 Centerline	23 "X" in Concrete
W	Water	5 PE (Polyethylene Pipe)	34 Back of Curb	24 Set Iron Rod and Cap 5/8"
SAN	Sanitary Sewer	6 AC (Transite)	35 Survey Hub	25
STM	Storm Sewer	7 CI (Cast Iron)	36 "X" in Concrete	26
CATV	Cable TV	8 DBC (Direct Buried Cable)	37 Swing Ties	
FM	Force Main	9 Concrete Pipe	38 Ref. Point in Driveway	
RW	Reclaimed Water	10 Corrugated Metal Pipe	39	
SL	Street Light	11 Duct	**Surface Type**	
TS	Traffic Signal	12 Fiberglass	A Asphalt	
FL	Fuel Line	13 Unknown	C Concrete	
EXP	Exploratory	14 Corrugated Plastic	NG Natural Ground	
UNK	Unknown	15 Concrete Duct		
IRR	Irrigation			

Conflict No.	Test Hole No.	Utility Type	Utility Material	Utility Size (O.D.) in. ☑ mm. ☐	Approx. Station	Approx. Offset Distance ft. ☑ m. ☐ L	R	Offset From	Manual Depth (Top) ft. ☑ m. ☐	Cross Sectional View	Utility Direction (N/S/E/W)	ID'd By	Surface Type	Pvmnt. Thick-ness in. ☑ mm. ☐
C47	27	BE	2	6"	40+00	75.0		31	2.85'	○	↔	22	NG	
C48	28	BE	2	6"	40+00	60.0		31	3.62'	○○○	⤢	22	NG	
C49	29	W	6	12"	40+00	55.0		31	3.96'	◯	⤢	22	NG	
C50	30	G	1	6"	40+00	53.0		31	4.63'	○	⤢	22	NG	
C51	31	BE	2	6"	40+00	50.0		31	3.8'	○	⤢	22	NG	
C52	32	CATV	8	1"	40+00	48.0		31	4.3'	○	⤢	22	NG	
C53	33	BT	8	1"	40+00	44.0		31	4.61'	○	⤢	22	NG	
C58	34	BE	2	6"	38+50	52.0		31	3.65'	○	⤢	22	NG	
C25	35	G	1	6"	39+75	102.0		31	4.25'		⤡	22	NG	
C26	36	BT	2	4"	39+75	102.0		31	3.66'		⤡	22	NG	
C27	37	BE	2	6"	39+85	95.0		31	3.82'		↔	22	NG	

Notes: ______

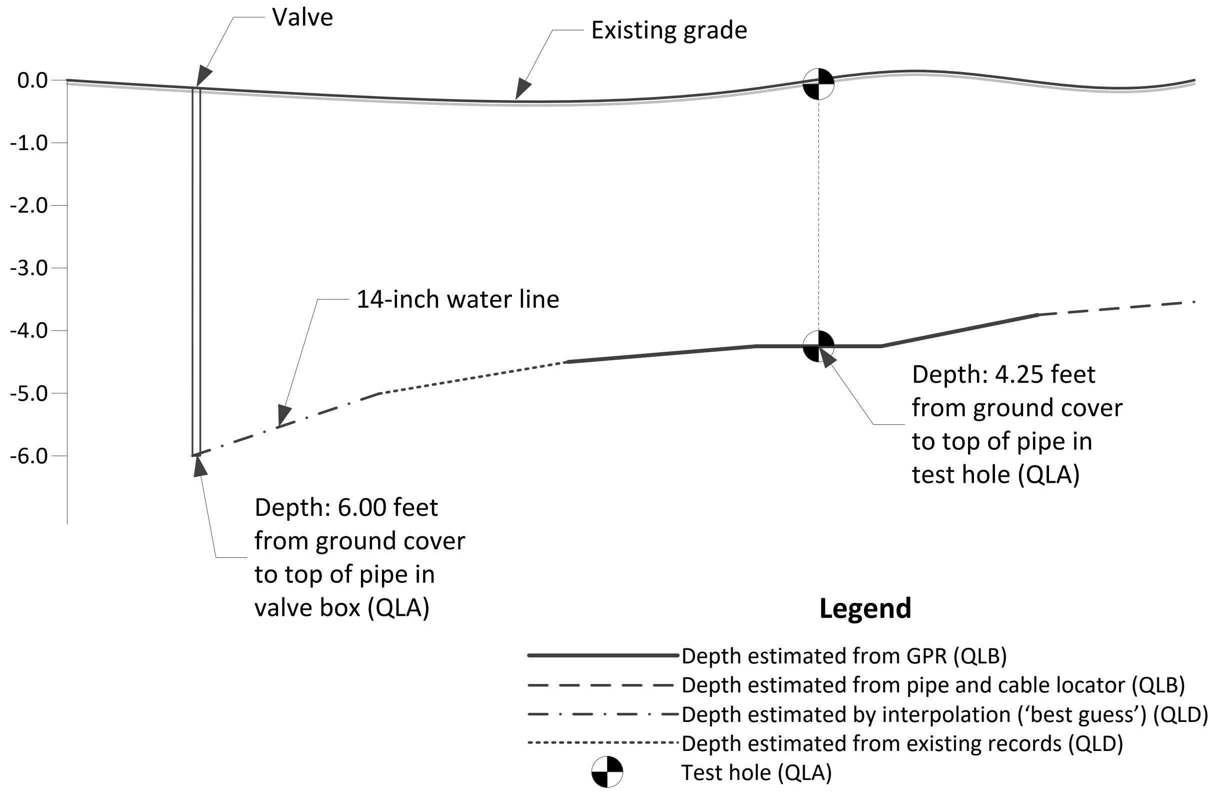
Sheet 1 of 1 Prepared By: VL Date: 10/13/06 Checked By: RMP Date: 10/14/06

Courtesy of TTI; adapted from an image provided by Cardno.

Figure 10. Screen capture. Example test hole summary report.

Alternate deliverables might include the delivery of a CAD file that includes X, Y, Z locations along the path of the designated utility facility and at test hole locations. The X, Y, Z locations along the route of the designated utility facility reflect the 3D position of the ground surface above the designated utility (i.e., the projected utility feature on the ground surface), while the X, Y, Z information at test holes generally reflects the 3D location of the top center of the exposed utility facility. Because of inherent errors in electronic depth estimates, whether they originate from pipe and cable locators or GPR, electronic depth estimates usually are not provided as part of the deliverables. In addition, utility facility elevations between test holes are not estimated, calculated, or interpolated in deliverables. By extension, 3D utility models are not created or delivered to clients. The delivery of 3D models is normally confined to aboveground attributes as part of a DTM. There is also a higher cost for collecting and documenting Z data, making project owners more reluctant to the possibility of committing resources to obtain that information.

Occasionally, profiles are developed that combine depth information from different sources (figure 11). This type of information will be an increasingly important function of 3D mapping going forward so that there is some indication of where the depth information originates.



Courtesy of TTI.

Figure 11. Diagram. Profile view for individual utility installation.

The literature includes documentation on the improvement in utility data completeness and accuracy by conducting QLB and QLA utility investigations.[8,42] However, it is still common not to recognize (1) the inability of existing utility records and utility-provided one-call markings to provide data of acceptable quality for design purposes and (2) the benefits of accurate and comprehensive utility mapping on project delivery.[43] One of the reasons is the lack of tools that provide information about these benefits as well as the risks agencies assume by not pursuing more detailed utility investigations. A clear indication of this need is the result of a recent survey in Texas, which reported that more than half of State transportation department officials contacted were not able to provide an approximate ROI for QLB and QLA investigations.[44]

Because of the variability in job site characteristics and project requirements, it is difficult to provide a generalized estimate of the cost to conduct utility investigations. A rule of thumb is to assume 1 percent of the total project design and construction cost (or 10 percent of the total design cost) for gathering QLB data throughout the project and QLA data in sufficient locations to identify important utility conflicts.[1] There could be significant variations from these percentages for actual projects. For example, a study in the late 1990s reported 2 percent as the overall utility investigation budget with respect to the total State engineering and construction budget in North Carolina.[8] Similarly, for 10 Pennsylvania Department of Transportation (PennDOT) projects analyzed in the mid-2000s, the cost to collect QLB and QLA data was 0.22 to 2.8 percent of the total project design and construction cost.[9]

According to information provided by North Carolina Department of Transportation (NCDOT) officials in 2013 (see chapter 3), a review of utility investigation costs yielded an average cost of $0.77 to $1.60 per linear foot of mapped utility feature for QLB investigations and $602 to $1,229 per test hole for QLA investigations. These costs did not include mobilization costs. Test holes deeper than 6 ft involved an additional cost per additional foot of depth.

ROI of utility investigations frequently cited in the literature include the following:

- **4.62:1 (Purdue University study)[8]**—The researchers found an average of $4.62 in savings for every dollar spent on QLB and QLA utility investigations based on data from 71 projects from North Carolina, Ohio, Texas, and Virginia. Average ROI values in States included $6.63 in North Carolina, $5.21 in Ohio, and $4.27 in Texas. (Note: The report did not include the average ROI in Virginia.) The research reported positive ROI values in all projects but three. The methodology included only cost data that the researchers could estimate with some degree of certainty (e.g., the cost of the utility investigations and the cost to resolve utility conflicts) as well as data that were available from existing documentation, such as change orders and utility-related delay information.

- **22:1 (PennDOT study)[9]**—The researchers identified average savings of $22 for every dollar spent on utility investigations based on data from 10 projects. The range was $3.25 to $33.

- **3.42:1 (Ontario, Canada study)[10]**—This study involved the review of nine case studies with projects valued at more than $500,000 and having a large number of underground utility facilities. The case studies included interviews with project owners and contractors, studies of project drawings, and comparisons of utility information before and after conducting the utility investigations. The case studies suggested an average ROI of $3.41 for each $1 spent on utility investigations with a range from $1.98 to $6.59.

Assuming, for simplicity, an ROI of 4:1 (which could be higher based on the trends described above) and that 1 percent of the total project design and construction cost is spent on a utility investigation at QLB for the entire project and QLA at strategic or critical locations, the result would be a savings of about 4 percent of the total project cost.

Despite the variability in ROI values and the uncertainty associated with the data collection and analysis methodology, all previous studies suggest highly positive ROIs. However, even with these positive indicators, there is no consensus among project managers and designers on the benefits or need to conduct utility investigations for specific projects beyond the traditional review of existing records and survey of visible appurtenances. One of the reasons is the lack of hard data documenting benefits under a variety of project types and local conditions. Another reason is the lack of ownership in the final product (because of the handoff that usually takes place when a transportation project progresses from design to construction). A third reason is the perception that utility installations are a utility owner problem, and public money should not be used to address them. A fourth reason is the lack of training opportunities and a standardized prequalification process for technicians and engineers responsible for conducting utility investigations.

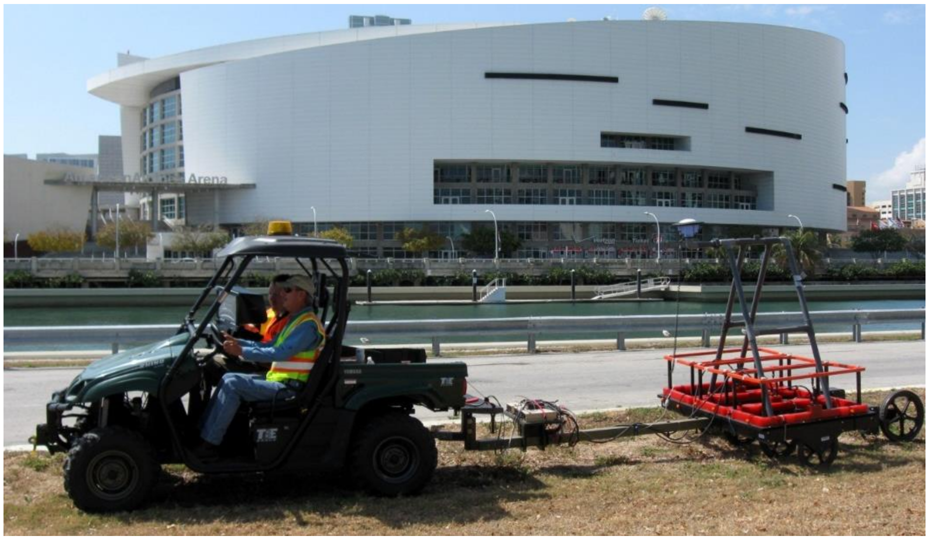
3D Utility Investigations

In recent years, GPR and EMI arrays have generated considerable interest because of their capability to produce 3D imagery that enables the identification of both horizontal and vertical positions of underground installations. This type of technology is sometimes referred to as "advanced geophysics." An early application of this type of technology was a GPR array developed in the late 1990s, later commercialized as a "computer-assisted radar tomography."[45] In the early 2000s, the Research and Special Programs Administration (later abolished and integrated into PHMSA) provided funding for a research project to evaluate the feasibility of a dual array that included an array of EMI sensors to complement the GPR array.[45]

A GPR or EMI array works through the simultaneous use of multiple sensors and data channels assembled in a single mobile cart, typically 4 to 7 ft wide (figure 12 and figure 13). To provide a georeference to the data, it is common for array units to have Global Positioning System (GPS) receivers (with or without real-time kinematics differential correction capabilities) or laser transmitters that work in conjunction with stationary theodolites (useful in situations where limited sky visibility is not adequate for satisfactory GPS reception).

Courtesy of Cardno.

Figure 12. Photo. GPR array.



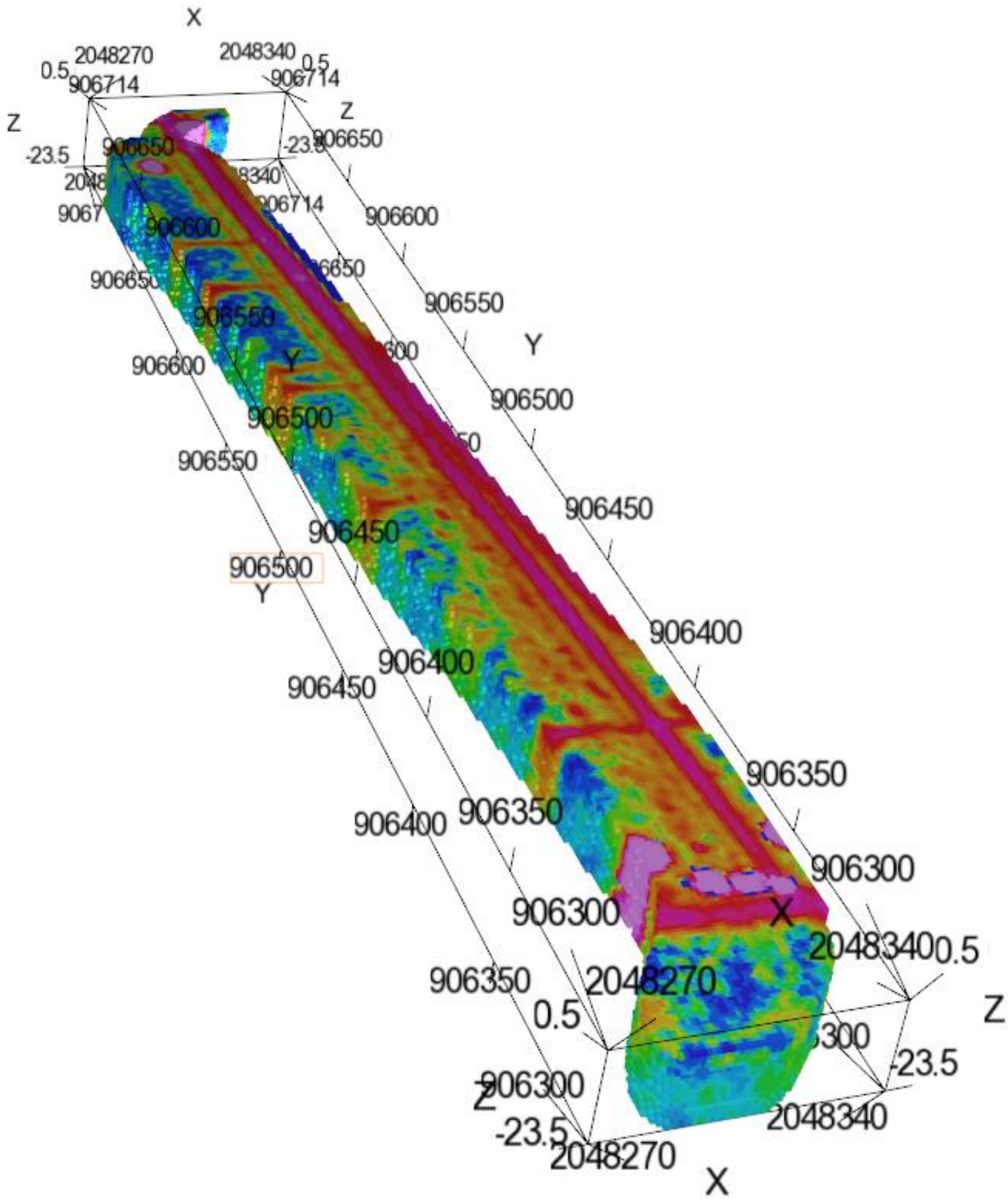
Courtesy of Cardno.

Figure 13. Photo. EMI array.

In general, operators follow a complex process that involves interpreting the 3D imagery and matching elements or patterns within the imagery to existing as-built documents or other records. This process enables the construction of virtual installations that show elements such as size and configuration of duct banks and other features, which are generally not resolvable in the geophysical data on their own. Special-purpose software is used to receive, process, and convert the signal data to 3D georeferenced images. In general, vendors use proprietary image processing software. Some vendors also use commercial software such as Golden Software®'s Surfer® or Hydesoft Computing®'s Dplot® to perform additional tasks (e.g., to provide shading and other 3D visualization effects).[46,47] In some applications, this process also includes generating 3D vector models that can be used for visualization or for design purposes.

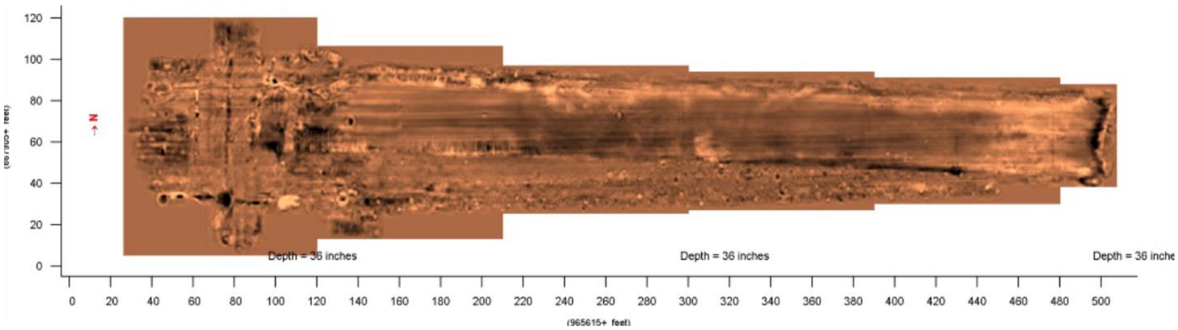
Figure 14 through figure 21 provide samples that illustrate some of the capabilities of the current technology and software. In general, a consensus has emerged that GPR and EMI arrays complement rather than replace conventional utility investigations, with 3D imagery providing a backbone for developing 3D deliverables but with all suitable data collection methods contributing to a more reliable deliverable than what would be possible with each method independently. For example, some installations might be found with EMI locators, but not with a GPR array. In other cases, it might be the opposite. Likewise, the depth obtained with either EMI locators or GPR array might be significantly different from the depth measured at test holes, but in other cases, depths obtained with a GPR array might be almost identical to those measured at test holes.

According to anecdotal information provided by a consultant, GPR arrays have reduced that consultant's need for test holes by up to 90 percent. Although this result is not typical, it highlights one of the main benefits of using advanced geophysics to support utility investigations. The same consultant indicated that it pre-scans locations with 2D radar randomly to make sure the area is favorable.



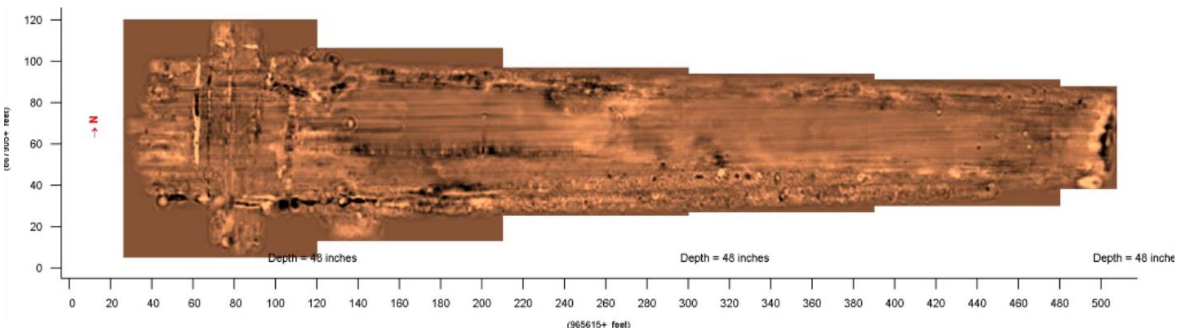
Courtesy of Underground Imaging Technologies.
Note: A 3D PDF file enables different interactive views within the file.

Figure 14. Screen capture. 3D imagery from TDEMI data collection.



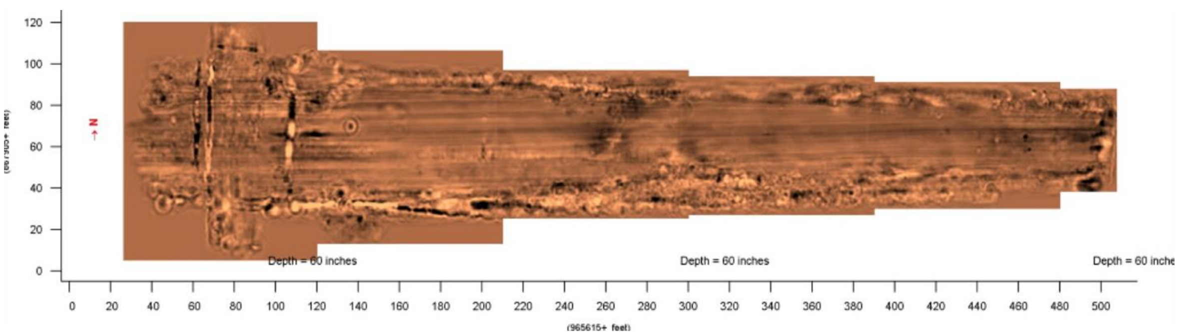
Courtesy of Craig A. Smith and Associates.

Figure 15. Screen capture. 2D imagery from GPR array at 36 inches.



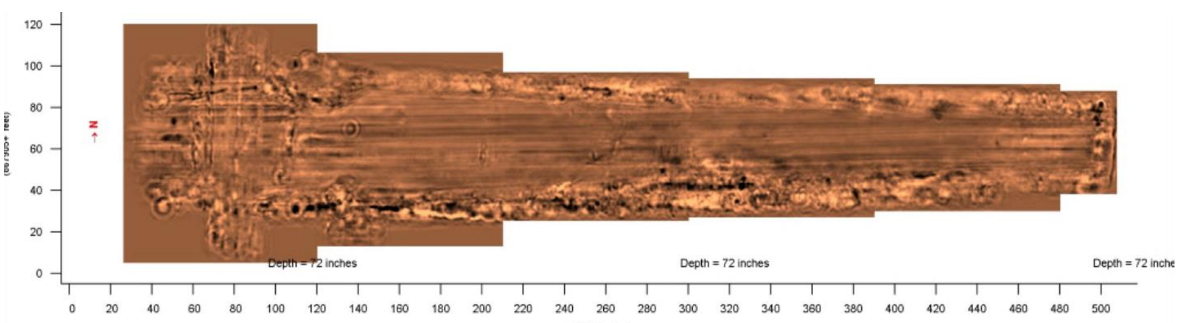
Courtesy of Craig A. Smith and Associates.

Figure 16. Screen capture. 2D imagery from GPR array at 48 inches.



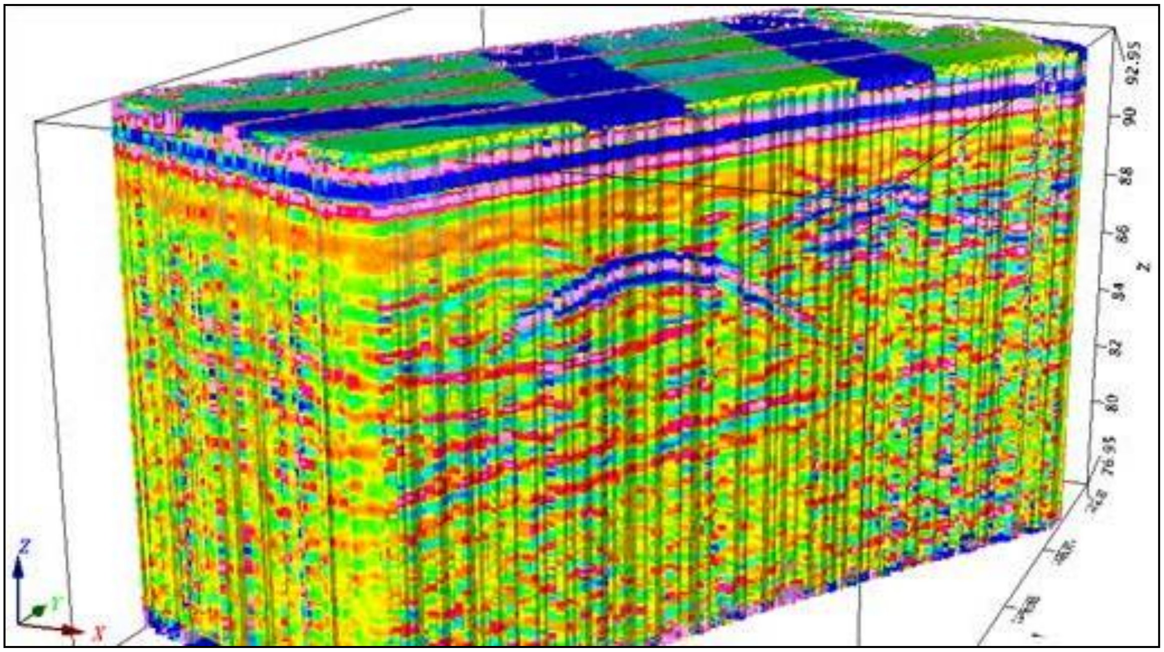
Courtesy of Craig A. Smith and Associates.

Figure 17. Screen capture. 2D imagery from GPR array at 60 inches.



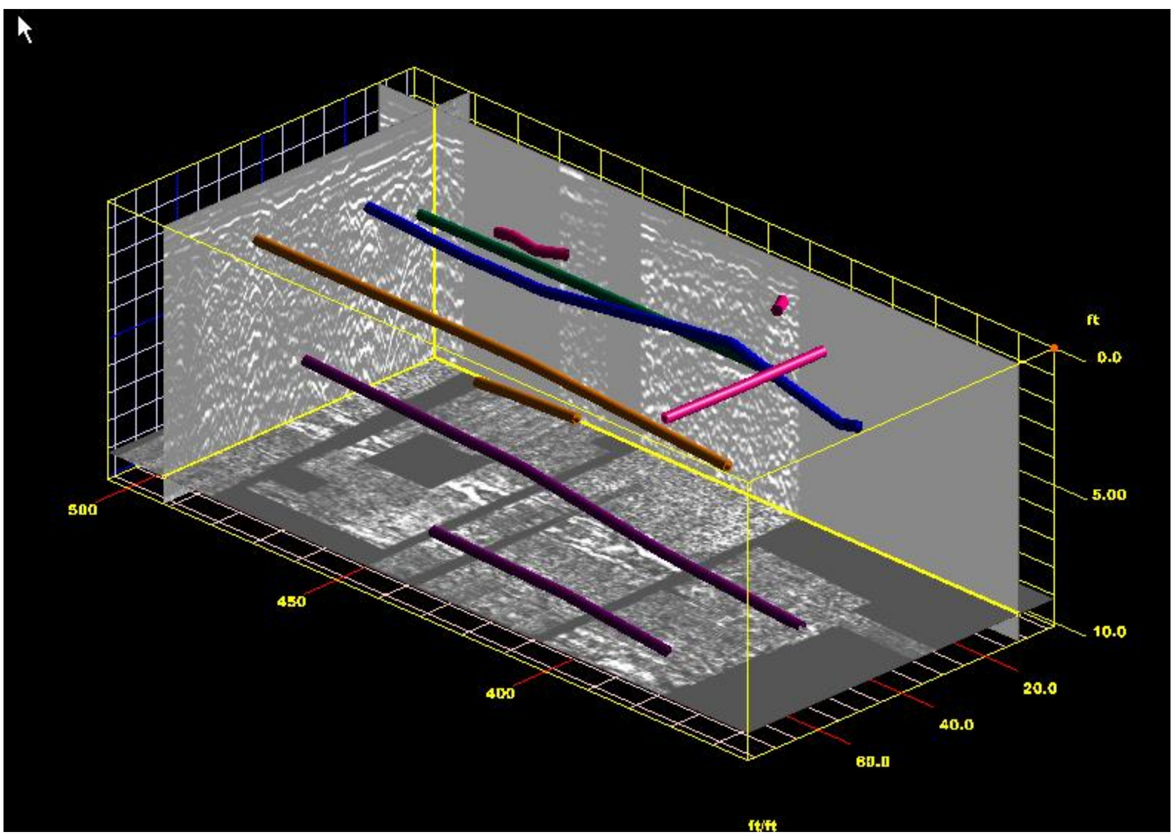
Courtesy of Craig A. Smith and Associates.

Figure 18. Screen capture. 2D imagery from GPR array at 72 inches.



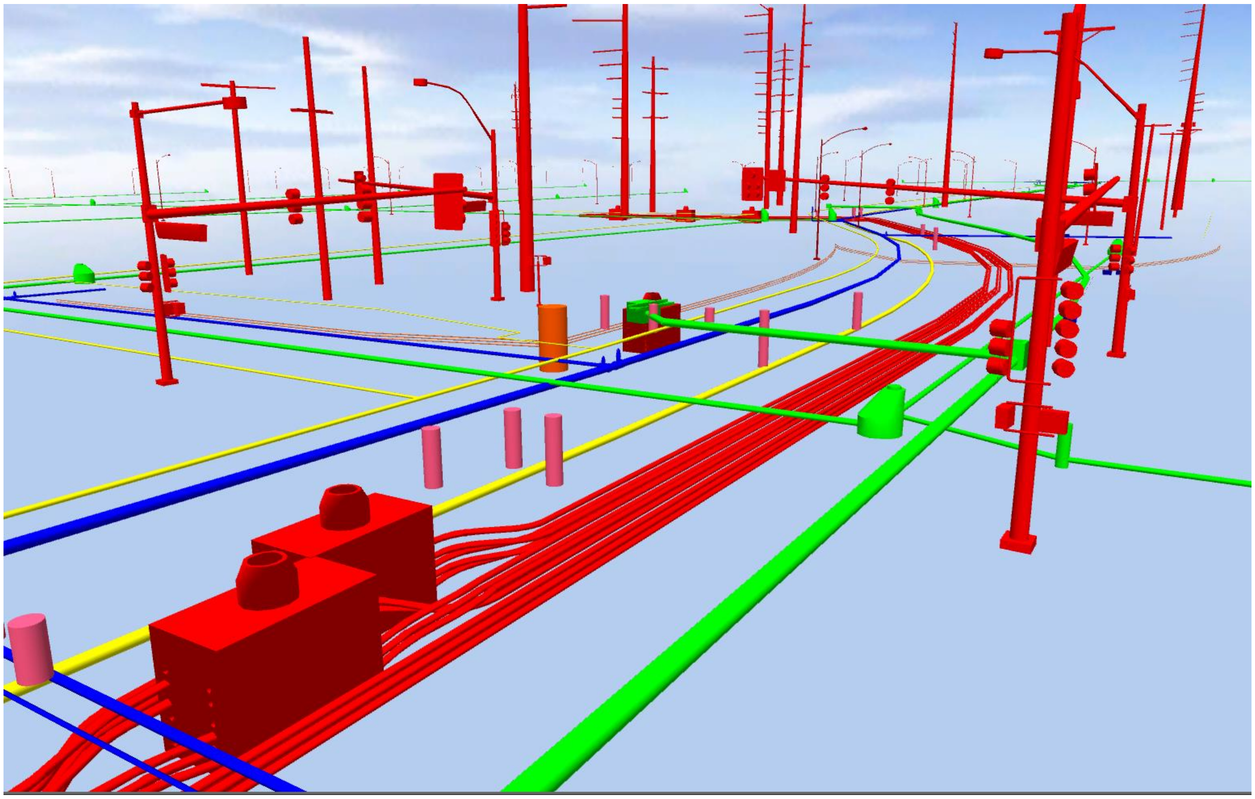
Courtesy of Underground Imaging Technologies.

Figure 19. Screen capture. 3D imagery from GPR array data collection.



Courtesy of Underground Imaging Technologies.

Figure 20. Screen capture. 3D imagery from GPR data with interpreted pipe locations.



Courtesy of VTN and Underground Imaging Technologies.

Figure 21. Screen capture. 3D models generated from 3D geophysical survey and other data sources.

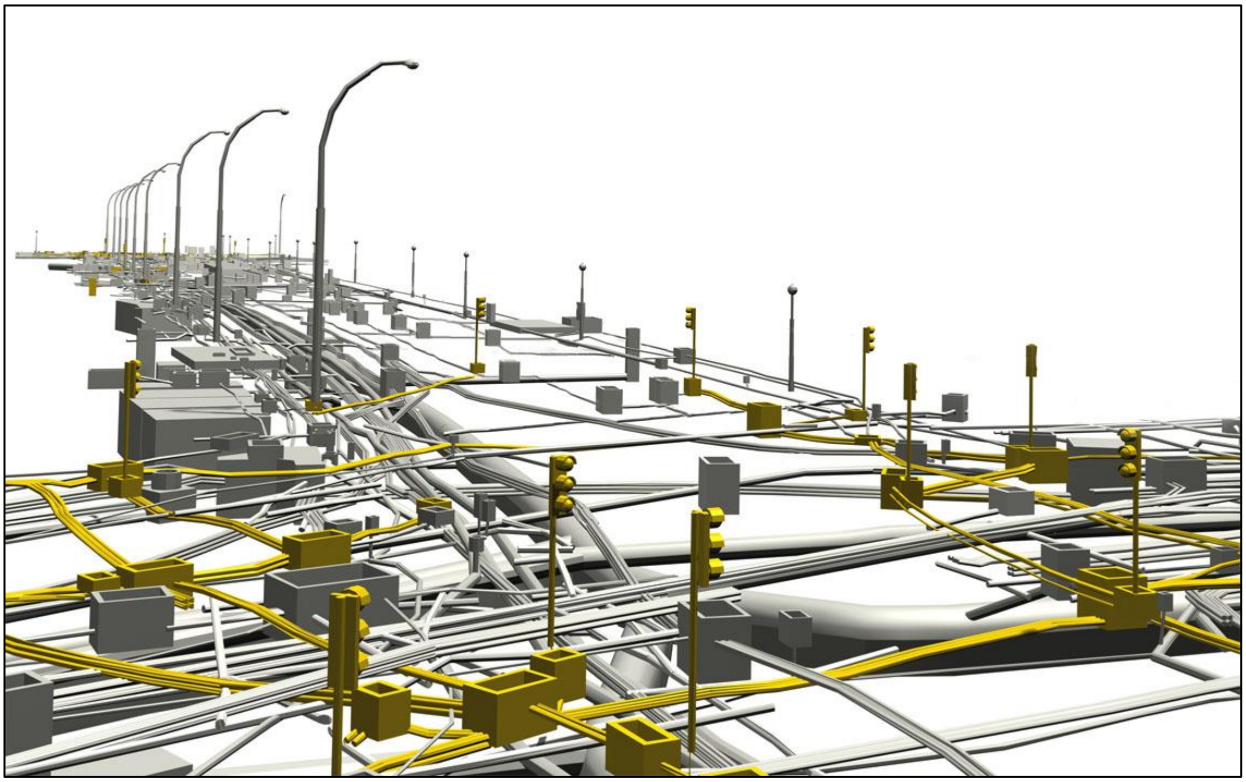
3D data collection and image processing tools increasingly provide the capability to generate vertex points and line work in 3D (and sometimes shapes such as pipes). The technology is not at the point yet to enable a reliable, consistent measurement of pipe diameters (or sometimes depth). The technology also requires substantial intervention and image manipulation by a knowledgeable operator. These are reasons that the typical output of this process is still 2D CAD files. (Another reason is that project owners typically request 2D CAD deliverables.)

Using GPR or EMI arrays adds to the cost of conducting utility investigations. Unfortunately, there are no reliable statistics on the cost of using advanced geophysics. One of the reasons for the lack of reliable statistics is the tendency to use these techniques to map utilities at specific "high-stakes" locations characterized by particularly complex utility infrastructure, which makes each application unique, and it is, therefore, difficult to develop typical estimates of the cost per linear foot of utilities mapped in relation to the larger utility mapping effort for the entire project.

To illustrate this point, consider a hypothetical four-legged intersection in an urbanized area, assuming 200 ft/approach. According to anecdotal information provided by a consultant who specializes in utility investigations, a ballpark estimate for a conventional utility investigation requiring QLB and QLA could be $50,000 to $70,000. For the same location, the cost of using GPR or EMI arrays could be $30,000 to $50,000, depending on local conditions (i.e., from 42 to 100 percent of the conventional utility investigation cost). However, if the utility mapping effort is for a corridor improvement project covering five signalized intersections, only one of which requires the use of GPR or EMI arrays, the relative increase in cost by using advanced geophysics would be 8 to 20 percent of the conventional utility investigation cost.

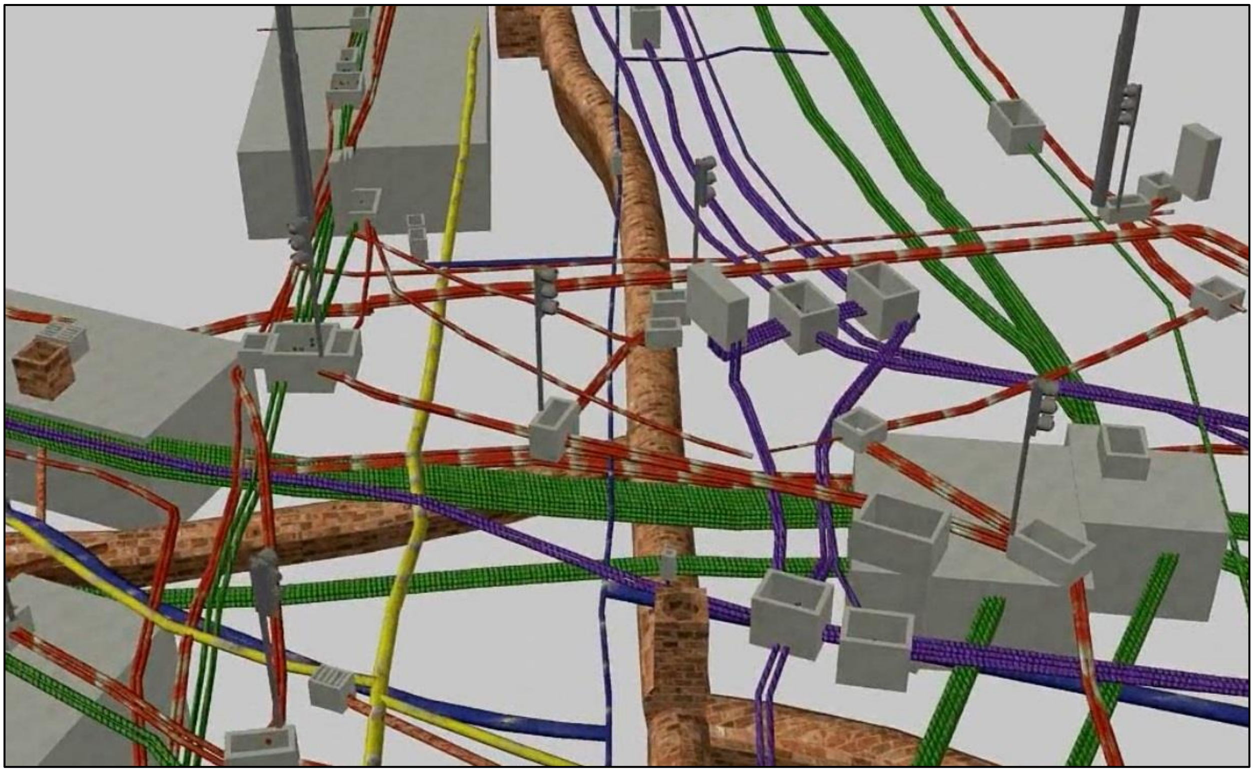
3D Utility Investigations in Europe

Anecdotal information suggests that 3D utility investigations are more common in Europe than in the United States. For many projects, it is relatively common to represent utility data in 3D throughout the entire project limits. As an illustration, figure 22 and figure 23 show sample visualizations of the 3D model of existing utility installations for a construction project as part of the Luas light rail system in Dublin, Ireland. The visualization includes a wide range of aboveground and underground facilities, including public lighting and traffic signal infrastructure.



Courtesy of TST Engineering.

Figure 22. Screen capture. 3D visualization of existing aboveground and underground infrastructure for the Luas light rail transit system in Dublin, Ireland (part 1).



Courtesy of TST Engineering.

Figure 23. Screen capture. 3D visualization of existing aboveground and underground infrastructure for the Luas light rail transit system in Dublin, Ireland (part 2).

In Europe, surface geophysical methods are frequently considered adequate for the production of fairly or sufficiently accurate X, Y, Z data for design purposes. Although there is data verification at critical locations, it is usually a requirement to provide depth information from GPR and EMI instruments. One of the reasons for this type of requirement is that the high concentration of access points (e.g., manholes or vaults) in urban environments in Europe facilitates the correction and calibration of GPR and EMI instruments, thereby increasing the reliability of the electronic depth estimate readings. Another reason is related to installation techniques, which frequently keep utility facilities at a constant depth or grade (e.g., in the case of gravity sewers). In general, a utility facility is represented by a 3D polyline with X, Y, Z attributes at every vertex. The X, Y, Z data represent the crown of the buried utility facility as determined by surface geophysical instruments and/or physical exposure.

Because the typical requirement is to provide a 3D model, the procedure to prepare the 3D model has a direct impact on the quality of the information delivered. Ideally, electronic depth estimates should be verified throughout the entire project to confirm the quality of the data. Depth estimates may be the result of merging several datasets, including GPR data post-processing, reading of electronic depth estimates generated by EMI instruments, visual inspection of utility accessible points, and data from test holes. It is important to know the source of the data collected in the field because depth measurements are usually to the top of the structure (from GPR devices), to the middle of the structure (from pipe and cable locators), and to the invert of the pipe (from sondes). Preparing a 3D CAD model may also require interpolating depth values between known points. If the known values used for the interpolation are of acceptable quality and recorded at short distances, it is likely that the interpolation will generate depth estimates that are close to the actual depth of the utility installation.

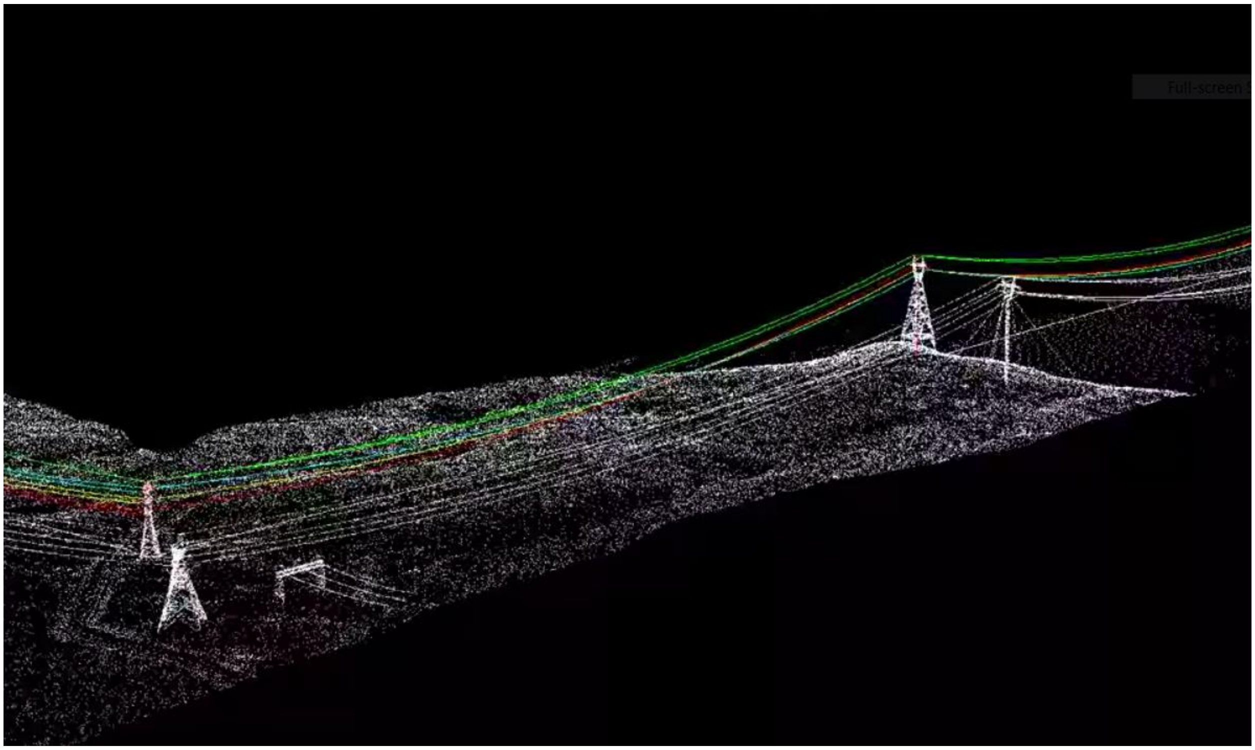
A 0.5-ft vertical variation with respect to the actual utility facility elevation is usually considered adequate in most projects, especially in the case of extensive areas that can be verified and confirmed at the most critical locations. However, this accuracy is not always possible. Depending on the availability of records or correlating data indicating the size of the utility, detection equipment, soil characteristics, and other factors, variations could be much larger than 0.5 ft, which highly trained operators must be able to recognize and interpret properly.

Use of LIDAR for Developing Inventories of Utility Facilities

Current use of LIDAR for documenting utility facilities is very limited but evolving. Typical LIDAR applications include the determination of minimum right-of-way widths during project planning, determination of erosion problems near existing utility structures, and locating right-of-way restrictions, such as streams and fences, and right-of-way encroachments, such as construction sites, recreational facilities, and debris. The utility industry also uses LIDAR for other applications such as vegetation management and asset inspection (e.g., for the assessment of damaged cross arms and braces, as well as broken or missing guy wires and anchors).

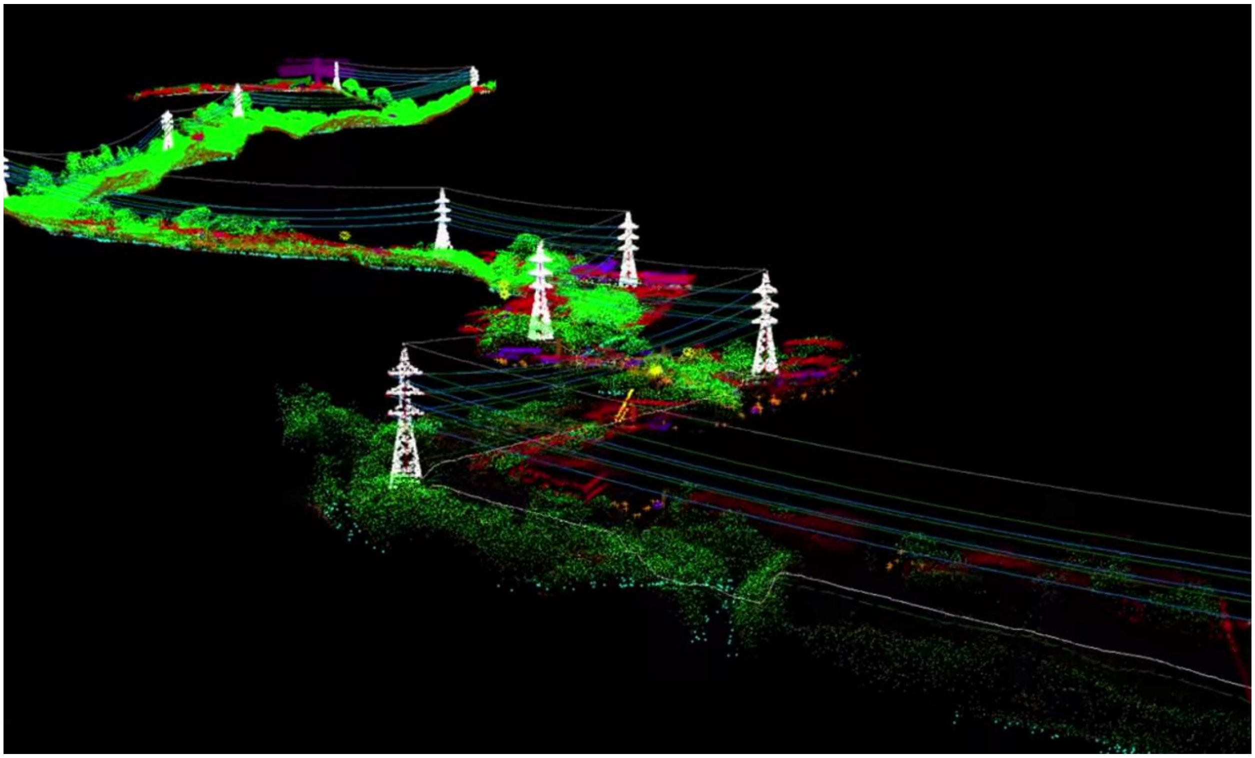
LIDAR is increasingly used to map the horizontal and vertical alignments of aerial cables (e.g., in the case of electric transmission lines). Depending on the application, data collection methods might include ground-based (mobile or stationary) or airborne. Positional accuracy varies as a function of the type of LIDAR equipment used, as well as the GPS receiver used for positioning.

The typical raw output of LIDAR is in form of a point cloud that must be converted using a data processor so it can be used for other applications (figure 24). As in the case of underground 3D utility data processing, image processing supplemented by information from other sources enables the production of information products that can be used for visualization and other applications (figure 25). It is also increasingly used to generate 3D vector models.



Courtesy of WIRE Services.

Figure 24. Screen capture. Partially unclassified LIDAR data of a transmission line.[48]



Courtesy of WIRE Services.

Figure 25. Screen capture. Processed LIDAR data of a transmission line.[48]

In 2011, the Washington State Department of Transportation (WSDOT) completed a research project to assess the feasibility of using mobile LIDAR technology to address WSDOT geospatial data requirements, evaluate the costs and benefits of mobile LIDAR technology to WSDOT business processes, and determine practices at other agencies that could be implemented at WSDOT.(49) The research provided a list of potential applications, including several that involve utilities and other similar installations (e.g., power lines, signals, and luminaires). Other closely related examples include construction inspection documentation, access encroachment, tunnel as-built production, and DTMs for machine control and guidance. Across all enterprise applications, the research estimated lifecycle savings up to $6.1 million for a mobile LIDAR system.

Relevant Standards

After the CI/ASCE 38-02 standard guideline was published in 2002, a number of other countries started initiatives to develop utility data collection and mapping standards of their own, including the following:

- **Canadian Standards Association S250-11, Mapping of Underground Utility Infrastructure (published in 2011)(50)**—S250-11 is a standard that specifies requirements for records used to identify and locate underground utility infrastructure. This is in contrast to CI/ASCE 38-02, which is essentially a guideline on the process to collect underground utility data.(1) CI/ASCE 38-02 also classifies data quality according to the process used to collect the data (as provided by four quality levels: QLD, QLC, QLB, and QLA) but does not include positional accuracy requirements, leaving this responsibility to the project owner. Table 1 shows positional accuracy requirements in S250-11 both for facilities that can be exposed and measured as well as facilities that cannot be exposed to obtain an accuracy level of 1, 2, 3, or 4.

Table 1. Positional accuracy requirements in S250-11.(50)

Accuracy Level	Accuracy	Confidence Level (Percent)	Reference	Comment
1	1 inch in X, Y, Z	95	Absolute	Facility exposed
2	4 inches in X, Y, Z	95	Absolute	Facility exposed
3	12 inches in X, Y, Z	95	Absolute or relative	Facility exposed
4	40 inches in X, Y, Z	95	Absolute or relative	Facility exposed
5	40 inches in X, Y	95	Absolute or relative	Exposure not possible or feasible
0	No spatial accuracy information	n/a	n/a	n/a

n/a = not applicable.

- **Malaysia's Standard Guideline for Underground Utility Mapping (published in 2006)(51)**—This standard guideline is very similar to the CI/ASCE 38-02 guideline, with four levels (D, C, B, and A) describing the process to collect and depict utility installations.(1) These four levels are the same as those in CI/ASCE 38-02. The Malaysian standard includes a positional accuracy requirement of 90 percent of all well-defined map features that are randomly chosen to be within 0.02 inches at map scale horizontally and within 4 inches vertically with respect to their true location on the ground.

- **Standards Australia AS 5488-2013, Classification of Subsurface Utility Information (published in 2013)[52]**—This standard provides a framework for classifying subsurface utility location and attribute data according to prespecified quality levels. The standard applies to subsurface utilities and associated surface features such as access chambers, valves, and terminal pads. It does not apply to aboveground facilities.

- **British Standards Institution Publicly Available Specification (PAS) 128, Specification for Underground Utility Detection, Verification, and Location (published in 2014)[53]**—This standard applies to active, out-of-service, redundant, or unknown underground utilities and their associated surface features. It applies to utilities up to 10 ft deep. It identifies the survey category, horizontal and vertical positional accuracy requirements, and a quality level designation that combines both survey category and positional accuracy (table 2). The standard does not apply to aboveground facilities, underground basements, tunnels, plant rooms, or non-utility features.

Table 2. Survey categories, quality levels, and horizontal and vertical positional accuracy requirements in PAS 128.[53]

Survey Category	Quality Level	Horizontal Positional Accuracy	Vertical Positional Accuracy
Desktop utility record search	QLD	Undefined	Undefined
Site reconnaissance	QLC	Undefined	Undefined
Detection	QLB4	Undefined	Undefined
Detection	QLB3	20 inches	Undefined (No reliable depth measurement possible)
Detection	QLB2	10 inches or 40 percent of detected depth, whichever is greater	40 percent of detected depth
Detection	QLB1	6 inches or 15 percent of detected depth, whichever is greater	15 percent of detected depth
Verification	QLA	1 inch	1.4 inches

RECENT RESEARCH INITIATIVES

SHRP2

SHRP2 R01 (Encouraging Innovation in Locating and Characterizing Underground Utilities)

The purpose of Project SHRP2 R01 was to document existing technologies for locating and characterizing underground utility installations and develop a research plan to identify new, emerging, or potential technologies.[42] The research plan included a recommendation for nine follow-up research initiatives, three of which were funded through SHRP2: SHRP2 R01A, SHRP2 R01B, and SHRP2 R01C. The research also produced a prototype decision support system called Selection Assistant for Utility Locating Technologies.

SHRP2 R01A (Technologies to Support Storage, Retrieval, and Utilization of 3D Utility Location Data)

The purpose of the research was to identify best practices for modeling, structuring, storing, retrieving, visualizing, and integrating 3D utility data in a multiuser environment and to develop an innovative approach that would leverage recent advances in technologies, including, but not limited to, GPS, GPR, and GIS technologies.(4) Initially, the researchers worked on a 2D GIS-based management system with a highly simplified approach for modeling utility facilities. In this environment, 3D data would simply be represented by a file or collection of files (in CAD format) for storage in the document management system. However, because of the requirement to model utility data in a 3D environment, a modified scope of work changed the focus to identifying processes in a 3D environment and a pilot demonstration of a 3D model using an existing CAD software platform.

Deliverables of the SHRP2 R01A project included an output, nonimplementable 3D model of utility facilities for a project in Virginia and a highly aggregated data model for utility facilities based on the Spatial Data Standards for Facilities, Infrastructure, and Environment.(54) This model used only two generic feature classes per type of utility: one feature class for point features and a second feature class for linear features. For example, there was one point feature class and one linear feature class each for water utilities, communication utilities, and electric utilities. Differentiation among facilities within a specific utility class was by attribute.

SHRP2 R01B (Utility Locating Technology Development Utilizing Multi-Sensor Platforms)

The purpose of the research was to enhance utility detection capabilities by developing and integrating nondestructive, multisensor geophysical techniques to detect and locate underground utilities under a variety of conditions.(55) The original goal as envisioned by SHRP2 was to combine GPR, TDEMI, RFID, acoustic, and seismic detectors into a single integrated towed platform. However, GPR and TDEMI equipment in close proximity tend to interfere with each other. A TDEMI unit is, in essence, a metal detector that can be affected negatively by the near presence of metal in the GPR equipment. Another reason is that GPR data collection tends to be data intensive, which makes it necessary to move the GPR unit slowly and stop frequently. By comparison, TDEMI units are less data intensive and can be operated at higher speeds than GPR units.

The research strategy for developing the multisensor platform technology involved refining an existing multichannel GPR array system, developing a new multisensor TDEMI system based on an existing platform, and developing or enhancing software for collecting, processing, fusing, and interpreting 3D imagery data from multiple datasets. The research also included developing a proof of concept for a seismic detection technology that included a shear-wave seismic imaging system with a similar detection capability as GPR but for use in soils where GPR is not appropriate. The proof of concept included testing at various locations in the United States as well as developing modeling capabilities to understand and predict high-resolution seismic measurements.

Field tests in Georgia and Virginia demonstrated that both the GPR and TDEMI platforms could detect underground utility installations if the conditions were appropriate. For example, both tools found most metallic water and metallic gas lines when soils were appropriate for the use of

GPR but had limited success with communication lines. A significant feature of both platforms was their ability to obtain images of geotechnical anomalies and detect some underground structures within those anomalies. Ultimately, a research conclusion was that the advanced geophysical tools offered their greatest value when used to complement not replace traditional utility mapping methods.

SHRP2 R01C (Innovation in Location of Deep Utility Pipes and Tunnels)

The purpose of the research was to develop and test devices to improve the capability to detect and determine the location of underground utility installations within an expanded locatable zone up to QLB as defined by the CI/ASCE 38-02 standard.(56) The research focused on current and evolving utility tagging and tracing practices, more specifically, active RFID tags, side-scanning EMI devices, acoustic devices, and seismic devices. Preliminary tests with a side-scanning EMI device and a 2D seismic device capably of looking 50 ft deep or more were not successful. For this reason, the research only proceeded further with the development and testing of an RFID tag (a battery-operated RFID tag capable of detection up to 50 ft in depth with an expected lifespan of 40 yr) and an acoustic device.

As part of the tests conducted in Georgia for the SHRP2 R01B project (see previous subsection), experiments were also conducted with the RFID tag and the acoustic detector. The tests resulted in limited success with these two prototypes, clearly indicating that it was too early to ascertain their potential for future use in actual applications. In the case of the active RFID tag, critical pending issues include how to package it correctly for utility use and the fact that locating the tag is highly sensitive to its alignment with the locator antenna, making it critical to place the tag correctly within the borehole. The tests also indicated the need for additional work on the reader interface. As for the acoustic detector, this unit failed to find two relatively simple shallow installations for which it should have been well suited. It also gave a false indication of a utility installation where none existed. It was then determined that there was either a hardware or software problem that could not be fixed in the field, and no further tests with the acoustic detector were conducted. It appears that the issue of signal distortion affecting the acoustic detector is being addressed, and there are plans to retest the detector at a site in Illinois.

SHRP2 R15 (Strategies for Integrating Utility and Transportation Agency Priorities in Highway Renewal Projects)

The purpose of the research was to gather data to identify existing institutional issues and processes that contribute to delays in planning, designing, and constructing highway renewal projects, as well as identifying practices, policies, and procedures to mitigate these delays.(57) This project resulted in a recommendation for six follow-up research initiatives, of which only one, dealing with the use of utility conflict lists, was subsequently funded as project SHRP2 R15B (Identification of Utility Conflicts and Solutions).

SHRP2 R15B (Identification of Utility Conflicts and Solutions)

The purpose of the research was to review the state of the practice on the use of utility conflict lists to organize and track utility conflict data, examine examples of innovative practices, and develop a set of tools to facilitate the identification and resolution of utility conflicts during project delivery. Research products included the following:(2)

- **Product 1 (standalone utility conflict list)**—This product includes a standardized utility conflict list template to analyze utility conflict resolution strategies.

- **Product 2 (utility conflict data model and database)**—This product is a scalable utility conflict list representation that facilitates managing utility conflicts in a database environment.

- **Product 3 (hands-on utility conflict management (UCM) training course)**—This product is a 1-d training course on the principles and application of UCM techniques.

SHRP2 R15C (Pilot Application of Products for the Identification of Utility Conflicts and Solutions)

The purpose of this pilot implementation of the SHRP2 R15B products was to work with a selected State transportation department on the implementation of the standalone utility conflict list and the 1-d UCM training course, as well as an introduction to the utility conflict data model and database. The pilot implementation took place at the Maryland State Highway Administration (MDSHA).(3)

MDSHA identified six projects to test the implementation of the UCM approach. Lessons learned from the implementation included the following:

- The UCM approach is useful for documenting and resolving utility conflicts.

- The UCM approach creates a proactive, efficient preconstruction engineering resolution process.

- The UCM approach helps to avoid utility relocations.

- Using the UCM approach has resulted in tangible economic and time benefits.

- The UCM approach enhances coordination and working relationships with utility owners.

- The UCM process facilitates MDSHA internal teamwork.

At the same time, MDSHA officials identified areas where the UCM approach would need some improvements. A critical issue was that populating and maintaining utility conflict lists took longer than originally expected, highlighting the need to provide more guidance on how to identify, characterize, and manage utility conflicts efficiently.

In addition to documenting lessons learned, the project resulted in updated versions of the three products listed in the SHRP2 R15B section above, including updates to the utility conflict and utility facility subject area components of the logical data model. Figure 26 shows the main groups or subject areas in the utility conflict data model. Figure 27 is a high-level view of entities in the utility conflict subject area. Figure 28 provides a high-level view of entities in the utility facility subject area. Table 3 is a list of attributes associated with all feature classes defined in the database.

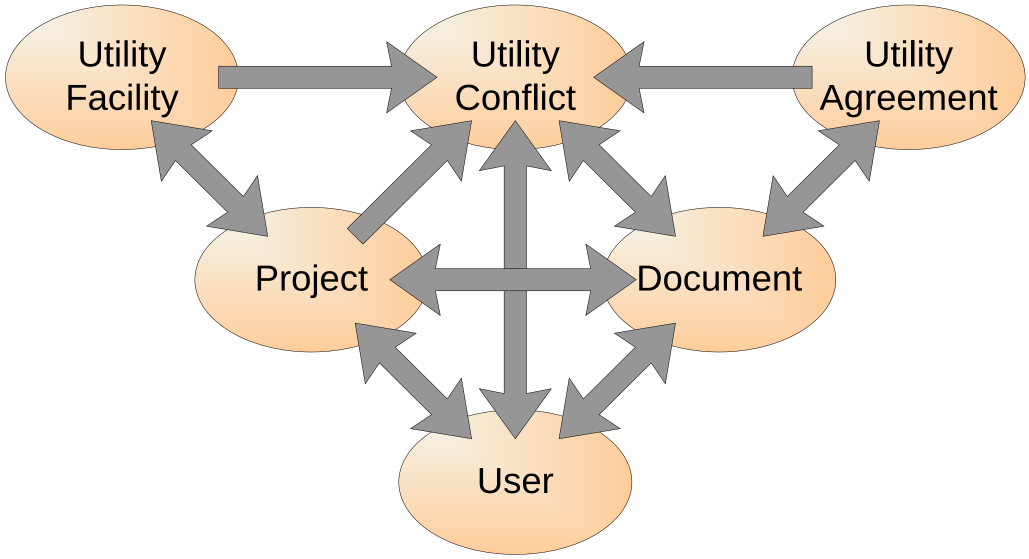


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Figure 26. Diagram. Utility conflict conceptual model.[(3)]

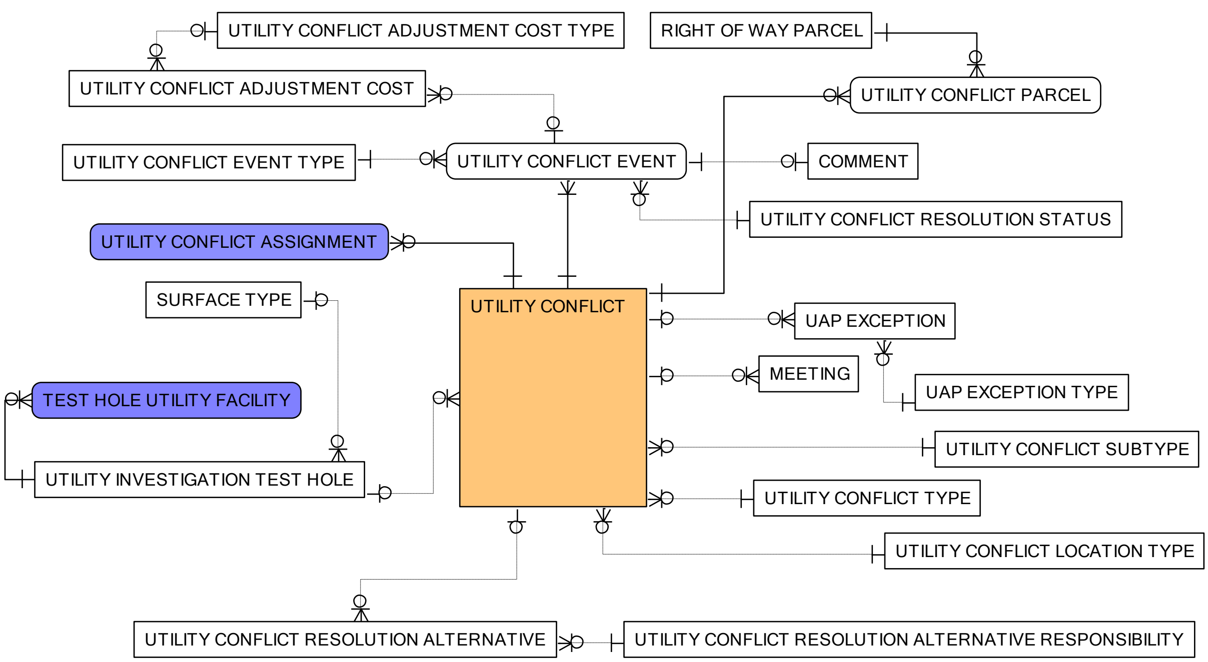

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Figure 27. Diagram. Utility conflict logical data model—utility conflict subject area.[(3)]

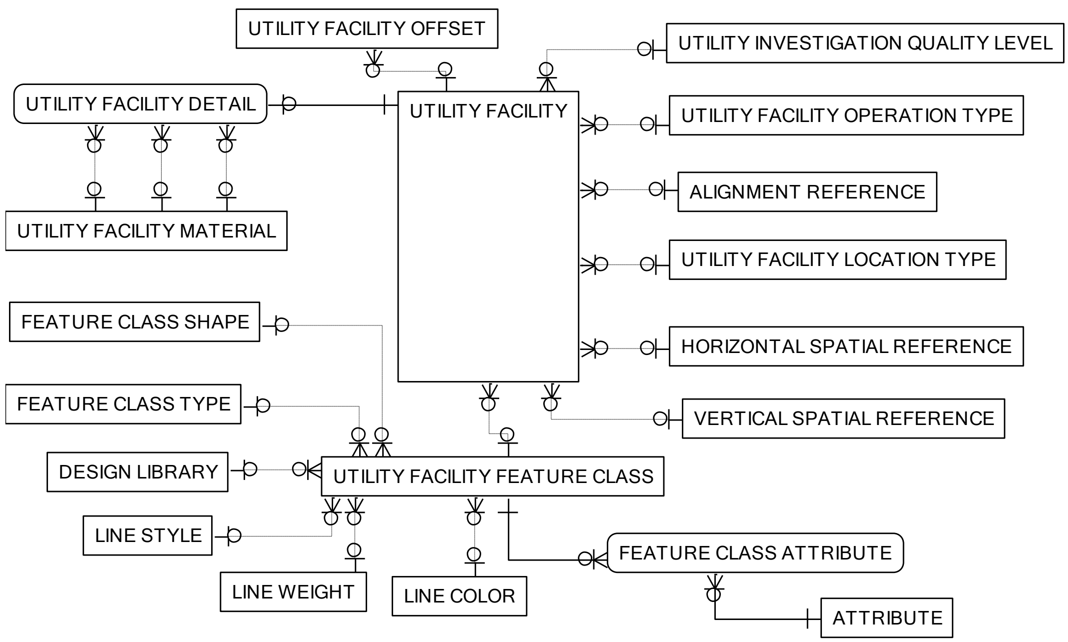

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Figure 28. Diagram. Utility conflict logical data model—utility facility subject area.[(3)]

Table 3. Feature class attributes in the utility conflict database.

Feature Class	Company	Description	Operation Type	Location Type	Age	Alignment Reference	Investigation Quality Level	Horizontal Spatial	Vertical Spatial Reference	Horizontal Positional	Vertical Positional Accuracy	Material	Depth	Diameter	Size	Duct Material	Duct Size	Width	Length	Height	Barrel Diameter	Barrel Height	Foundation Depth	Foundation Width	Cathodic Protection Flag
Communication Duct Bank	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	x	x	x	—	x	—	—	—	—	—
Communication Guy	x	x	x	x	x	x	x	x	x	x	x	x		x	—	—		x	—	x	—	—	—	—	—
Communication Handhole	x	x	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	x	—	x	—	—	—	—	—
Communication Junction Box	x	x	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	x	—	x	—	—	—	—	—
Communication Line	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	—	—	—
Communication Manhole	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	x	—	x	x	x	—	—	—
Communication Pedestal	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	x	—	x	—	—	—	—	—
Communication Pole	x	x	x	x	x	x	x	x	x	x	x	x	—	x	x	—	—	x	—	x	—	—	x	x	—
Communication Pull Box	x	x	x	x	x	x	x	x	x	x	x	x	x		x	—	—	x	—	x	—	—	—	—	—
Communication Push Brace	x	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	—	x	—	x	—	—	—	—	—

Feature Class	Company	Description	Operation Type	Location Type	Age	Alignment Reference	Investigation Quality Level	Horizontal Spatial	Vertical Spatial Reference	Horizontal Positional	Vertical Positional Accuracy	Material	Depth	Diameter	Size	Duct Material	Duct Size	Width	Length	Height	Barrel Diameter	Barrel Height	Foundation Depth	Foundation Width	Cathodic Protection Flag
Communication Splice Enclosure	x	x	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	x	—	x	—	—	—	—	—
Communication Tracer Wire Protector	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	—	—
Communication Vault	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	x	—	x	—	—	—	—	—
Electric Duct Bank	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	x	x	x	—	x	—	—	—	—	—
Electric Grounding Grid	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	x	x	—	—	—	—	—	—
Electric Guy	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	x	—	—	—	—	—	—	—
Electric Handhole	x	x	x	x	x	x	x	x	x	x	x		x	—	—	—	—	x	—	x	—	—	—	—	—
Electric Junction Box	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	x	—	x	—	—	—	—	—
Electric Line	x	x	x	x	x	x	x	x	x	x	x	x	—	x	x	x	x	—	—	—	—	—	—	—	—
Electric Manhole	x	x	x	x	x	x	x	x	x	x	x		—	x	—	—	—	—	—	—	x	x	—	—	—
Electric Pedestal	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	x	—	—	—	—	—
Electric Pole	x	x	x	x	x	x	x	x	x	x	x	x	—	x	x	—	—	x	—	x	—	—	x	x	—
Electric Pull Box	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	x	—	x	—	—	—	—	—
Electric Push Brace	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	x	—	—	—	—	—	—	—
Electric Transformer	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	—	—	x	—	x	—	—	—	—	—
Electric Vault	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	x	—	x	x	x	—	—	—
Gas Compressor Station	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	x	x	—	—	—	—	—	—
Gas Custody Transfer Station	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	x	x	—	—	—	—	—	—
Gas Line	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	x
Gas Metering Station	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	x	x	—	—	—	—	—	—
Gas Pressure Reducing Station	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	x	x	—	—	—	—	—	—
Gas Valve	x	x	x	x	x	x	x	x	x	x	x	—	—	—	x	—	—	—	—	—	—	—	—	—	—
Gas Vent	x	x	x	x	x	x	x	x	x	x	x	—	—	—	x	—	—	—	—	—	—	—	—	—	—
Miscellaneous Line	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	x	—	—	—	—	x
Miscellaneous Point	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	x	—	x	—	—	—	—	—
Non-Potable Water Point	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	—
Non-Potable Water Line	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	x
Petroleum Custody Transfer Station	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	x	x	—	—	—	—	—	—
Petroleum Line	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	x
Petroleum Metering Station	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	x	x	—	—	—	—	—	—

Feature Class	Company	Description	Operation Type	Location Type	Age	Alignment Reference	Investigation Quality Level	Horizontal Spatial	Vertical Spatial Reference	Horizontal Positional	Vertical Positional Accuracy	Material	Depth	Diameter	Size	Duct Material	Duct Size	Width	Length	Height	Barrel Diameter	Barrel Height	Foundation Depth	Foundation Width	Cathodic Protection Flag
Petroleum Pressure Reducing Station	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	x	x	—	—	—	—	—	—
Petroleum Valve	x	x	x	x	x	x	x	x	x	x	x	—	—	—	x	—	—	—	—	—	—	—	—	—	—
Sanitary Sewer Cleanout	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	—
Sanitary Sewer Line	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	x
Sanitary Sewer Manhole	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	x	—	x	x	x	—	—	—
Sanitary Sewer Pump Station	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	x	x	—	—	—	—	—	—
Sanitary Sewer Thrust Block	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	—	—	x	x	x	—	—	—	—	—
Sanitary Sewer Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	—
Steam Line	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	x
Steam Valve	x	x	x	x	x	x	x	x	x	x	x	x	—	—	x	—	—	—	—	—	—	—	—	—	—
Sump Pit	x	x	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	x	—	x	—	—	—	—	—
Utility Tunnel	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	x	—	x	—	—	—	—	—
Utility Warning Sign	x	x	x	x	x	x	x	x	x	x	x	x	—	—	x	—	—	—	—	—	—	—	—	—	—
Water Hydrant	x	x	x	x	x	x	x	x	x	x	x	—	—	—	x	—	—	—	—	—	—	—	—	—	—
Water Line	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	x
Water Manhole	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	x		x	x	x	—	—	—
Water Pump Station	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	x	x	—	—	—	—	—	—
Water Thrust Block	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	—	—	x	x	x	—	—	—	—	—
Water Valve	x	x	x	x	x	x	x	x	x	x	x	x	x	x	—	—	—	—	—	—	—	—	—	—	—
Wet Well	x	x	x	x	x	x	x	x	x	x	x	x	x	—	x	—	—	x	—	x	—	—	—	—	—

—Not applicable or not considered critical by users.
x = applicable attribute.

Cooperative Research Program

NCHRP Synthesis 405 (Utility Location and Highway Design)

The purpose of the synthesis was to explore current practices at transportation agencies during the project development process, including where in the process utility impacts are assessed and relocation decisions are made; what policies, regulations, manuals, and guidelines are used; and how design decisions are influenced by utility considerations.(43) The study included both underground and aboveground installations. The study concluded that State transportation departments handle utility issues in a variety of ways and that Federal guidance documents from FHWA and AASHTO are not always followed by the States. At the same time, virtually all State transportation departments follow their in-State utility accommodation policies, which reference some of these other documents. Most of these policies pertain to cost reimbursement issues.

Airport Cooperative Research Program (ACRP) 34 Subsurface Utility Engineering Information Management for Airports)

This project is not related to highway projects but is included here for completeness. ACRP 34 was a synthesis project that identified ways in which information on subsurface utility installations was collected, maintained, and used by airports, their consultants, and the Federal Aviation Administration.(41) This study identified gaps between existing technology and processes for utility risk management in other industries with those in the airport industry, including insufficient deployment of up-to-date geophysical tools to identify utility installations during capital improvement projects, lack of use of accepted engineering standards in collecting and depicting utility data, and lack of standardized data models for utility information. Other issues included inability to capitalize on cost-effective methods of data capture owing to process silos, inability to enforce contractual requirements on vendors to produce accurate and complete record drawings, and no clearly defined scopes of work for utility investigations.

State-Level Research

Texas Department of Transportation (TxDOT) Research Implementation Project 5-2110-01 (GIS-Based Inventory of Utilities)

The purpose of this project was to develop and test a GIS-based prototype model for the inventory of utility installations within the State right-of-way.(58) The prototype utility inventory model included the following subject areas, which represent most utility features typically found on the State right-of-way: communications, electric, gas, miscellaneous, oil, sanitary sewer, steam, storm sewer, and water. Also included in the utility inventory model was an attachment subject area to handle utility attachments such as electric lines to utility poles.

The researchers tested the utility inventory model using GPS and CAD data from the Katy Freeway reconstruction project in Houston. Testing also enabled the researchers to observe how inspectors manage specific situations in the field, such as inconsistent or irregular edges of pavement and inaccessible utility feature locations. Inspector feedback indicated a high level of interest in features such as staking out and automatic attribute data entry. Testing also enabled the researchers to observe significant differences between GPS locations on the ground and design drawings that utility owners had provided, highlighting the need to collect actual location data while construction was taking place and translating those coordinates into reliable, accurate as-built plans (figure 29).

Courtesy of TTI.

Figure 29. Photo. Collection of coordinate data for electric transmission duct bank.

TxDOT Research Implementation Project 5-2110-03 (Internet Based Utility Data Submissions and a GIS Inventory of Utilities)

The purpose of this project was to develop and implement a GIS/Web-based system, called Utility Installation Review (UIR), which automates the submission, review, approval, construction, and post-construction phases of the utility permitting process at TxDOT.[59] TxDOT issues nearly 20,000 permits every year for new utility installations on the State right-of-way. The permit review process typically includes several offices at the district and, as needed, communication exchanges with utility applicants. Prior to the implementation of UIR, the process was paper intensive and not appropriate for developing a long-term inventory of utility installations on the State right-of-way. In addition, document retention practices varied widely around the State.

TxDOT Research Project 0-5475 (Collection, Integration, and Analysis of Utility Data in the Transportation Project Development Process)

The purpose of this research was to develop a prototype Web-based system called Utility Accommodation and Conflict Tracker (UACT), which allows tracking of utility conflicts, automates the submission and review of documentation provided by utility owners, and provides a mechanism for standardized production of utility agreements during the project development process at TxDOT.[60] UACT guides the user through the completion process and selects appropriate forms based on the specific circumstances of the utility conflict. To facilitate coordination among utility stakeholders, UACT allows users to upload documents that are accessible to other users based on roles and privileges, and converts all documents automatically to PDF.

Florida Department of Transportation (FDOT) Research Project BDR74 977-03 (Strategic Plan to Optimize the Management of Right-of-Way Parcel and Utility Information at FDOT)

The purpose of the research was to provide recommendations for the management of right-of-way parcel and utility data at FDOT.[61] The research involved reviewing current FDOT systems and practices, developing data models, conducting a demonstration of a prototype application developed to test the data models, and preparing recommendations for implementation. The research included a comprehensive review of MicroStation® design libraries in use at the department and a determination on how to apply this information to the development of a data model and protocol for the extraction of parcel and utility data from MicroStation® into a GIS environment. The research team evaluated compact and expanded versions of the data model, which includes features, feature attributes, and linkages to other business processes within the department, including projects and documents. Recommendations also included steps for integrating parcel and utility data into FDOT's enterprise GIS framework.

Mapping the Underworld

Mapping the Underworld (MTU) was a multiyear research program in the United Kingdom that focused on the need to address challenges associated with the inaccurate location of underground utility installations.[62] MTU was funded primarily by the British Engineering and Physical Sciences Research Council (EPSRC) and involved several universities in the United Kingdom and the utility industry. The primary focus of MTU was development and testing of a multisensor tool for detecting underground utility facilities. Additional areas of emphasis were development of databases and other information products to manage utility data and development and testing of devices to mark utility installations during construction. This section covers the multisensor tool and the utility data information products. Chapter 5 covers the research completed to develop and test utility marking devices.

The MTU multisensor utility detection tool research program included two phases. Phase 1 (2005–2008) focused on the assessment of feasibility of a multisensor detection tool. It included four complementary projects that covered the feasibility of a multisensor detection tool, mapping and position, data integration to develop a single repository of utility records, and RFID tags to assist in future pipe locations. EPSRC provided £1 million (about $1.6 million) to fund this effort. U.K. Water Industry Research (UKWIR) provided an additional £200,000 (about $320,000) to facilitate stakeholder interaction.

Phase 2 (2008–2013) focused on the development of a multisensor device using GPR, acoustics, and electromagnetic technologies. EPSRC provided £3.5 million (about $5.7 million) to fund this effort. Other project partners provided an additional £1.36 million (about $2.2 million). The following is a short description of the work included in this phase:

- **GPR**—The purpose of this research was to develop recommendations on antenna deployment strategies for surface and in-pipe deployment and to develop and test a working prototype. The research resulted in a better understanding of GPR propagation effects and development of signal processing techniques to improve registration of responses.

- **Low-Frequency Electromagnetic Fields (LFEMs)**—The purpose of this research was to conduct four interrelated studies based on LFEM technologies. The research resulted in a noncontact method capable of detecting assets under paved areas. The research also produced models for the propagation of ultra-low frequency signals in a geologically layered medium.

- **Passive Magnetic Fields (PMFs)**—The purpose of this research was to use a passive array of magnetic sensors to detect underground electric cables and other metallic infrastructure. The research demonstrated that a relatively simple sensor made it possible to locate power cables using PMF techniques (i.e., using the magnetic field resulting from 50-Hz current flowing during normal operation rather than injecting a "tone" signal into the cable).

- **Vibro-Acoustics**—The purpose of this research was to determine the effectiveness and limitations of acoustic technologies for detecting underground installations. The research involved developing and testing detecting methods using three complementary acoustic techniques for vibration excitation: directly on a pipe, at the ground surface (shear-wave method), and at the ground surface (point-measurement method).

- **Development of Multisensor Array and Signal Processing**—The purpose of this research was to develop a multisensor array demonstration unit, bringing together the outputs of the sensor research described in the previous bullets in this list. The research demonstrated that, by combining data from the four sensors, it was possible to produce a more reliable assessment of underground facilities, therefore increasing the confidence in utility location. This result was particularly evident when the sensors produced target signatures that agreed horizontally and vertically, thereby reinforcing each other.

- **Fusion of Sensor Data With Buried Asset Records**—The purpose of this activity was to fuse georeferenced information from multiple sensors and to combine this information with existing utility facility records to increase confidence in their presence and location, and to determine missing asset records.

- **Tuning of Multisensor Device to Ground Conditions**: The purpose of this activity was to develop a knowledge-based system to predict geophysical soil data using georeferenced geotechnical and geological data.

- **Proving Trials and Specification of a National MTU Test Facility**: The purpose of this activity was to conduct a program of tests for each of the sensors as well as the multisensor device in a variety of soil and groundwater conditions.

Lessons learned from a U.S. perspective (facilitated by the close interaction of members of the research team and the MTU team, which included annual visits to the United Kingdom) include the following:

- MTU's focus was understanding the science behind utility location and on developing and testing a multisensor array demonstration unit. The multisensor tool and companion technologies did not show sufficient potential to provide a path to commercialization. The MTU program started from scratch whereas similar efforts in the United States had a longer history of research and development. In several areas, the state of the art in the United States is ahead (e.g., in geospatial positioning integration with sensors, use of test holes and direct connections for signal injection, and common use of multiple tools and insertion devices). At the same time, the MTU program was effective in educating the public and government officials on issues related to underground utilities. Of particular interest was a series of blogs, videos, and promotional materials that provided a concise view of the typical problems caused by unknown utility locations and the solutions offered by the MTU program.

- An important result of the MTU program was recognition of the need for utility mapping standards in the United Kingdom and technician and professional certifications. A resulting initiative in the United Kingdom was the PAS 128 utility mapping standard described previously in the Utility Data Collection and Mapping Standards section of this chapter.(53) Certifications are not in place in the United States and are perhaps an important path forward. To this end, ASCE's newly formed Utility Engineering and Surveying Institute is pursuing development of professional and technical certifications, with one of the goals being to provide agencies with additional tools to improve the technical capacity of its own workforce as well as that of consultants, contractors, and other related stakeholders.

- Although transportation agencies were involved throughout the research, MTU was a utility industry-centric initiative. Nevertheless, the fact that the utility industry was involved in this type of research could provide a model for similar opportunities for partnership and collaboration in the United States.

At the conclusion of the MTU program, a consortium of universities pursued and received funding for a follow-on program called Assessing the Underworld.(63) This multiyear initiative is focusing on developing technology solutions to address problems such as pipe integrity, leaks in pipes, faults in cable joints, voids in road surfaces, and tree interactions. A related but separate initiative is looking at quantum gravity measurements for utility location and condition assessment.

Utility Data Management Initiatives in the United Kingdom

Research involving accurate utility mapping in urban canyons and a means of finding a common basis for exchanging records among utility service providers led to the establishment of the Visualising Integrated Information on Buried Assets to Reduce Streetworks (VISTA) project in 2005.(64) The U.K. Department for Trade and Industry provided £900,000 (about $1.5 million), and UKWIR and other partners provided £1.3 million (about $2.1 million) to fund the development of VISTA. The purpose was to develop Web-based protocols for querying data about existing utility facilities when a user specifies a spatially constrained query (e.g., the location of a highway project). Conceptually, this query is very similar to the queries that one-call systems in the United States use to generate locate tickets.

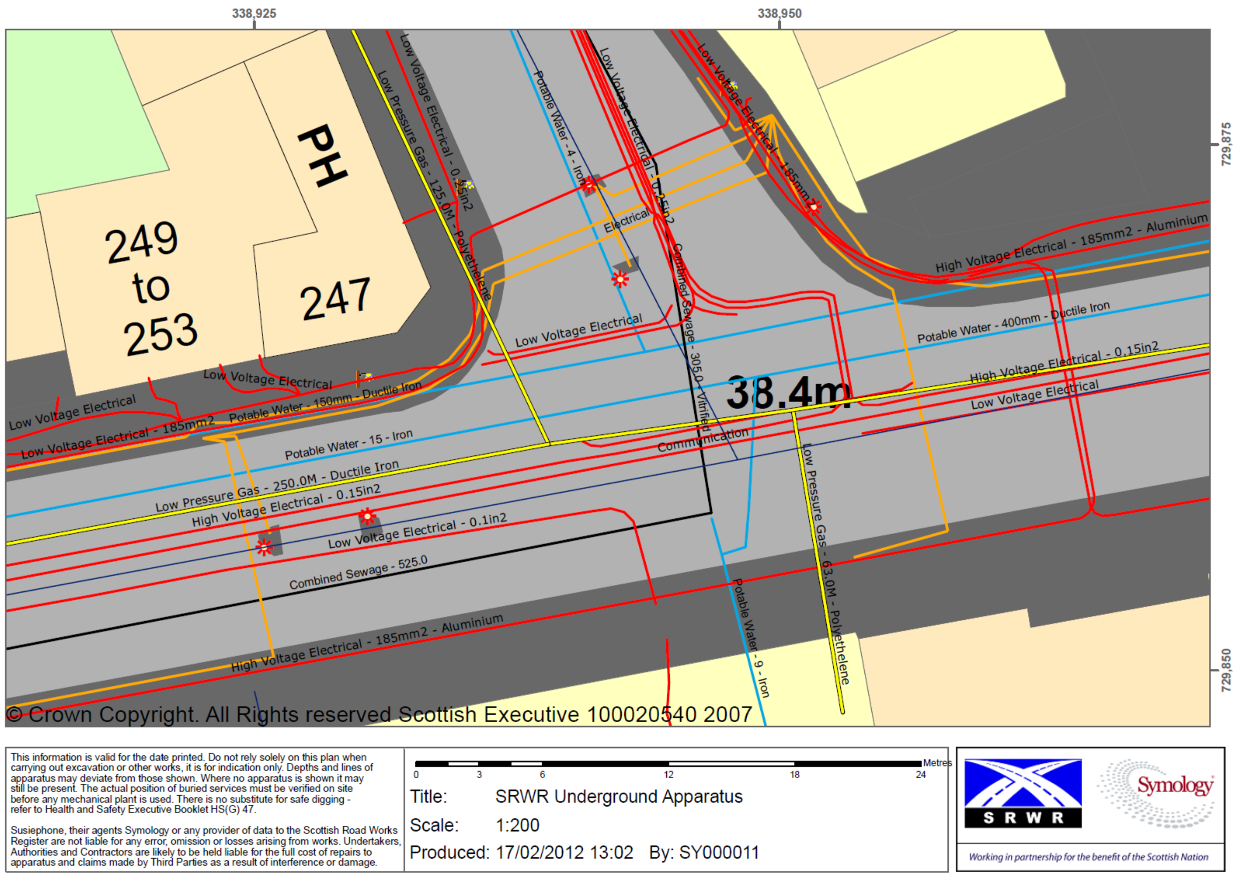
The mapping aspect of the VISTA project, which focused on combining utility records from different utility providers onto one platform, led to an implementation in Scotland called the Scottish Community Apparatus Data Vault (VAULT).[65] The Office of the Scottish Road Works Commissioner implemented VAULT to assist in that office's mission to improve the planning, coordination, and quality of roadway construction projects in Scotland. Interestingly, one of the powers of the office is to impose financial penalties on transportation agencies that systematically fail in their duty to coordinate and on utility owners that systematically fail to cooperate during a roadway project.

VAULT contains a GIS-based repository of underground installations owned by 33 transportation agencies and 34 utility owners in Scotland (except telecommunication providers, which, apparently, are not participating). VAULT overlays utility data on top of Ordnance Survey (OS) MasterMap®, which is a centralized GIS-based system managed by the United Kingdom's national mapping agency Ordnance Survey (figure 30).[66] OS MasterMap® includes four data layers, including some 450 million features, each of which has a unique topographical identifier:

- High-resolution (typically 6- to 8-inch) aerial imagery.
- Topography (1:1,250 to 1:10,000 scale), including administrative boundaries, buildings, historical features, land features, railroads, highways, paths, structures, terrain and height, and water features.
- Property addresses.
- Transportation network (links and nodes) of all roads in Great Britain.

Utility owners maintain a record of where their facilities are located on the ground but then translate this information so that features can be overlaid on OS MasterMap®. Utility owners upload their asset data on a quarterly basis.

Access to data stored in VAULT is limited to transportation agencies and utility owners and is provided to these stakeholders via the Scottish Road Works Register, which is Scotland's system for the electronic transfer, retention, and management of roadway information. Authorized users can access the data online or request maps in A3 or A4 paper size. Because of the system design, it is currently not possible to generate locate tickets similar to those generated through one-call notification centers in the United States.



Reproduced with permission of the Scottish Road Works Commissioner.

Figure 30. Screen capture. VAULT map.(65)

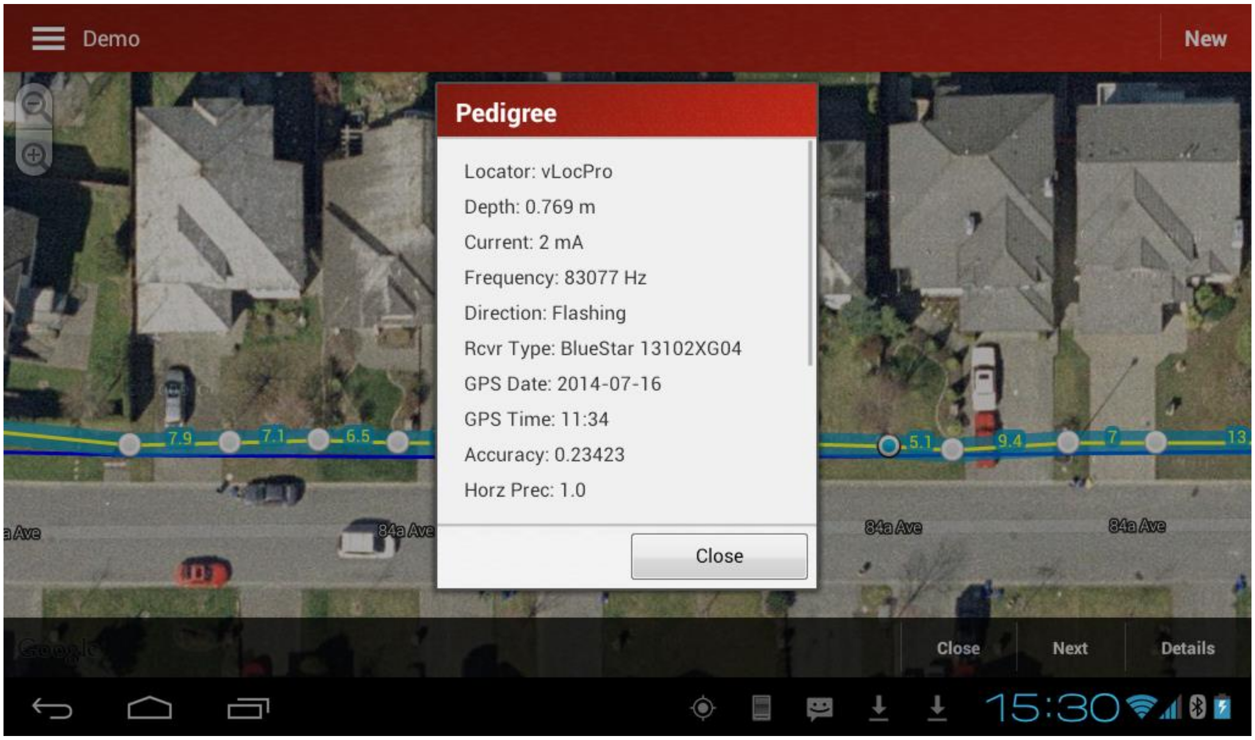
Other Initiatives

Excavation Encroachment Notification System

The excavation encroachment notification project in northern Virginia focused on the development of a GPS-based system to prevent excavator encroachment.(67) The consortium included the gas industry, construction equipment manufacturers, VDOT, the Virginia Utility Protection Service, and various utility owners and excavators in northern Virginia. The system built on technology deployed in earlier pilot projects lead by the Virginia one-call center. Phase I focused on technology allowing the boundary of one-call tickets to be identified electronically in the field using a GPS-enabled mobile telephone. Phase II resulted in a system that allowed facility locators to use GPS-enabled locating devices to capture the coordinates of underground facilities during routine one-call locates. Phase III added excavation location monitoring technology to provide real-time excavation encroachment warnings. The technology was tested in a series of demonstrations in Virginia. The project proved the concept and value of excavation location monitoring and real-time warning to excavators.

ProStar Geocorp™

ProStar Geocorp™ is a provider of geospatial solutions and services to manage surface and underground assets for the utility and pipeline industries. Its Web-based platform includes three main components: data collection tools, data integration tools, and a Web-based dashboard application.[68] PointMan® is a GPS-based mobile software application to capture asset location and other location-related data from a data capturing tool or (compatible) mobile device. The application enables users to collect and upload the data to an online geospatial database in real time. Users can also visualize locations relative to other existing infrastructure (figure 31). PointMan® also enables users to georeference photos, complete electronic forms, mark up design drawings, take field notes, and create sketches. The Prostar Geocorp™ data collection platform, which is 2D-based, currently includes mapping-grade GPS receivers that are adequate for most asset management and damage prevention purposes. It also supports survey-grade receivers.

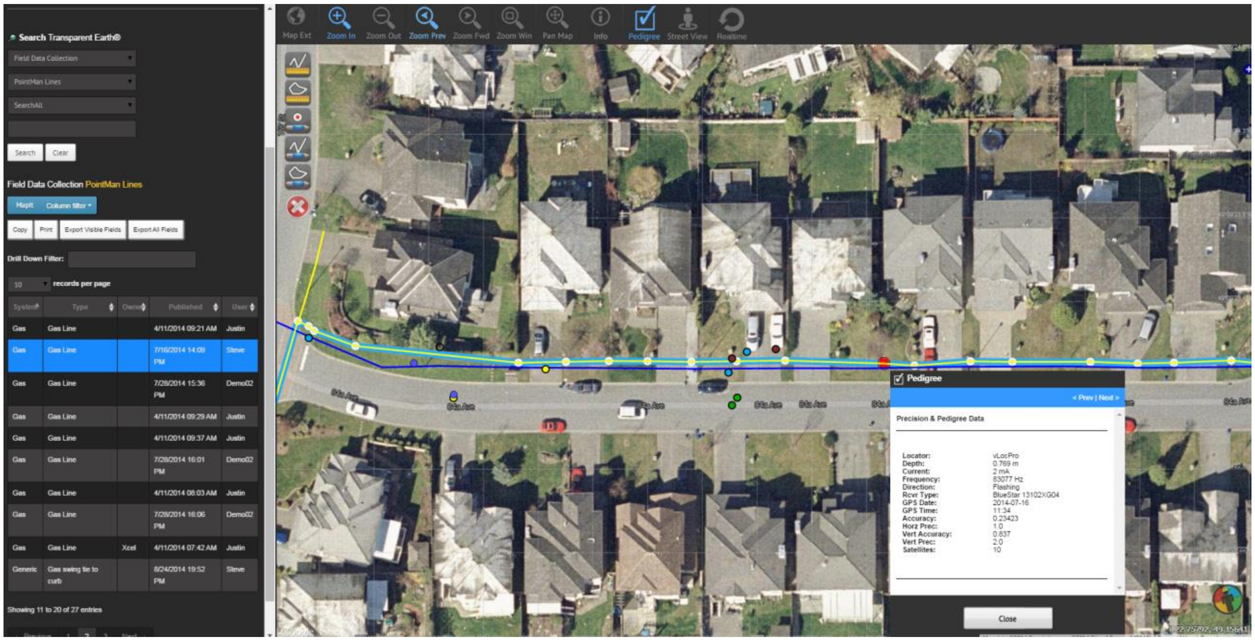


Courtesy of ProStar Geocorp™.

Figure 31. Screen capture. ProStar Geocorp™'s mobile application to record, display, and query utility features.

EarthWorm® is a back-office integration service that captures, aggregates, integrates, and routes utility and pipeline facility data. EarthWorm® receives asset location data from compliant data collection devices that run PointMan®. EarthWorm® provides integration with applications such as GIS, CAD, and mapping services.

Transparent Earth® is a Web-based dashboard application to visualize and analyze utility and pipeline assets based on information received from data collection devices running PointMan® via a real-time interface (figure 32). It covers information such as aboveground or underground assets, as-built information, photos, and documents. The dashboard application enables users to mark up and edit map and tabular data and serve that information to field users via the cloud.



Courtesy of ProStar Geocorp™.

Figure 32. Screen capture. ProStar Geocorp™'s Web application to view field map data in real time.

The Web-based mapping engine supports OGC open standards and leverages services such as the Web Mapping Service and Web Feature Service standard protocols to serve georeferenced images and vector feature data over the Internet. Although the rendering system is 2D based, the Web-based cloud mapping engine supports rendering of 3D objects via the Web 3D Service (W3DS) interface standard. W3DS provides visual representations (called scenes) of the original georeferenced data optimized for real-time rendering of the objects using Web browsers.

CHAPTER 3. CASE STUDIES

OUTREACH TO STATE HIGHWAY AGENCIES

Under the auspices of the AASHTO subcommittees on design; construction; maintenance; right-of-way, utilities, and outdoor advertising control; and information systems, the research team contacted State transportation departments in late 2012 to develop a general assessment of practices, issues, and initiatives related to mapping and marking of underground utilities. Based on this assessment, the goal was to determine potential candidate agencies for case studies to include in the research. Topics of interest included the following:

- Examples of projects or initiatives involving the use of 3D technologies, such as 3D models or fully rendered 3D structures, LIDAR point clouds, BIM, or 3D animation to support the project delivery process.
- Examples of projects or initiatives involving the use of 3D technologies, including specific 3D data collection technologies such as EMI and/or GPR arrays to generate 3D renderings of utility facilities.
- Quality control (QC) procedures to manage issues such as completeness and accuracy of 3D data, including survey control.
- Long-term storage and maintenance of project data, including 3D data.
- Cost elements or other relevant information to determine the effectiveness or feasibility of using 3D data for project delivery.
- Use of RFID technology to mark utility facilities.
- Feasibility of having State transportation departments as the central repository of utility data within the State highway right-of-way.

Outreach to State transportation departments included an online instrument that officials could use to provide feedback and follow-up telephone interviews as needed to expand on or clarify responses. Invitations to participate were emailed to agency representatives to the five AASHTO subcommittees mentioned at the beginning of this chapter. A total of 90 officials from 47 agencies, including transportation departments of 45 States, Puerto Rico, and the District of Columbia, provided feedback. The result of this effort was the selection of candidate agencies for case studies. This section summarizes the feedback received from State transportation departments. The following sections summarize lessons learned from the case studies in California, Connecticut, Florida, Iowa, North Carolina, Texas, Washington State, and Wisconsin.

Use of 3D Technologies in Project Delivery

Table 4 summarizes the feedback provided by 55 officials representing 37 agencies. In general, agencies reported increasing use of 3D technologies during project delivery. In the case of 3D models and 3D visualization, the use was more sporadic, often on a trial basis, and for the most part reserved for large-scale projects. 3D visualization and animation were also reported for sensitive projects to give the public a better picture of the project impacts.

Table 4. Use of 3D technologies for project delivery.

State	Responses
Alaska	Design projects that are more than resurfacing projects use DTMs for ground surface modeling in Autodesk® Civil 3D®, from which cross sections, slope limits, and earthwork quantities are obtained.
Arizona	Rarely used. Individual projects use a 3D modeling approach for conflict resolution.
California	LIDAR point clouds are used to collect roadway and roadside information. There are numerous examples of projects using LIDAR point clouds collected by airborne, mobile, and stationary platforms. The California Department of Transportation (Caltrans) is using LIDAR mounted on fixed-wing or helicopter aircraft for mapping large areas that cannot be done with conventional photogrammetry and/or on emergency repair projects. The San Francisco Oakland Bay Bridge and Presidio Parkway have both made use of 3D models and 3D animation.
Colorado	The Colorado Department of Transportation went to Bentley® InRoads® in 2000.
Connecticut	The Connecticut Department of Transportation (CTDOT) completed a five-legged roundabout. The design model was rendered and photo-matched with existing photos. In addition, the surface models were used during construction with GPS-enabled rovers. CTDOT transportation projects typically leverage the use of Bentley® Inroads® and MicroStation® to generate 3D design models, 3D surface files, and 3D geometry files, from which 2D sheet drawings are created. Projects involving facilities, depending on the scope, use BIM technologies (e.g., new terminals at Bradley International Airport). CTDOT developed a specification, “Electronic Engineering Data,” to determine what 3D data should be delivered to the department and what data should be made available to the contractor and inspector potentially for GPS AMG and real-time GPS inspection.
Delaware	Most projects are modeled using Bentley® InRoads®. The Delaware Department of Transportation (DelDOT) uses 3D models for visualization, design, and construction management purposes.
Florida	There have been several design–build projects that developers have designed and built using 3D technology. The department is rolling out an agency initiative to move conventional projects into full 3D design.
Georgia	For the Mitchell Street project in downtown Atlanta, the goal was to locate a major communication duct line that ran under several tracks of railroad. Unfortunately, the 3D technology used by the utility owner to obtain the duct line position was unsuccessful.
Idaho	Various roadway projects have used Bentley® InRoads® for 3D modeling. Use of LIDAR technology has been limited to a few structures and roadway projects.
Iowa	Bentley® software generated products include 3D design surfaces, 3D preconstruction project visualizations, 3D drive-through project models, and machine guidance construction files. 3D survey-generated LIDAR products (static terrestrial, mobile terrestrial, airborne) are also generated.
Kansas	The Kansas Department of Transportation uses or plans to use 3D technologies such as LIDAR and 3D models to support project delivery.
Kentucky	The Kentucky Transportation Cabinet has used statewide aerial photography and elevation program (statewide LIDAR), mobile mapping (US 31W Warren County), and mobile mapping and airborne LIDAR (Johnson County Rock Slide).
Maryland	MDSHA has used 3D technologies on some critical projects to show how the road or bridge project could look after completion. MDSHA has also used 4D or driving animation to inform the public of a project’s impact on the surrounding environment if the project is built. The agency has generally received positive feedback, particularly for developing ways the public could better understand the project rather than looking at 2D engineering-type documents. MDSHA develops base map files with 3D datapoints from topographic surveys, augmented with utility location surveys. Bentley® InRoads® is used along with MicroStation®. The base topographic files can

State	Responses
	be used to produce cross sections and profiles of existing and proposed surfaces and located utilities. MDSHA is considering LIDAR point clouds and other options for 3D products.
Michigan	MDOT rolled out GEOPAK® Roadway Designer®. MDOT is beginning to use the software to produce 3D models. Very few bridges have been designed or modeled in 3D. MDOT is using LIDAR point clouds extensively during design survey. Very little has been accomplished with BIM or 3D animation. Some large consultant-designed projects have used animation and 3D modeling. MDOT has been aggressively pursuing use of LIDAR for data acquisition. Several survey projects have been completed with this technology including the US 23/I 96 interchange, US 2 in Ironwood, and US 23 south of Alpena. The use of 3D model data for design is being promoted too, with the recent training for Roadway Designer® within GEOPAK® as the standard design software. Efforts are underway to define requirements for model-based designs.
Minnesota	The Minnesota Department of Transportation has a laser scanner to generate point clouds, extract line work, and develop ground TIN models. Designers mainly work in 2D.
Missouri	The Missouri Department of Transportation (MoDOT) requires delivery of 3D models for all design projects. MoDOT delivers these models to prospective contractors pre-bid. The models consist of an existing ground surface and an as-built final condition surface. MoDOT obtains existing ground surfaces using LIDAR. MoDOT uses GEOPAK® and other similar software tools. The department does not use these tools for marking fiber or other information technology (IT) resources.
Montana	Road designers at the Montana Department of Transportation have used 3D models in GEOPAK® on a few complex projects to determine the fit of a feature, to avoid conflicts with existing structures, or to develop contour grading. Rendering has been used for public involvement, and the department is starting to develop 3D animations to show stakeholders how a project will be constructed. The department is beginning to use LIDAR for project mapping.
Nebraska	The Nebraska Department of Roads has traditionally relied on 2D information on plans. The department has started to provide DTMs to grading contractors at their request.
Nevada	Terrestrial LIDAR has been used for quite some time to collect surface and as-built data. Recently, the Nevada Department of Transportation begun to experiment with data fusion from a variety of sources, including aerial imagery, LIDAR, DTMs from traditional photogrammetry or survey, and off-the-shelf interferometic small aperture radar imagery. Some of these products include digital fly-through animations of proposed projects and terrain model generation on project planning that does not need an engineering grade surface. The department is beginning an initiative to use aerial and mobile LIDAR services.
New York State	Most structures with utility conflicts at the New York State Department of Transportation are designed in 3D. DTMs are provided to contractors as supplemental information when available. GPR has been used in limited situations. LIDAR point clouds were used recently for high-speed intercity passenger rail project corridors.
North Carolina	NCDOT is creating 3D project design models using Bentley® tools. However, these models do not include underground utilities. NCDOT develops DTMs for all projects. 3D modeling for roads relies on Bentley® software. There are several older, legacy projects developed with criteria using MicroStation® and GEOPAK®. TIN files and proposed DTMs are generated for use at bidding.
Oklahoma	The Oklahoma Department of Transportation delivers all survey information in 3D except underground utilities. The reason is that utility owners or locators refuse to divulge the depth of their facilities.
Oregon	The Oregon Department of Transportation (ODOT) currently uses MicroStation® with Inroads® for all projects. ODOT uses 3D technologies on some projects if it is deemed viable.

State	Responses
Pennsylvania	In the past, PennDOT developed 3D models mainly for visualization purposes. More recently, 3D models have been used on selected projects including large earthwork jobs and small box culvert jobs. Typical mill-and-fill jobs are generally in 2D. The department is beginning to use 3D modeling in Bentley® InRoads®. PennDOT uses LIDAR.
Rhode Island	The Rhode Island Department of Transportation (RIDOT) started to use 3D modeling with scheduling (i.e., 4D) on large projects. Two examples are the replacement of the Providence Viaduct and the Central Bridge in Barrington. RIDOT uses 3D modeling to assist in evaluation of the constructability and the contract time determination of a project.
Tennessee	The Tennessee Department of Transportation (TDOT) has used mobile terrestrial LIDAR point clouds to extract roadway asset inventories and to measure vertical clearance on highway bridges and overpasses on all interstate and State routes on a 2-yr cycle since 2009. High-resolution 3D cameras are used to evaluate distress in pavements. Deliverables from the LIDAR program include raw point clouds, digital photolog images, geodatabase files containing the extracted asset data, text files containing extracted asset data for import into TDOT's Tennessee Roadway Information Management System database, text files containing the vertical bridge clearances, high-resolution 3D downward-facing images of the pavement, and pavement distress data.
Texas	TxDOT is beginning to use 3D modeling for machine control (using Bentley® GEOPAK® XM tools). The Bridge Division uses 3D modeling for conceptual designs and displays. The Bridge Division has also used LIDAR to document all bridge clearances. District roadway designers and consultants use GEOPAK® and GEOPAK® Drainage. 3D models and animation have also been completed for public hearing and other uses. Comprehensive development agreement contracts have been modified to include 3D models and animations as part of the deliverables. Models have been provided in the past to roadway contractors, but they typically opt to build their own. LIDAR point clouds and mobile mapping is contracted out and used for design surveying.
Utah	The Utah Department of Transportation (UDOT) is researching techniques and methodology to use LIDAR point cloud data for design. Initial results indicate that with minimal additional effort, LIDAR data can be successfully calibrated to obtain survey quality location data of highway inventory features. Highway features exclude third-party utility installations, but the cloud data contain data representing all aboveground features. Upcoming pilot projects will use LIDAR data calibrated to survey quality to produce a DTM and a topographic file.
Vermont	Most agency projects are done through MicroStation® plans development in 3D.
Virginia	Typically, 2D information is provided to contractors, who build their own 3D models. VDOT has some experience with 3D modeling and machine control in the past. The Lynchburg District has produced 3D models for several projects where machine control was used. VDOT is currently using terrestrial scanning to complete 3D models of existing structures. VDOT has also used LIDAR technology for topography on Route 460. This project has progressed, and VDOT is completing the mapping on the proposed corridor using photogrammetry and the original LIDAR data to create a DTM.
Washington State	On the Alaska Way Viaduct project, WSDOT used 3D modeling, including the use of LIDAR data to map suspended utilities mounted under the lower deck of the viaduct. WSDOT used AutoCAD® Civil 3D® for some of the utility data for the Alaskan Way Viaduct Bored Tunnel Project. InRoads® has been used for drainage models. The GeoMetrix Office's Geodetic Survey Branch has 3D capabilities and has performed large facility inventories using 3D LIDAR scanning equipment, such as the entire I-90 Mount Baker Tunnel and Mercer LiD complex. This involved hundreds of miles of electrical conduits, fire suppression piping, and heating, ventilation, and air conditioning (HVAC), as well as an entire structural as-built.

State	Responses
West Virginia	Since about 2006, the West Virginia Department of Transportation's (WVDOT) Engineering Division has used 3D models for roadway design. All survey data and mapping are in 3D, including utility facilities (when accessible) and drainage structures. The recent advent of "edge modeling" (combination of point clouds and high-density digital photos) is the next step in the agency's use of 3D design.
Wisconsin	The Wisconsin Department of Transportation (WisDOT) is implementing AutoCAD® Civil 3D®. The agency has provided 3D surface models to contractors for use with AMG on several contracts. WisDOT's South East Freeways group has used 3D models on several projects during design and construction for conflict detection, 4D modeling, visualizations, and use with rovers for inspection and contract administration. WisDOT also started using LIDAR but is currently researching the best software to address agency needs.
Wyoming	The Wyoming Department of Transportation occasionally uses 3D utility surveys on selected projects, usually urban projects with numerous utility conflicts.

Examples of the use of 3D models for planning and presentation purposes included conceptual designs and displays as well as 3D modeling for visualizations and animations. Examples of the use of 3D models for design and construction purposes include the following:

- 3D surface or terrain models, including drainage models.
- Constructability analysis.
- Construction management and/or machine control. Models are often developed and delivered before contractors bid on a project.
- 3D modeling in conjunction with scheduling software (i.e., 4D) to determine constructability, project duration, and construction schedule.
- Use of BIM software on a trial basis.

Agencies with LIDAR experience reported using this technology (both mobile and stationary) for one or more of the following applications:

- Gathering of roadway asset data for use in asset inventories.
- Determination of vertical clearances on highway bridges and overpasses.
- Statewide elevation mapping.
- Ground surface and topography mapping for DTMs.
- Development of DTMs.

Agencies also reported using LIDAR for experimental applications, such as the following:

- Capturing aboveground utility installation data for roadway projects.
- Fusion of LIDAR data with aerial imagery, DTM, and radar data.
- DTMs for 3D animation and planning.

One respondent also mentioned using high-resolution 3D cameras to evaluate pavement quality conditions.

Use of 3D Technologies for New or Existing Utility Installations

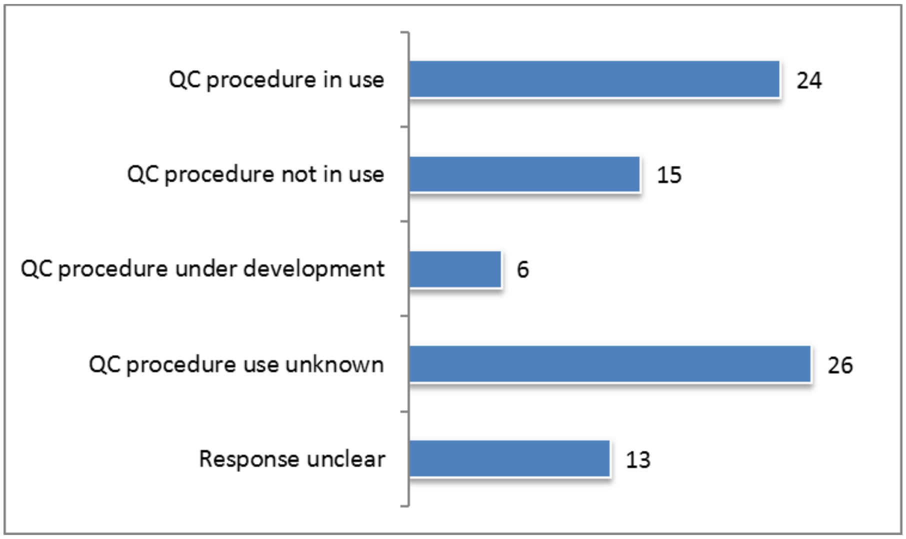
Only a few State transportation departments reported using 3D technologies for utility installations (table 5). For these agencies, a common application was the use of GPR or similar technology to discover underground utility structures and develop a 3D model. A respondent indicated developing a 3D utility visualization using 3D visualization software but did not explain the process followed to gather the necessary data.

Table 5. Use of 3D technologies for new or existing utility facilities.

State	Responses
California	Current LIDAR use focuses on the collection of paved surface information, limiting exposure of survey crews to traffic. Two examples in District 4 include the Presidio Parkway Project and the SCl-185 Ramp Metering Project. The Geotechnical Services Unit started a pilot to offer GPR, electromagnetic conductivity, and magnetometry to designate subsurface utilities within project limits. Prior business practice was to use this equipment for minor investigations for conflict avoidance associated with drilling operations. GPR has been used by consulting firms to locate buried structures or facilities and deliver them in 3D model formats. The proposed San Francisco Bay Bridge Maintenance Complex is an example in which underground structures were discovered. The I-405 design–build contractor used a consultant to provide an array of surface geophysical tools to locate previously undiscovered underground utilities prior to construction.
Connecticut	For a research project that involved construction inspection techniques, CTDOT located road crossing drainage structures, which proved valuable.
Delaware	Existing and proposed utilities are modeled in InRoads®. DelDOT uses specific technologies to collect 3D data.
Florida	The scope of services for the statewide consultant support for radar tomography contract includes the requirement to provide 3D data collection upon request. In 2006, the agency piloted two projects based on radar tomograghy. FDOT has two consultants to provide 3D imaging services statewide to support design and construction.
Maryland	MDSHA normally has consultants to identify existing utilities from utility records complemented with field topography and QLB efforts, including GPR and pipe and cable locators. For funded projects, utility locations are performed using test holes and surveying the exposed utilities.
Michigan	MDOT Survey Support is doing limited testing on 3D presentation of existing (visible) utility features (pipes) located during a design survey. The software platform used for automated mapping has the capability to represent the 3D pipeline in the model.
North Carolina	NCDOT has created 3D visualizations of specific underground utilities for post-design conflict analysis using Autodesk® 3D Studio Max®. Respondent was not sure what technology was used to capture the utility locations.
Utah	On the Mountain View Corridor project, UDOT used 2D information for existing underground utilities along with test hole data to prepare a 3D model. The designers created a DTM for all the existing utilities, which was helpful in finding conflicts and designing solutions.
Washington State	WSDOT has contracted utility investigation consultants for many projects (e.g., in the case of the SR 285/West End of the George Sellars Bridge, Intersection Improvements, SR 522-Snohomish River Bridge, SR 522/US2 Interchange project, I-5 to Horton Road, Valley Mall Blvd.). Interchange, I-5 BNSF Overcrossing, I-5/Albro-Corson Ave I/C Bridges Seismic Retrofit, and the Columbia River Crossing project.
West Virginia	WVDOT has a recent project in Morgantown that includes widening and intersection improvements in a high-density urban setting. WVDOT used a consultant to gather data about utility and drainage structures using GPR, cable locators, and test holes. This proved to be very valuable and confirmed what was located in the original survey using traditional methods.

QC Procedures for 3D Data

About a third of State transportation department officials indicated that their agency had a QC procedure in place for 3D data (figure 33). A slightly higher number did not know whether the agency had a QC procedure in place or indicated that the issue did not apply to them (suggesting that another group within the agency (e.g., surveying, had that responsibility)).

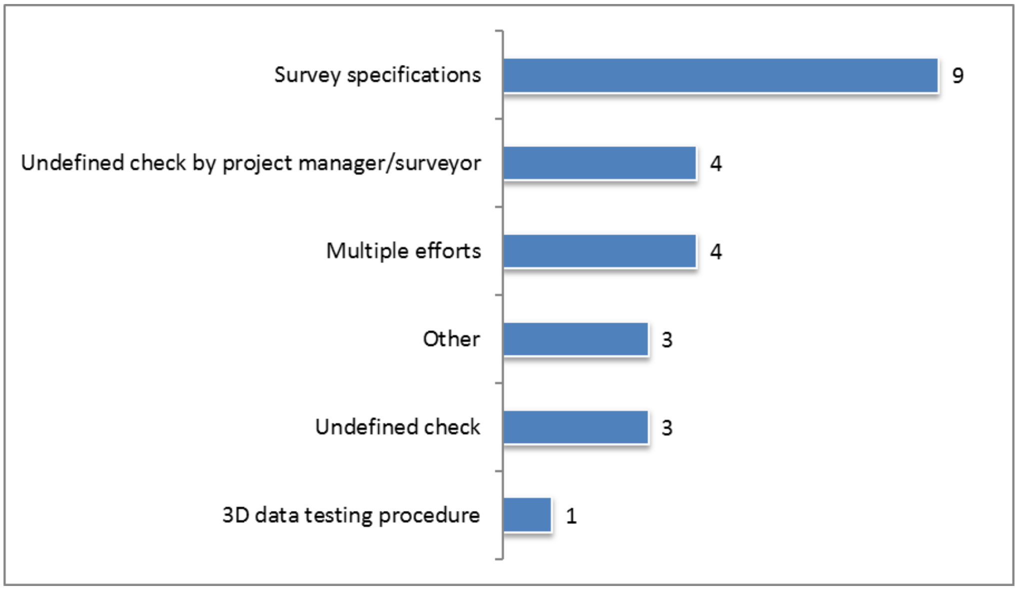


Source: FHWA.

Figure 33. Chart. Use of QC procedures for 3D data.

Figure 34 provides more information about the use of QC procedures. The most common reference was to the agency's survey specifications or a combination of approaches that included the survey specifications. Examples of approaches included contractor pre-qualifications, a requirement for the contractor to perform quality checks following standard agency requirements, a requirement for independent evaluations, and an internal review process for 3D data deliverables. Additional examples included the development of guidelines for mobile LIDAR surveys and, in the case of utility investigations, compliance with the CI/ASCE 38-02 standard guideline.(1) Other procedures included having the project manager, a surveyor, or another official check the data; using spot checks; using professional registered surveyors to seal and certify data, and using a data survey coordinator to oversee data collection and production.

One State transportation department official mentioned a specific testing procedure in use at the agency: The Oklahoma Department of Transportation's Oklahoma Standard for Spatial Data Accuracy, which provides a statistical and testing methodology for estimating the vertical accuracy of DTMs with respect to georeferenced ground positions of higher accuracy.(69) Other States did not provide information about specific or similar testing procedures. However, it is worth noting that, according to a recent NCHRP report, 38 State transportation departments that participated in a study on the state of the practice of mobile LIDAR indicated they had published surveying and QC standards.(70)

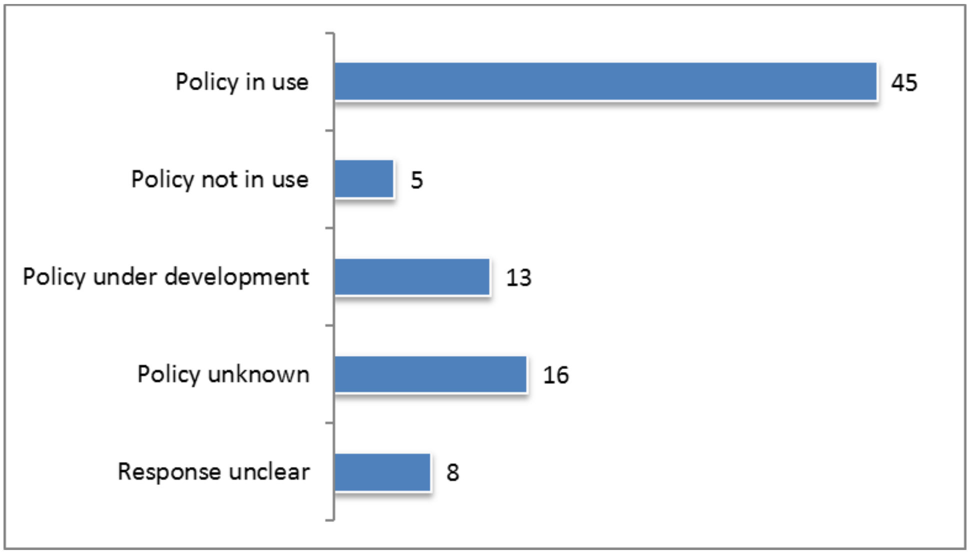


Source: FHWA.

Figure 34. Chart. Types of QC used for 3D data.

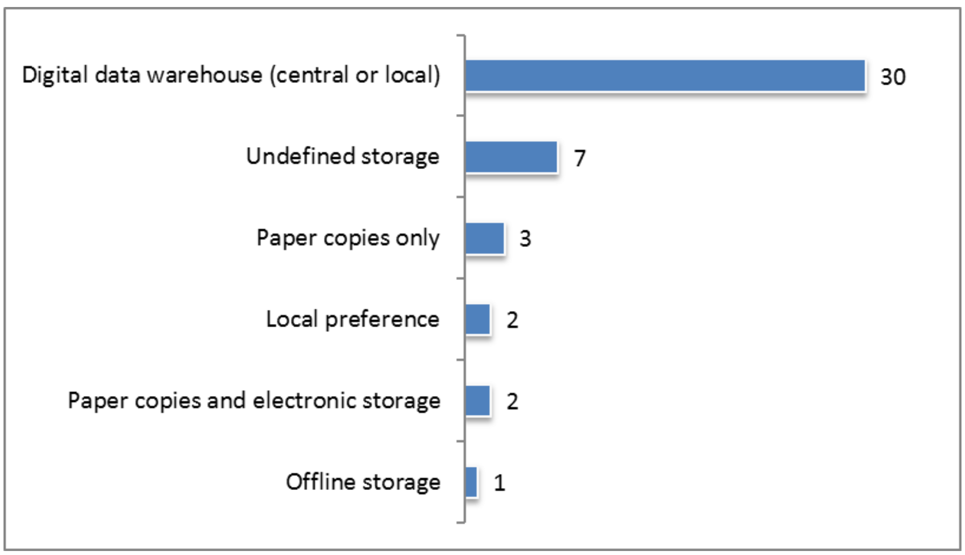
Long-Term Storage and Maintenance of Project Data

Most State transportation departments indicated that they have a policy or practice in place for the long-term storage and maintenance of project data (figure 35). In most cases, State transportation departments use some type of digital data warehouse, ranging from simple backup servers or electronic archives to formal electronic data management systems (figure 36). Data warehouse solutions included both local and centralized solutions. Agencies did not provide any information about storage size requirements or costs. One issue that respondents with LIDAR experience mentioned was the challenge of how to manage extremely large LIDAR datasets. Some agencies mentioned storing LIDAR data on offline devices. Other agencies were currently evaluating best practices to store LIDAR data.



Source: FHWA.

Figure 35. Chart. Use of policies or practices for long-term storage and maintenance of project data, including 3D data.

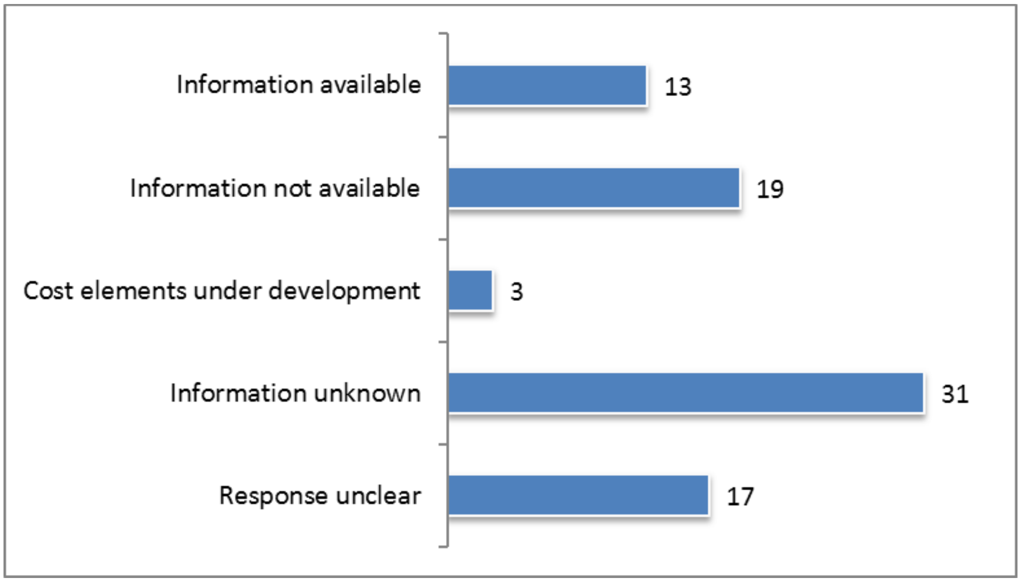


Source: FHWA.

Figure 36. Chart. Types of State transportation department policies and practices for long-term storage and maintenance of project data, including 3D data.

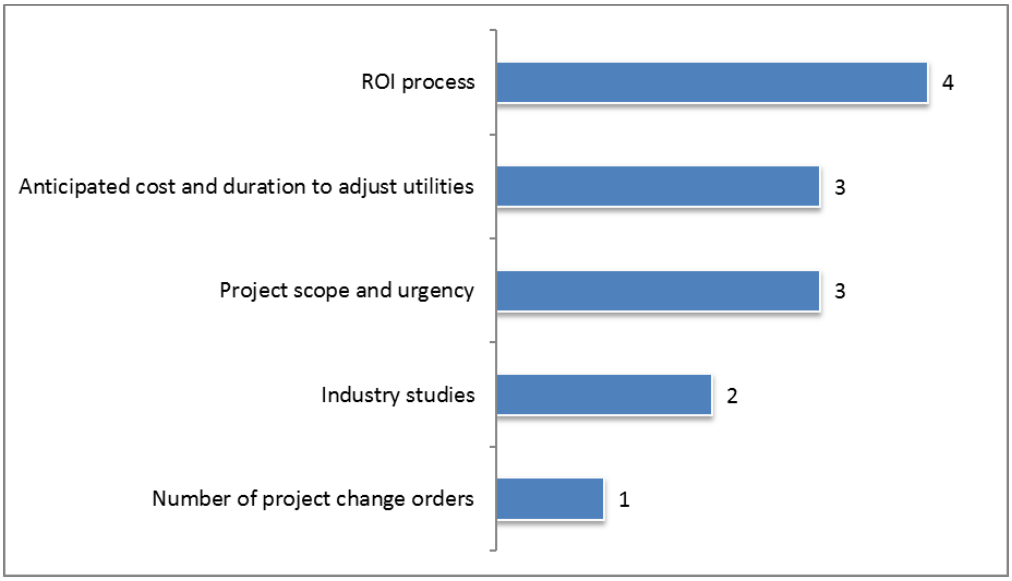
Information to Determine 3D Data Effectiveness

Only a few State transportation departments reported having cost elements or other information to determine the effectiveness of 3D data (figure 37). Most agencies were unsure or did not know whether this type of information was available. In some cases, they indicated that some cost information might be available. However, this information was generic. For example, several agencies mentioned an ROI process but not which cost elements they considered for the ROI analysis (figure 38).



Source: FHWA.

Figure 37. Chart. Cost elements and other information to determine effectiveness of 3D data.



Source: FHWA.

Figure 38. Chart. Types of cost elements and other information used to determine 3D Data effectiveness.

Use of RFID Technology for Marking Utility Installations

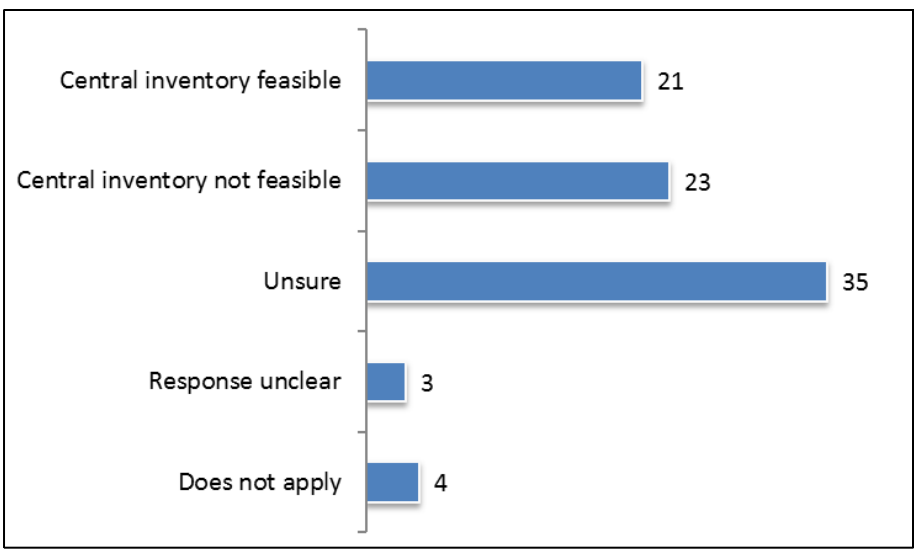
Only a few State transportation departments indicated some level of experience with RFID technology to mark utility installations (table 6). Of particular interest was the use of RFID ball markers in Virginia, as explained in detail in chapter 5.

Table 6. Use of RFID technology for utility installations.

State	Responses
Alaska	Minimal use.
Florida	FDOT allows the use of RFID technology.
Georgia	Participation in a pilot demonstration in Columbus, GA, as part of a SHRP2 project.
Kentucky	Consultants have used RFID ball markers in conjunction with utility investigations at the request of the department.
Minnesota	Use of ball markers, a line management system, and locating wands.
Texas	Involved in research projects but nothing in production.
Virginia	VDOT has established practices, installation guidelines, specifications, and protocols to install RFID markers and map utility systems using GPS technology. This system has been used in conjunction with a SHRP2 project to store, record, and retrieve underground utility data. The process started as a pilot program and has become an inspection procedure for new and relocated utility systems. The process has been implemented on numerous projects in the Northern Virginia District. It is also being used to map internal VDOT infrastructure, including fiber optic systems, interstate lighting, traffic signal systems, and signs. Installation management practices, field controls, and cost analysis have been performed.
Washington State	Some consultants use it, as well as some utility owners and utility location services.
West Virginia	Only used by third parties.

Centralized Utility Inventories at State Highway Agencies

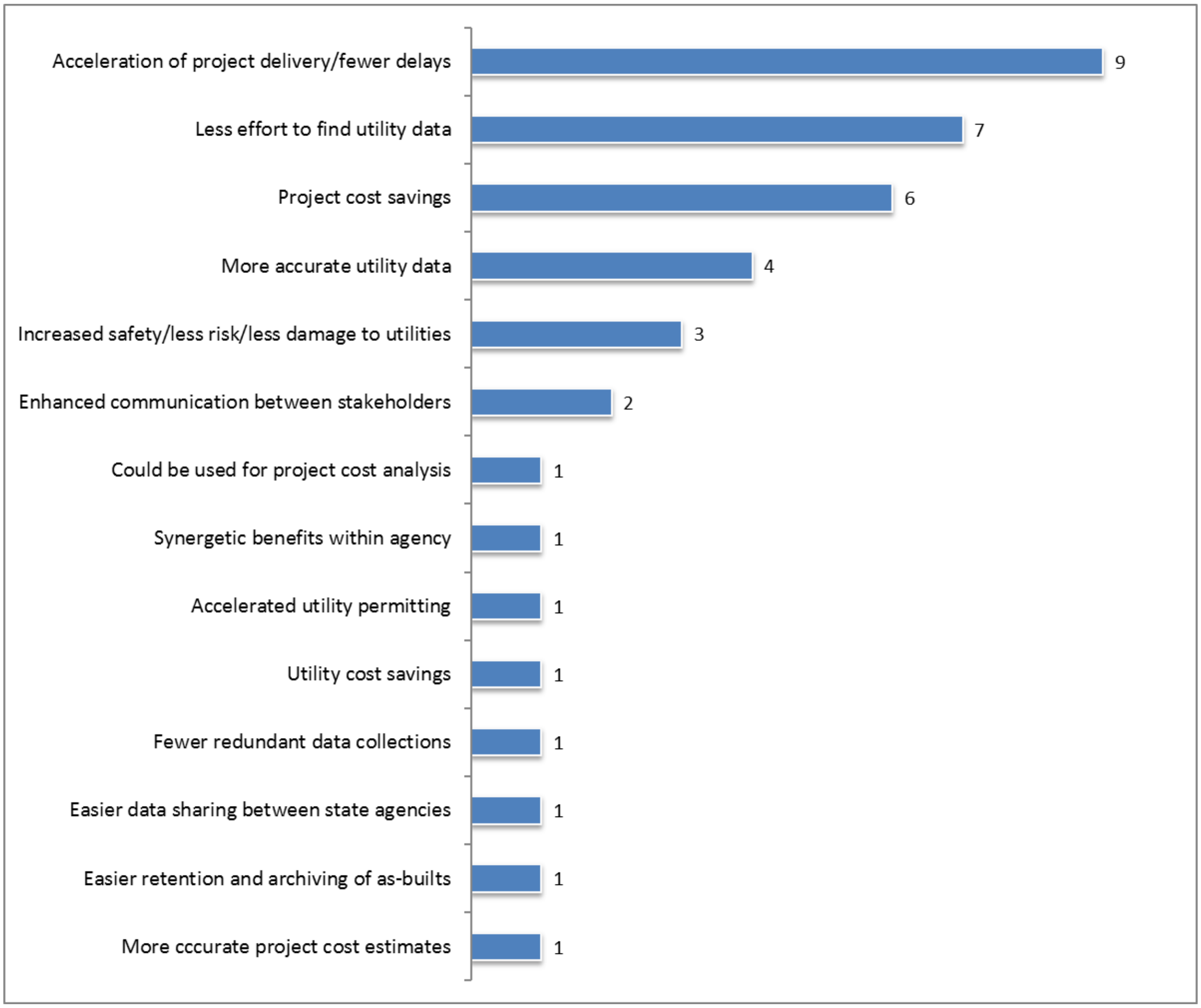
Most State transportation departments are skeptical about the feasibility of being the central repository of utility information within the highway right-of-way. As shown in figure 39, 35 respondents (or 41 percent) were unsure whether having State transportation departments as the central repository of utility information within the highway right-of-way was feasible. A total of 23 respondents (or 27 percent) indicated that having State transportation departments as the central repository of utility information was not feasible. Only 21 respondents (or 24 percent) indicated that it was feasible.



Source: FHWA.

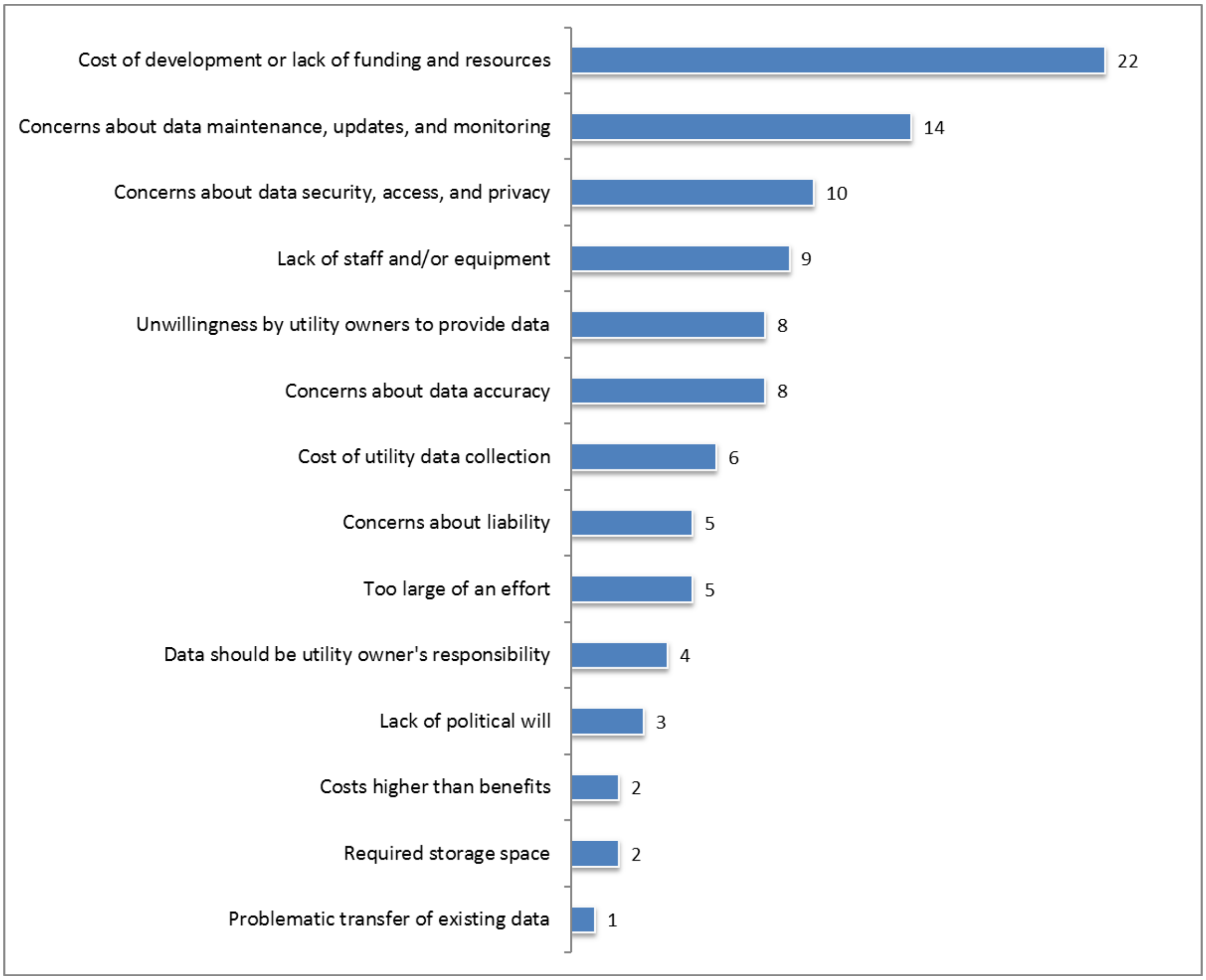
Figure 39. Chart. Feasibility of having State transportation departments as the central repository of utility information.

Although skeptical about the feasibility of having State transportation departments as the central repository of utility information, many State transportation department officials provided feedback about the benefits of developing utility data inventories at their agencies. Figure 40 summarizes potential benefits that State transportation departments mentioned, grouped into categories. The research team followed a similar approach for anticipated barriers (figure 41). As a side note, the number of barriers mentioned (99) was almost triple the number of anticipated benefits (39). However, a simple 1:1 comparison of the number of anticipated benefits versus the number of barriers is not meaningful because the benefits and barriers mentioned are not necessarily at the same level.



Source: FHWA.

Figure 40. Chart. Benefits of a centralized inventory of utility information.



Source: FHWA.

Figure 41. Chart. Barriers to implementing a centralized utility inventory.

By far, the main barrier to implementation that participants mentioned was the lack of funding and resources. Participants also voiced concerns about the effort and cost to maintain and update the system, and monitoring the submission of utility data to maintain systemwide data accuracy standards. These issues were followed by concerns about data security, access, and privacy; concerns about the lack of staff and/or equipment to conduct an implementation; concerns about a lack of interest by utility owners to participate; and concerns about the accuracy of the data that would reside within the system.

CALIFORNIA

Caltrans

Historically, Caltrans has used 3D for visualization mainly for outreach purposes. Caltrans is beginning to use 3D for design and construction. One of the motivations for using 3D in this capacity is the anticipation of fewer delays and lower project costs. Although the agency does not have disaggregated data to confirm it, Caltrans officials estimate that up to 30 percent of construction change orders are attributable to not knowing the location of existing underground facilities.

Caltrans does not have specific rules or guidelines to develop projectwide locations using 3D data, except in the case of surface models, where the current requirement is to develop the original ground surface model in a 3D MicroStation® .dgn file or Autodesk® .dwg file. Within the Autodesk® Civil 3D® environment, which Caltrans is beginning to use, the expectation is that at the end of the workflow process, every project with earthwork will have a 3D model.

In 2009, Caltrans completed an evaluation of the use of 3D models for AMG applications, which resulted in an update to its 2005 AMG guidelines.(71,72) The updated AMG guidelines were later included in a national compendium of practices assembled by the AASHTO Subcommittee of Construction.(73) The 2009 evaluation was based on a pilot application that involved developing a 3D surface for the Brawley Bypass Stage II construction project in Imperial County and providing the 3D model to the contractor for AMG purposes. The contractor reported benefits such as producing much faster takeoffs from 3D CAD files, 30 percent less time for checking grade and providing intermediate control, and 20 to 25 percent less survey for grading operations. Several lessons learned from that evaluation are relevant to this research, including, but not limited to, the following:

- Designing in 3D should start at the beginning of the design phase. It is less efficient to generate 3D files after the design is substantially complete.
- Providing 3D files to contractors at bidding time can result in better, closer bids, as well as lower risk for the contractor.
- Separate preconstruction meetings between the contractor and project managers and surveyors should take place to discuss survey control and Global Navigation Satellite System calibration. It is advisable to recheck the ground control prior to construction.
- Designers should meet with contractors to learn about the machine guidance process so they can prepare a better product for the contractor.
- There were some issues with the conversion of 3D CAD files to LandXML format, leading to the recommendation for using LandXML for horizontal alignments, vertical alignments, and the 3D surface model, as well as original 3D CAD files for original ground files.

Caltrans uses test holes for utility investigations, but they are not certified at QLA. Depending on the project, consultants use noninvasive geophysical methods such as GPR, but the resulting data are not certified at QLB. The Caltrans Geotechnical Services Unit has started a pilot initiative to offer GPR, magnetometry, and electromagnetic conductivity services to identify underground utility installations. The department has used LIDAR extensively to collect roadway and roadside information. However, it is not clear to what degree LIDAR point clouds have been used to develop systematic inventories of visible utility features.

Caltrans has X, Y, Z data collection requirements for utility installations. The current guideline for spatial resolution of utility facilities includes different requirements according to a preestablished classification between high-risk and low-risk facilities.(74) This differentiation only applies to facilities that carry petroleum products, gas, oxygen, chlorine, toxic or flammable gases, and electricity. It does not cover installations such as water, sanitary sewer, or communications. For high-risk facilities, the minimum requirement is to collect X, Y, Z data within 0.5 ft horizontally and vertically every 100 ft or less. Contract plans must show horizontal and vertical locations for those facilities. For low-risk facilities, the requirement is to show horizontal locations every 100 ft or less, but showing vertical data is optional. Allowable methods for documenting horizontal and vertical locations include test holes, probes, electronic detectors (defined as devices "designed to detect underground utility facilities via electronic signals with sufficient accuracy to determine horizontal and vertical location"), and as-built documents.

Caltrans is developing a prototype utility database using GIS and CAD technology. District 11 is taking the lead in developing and implementing this strategy. The district also established a task order for a contractor to collect utility data using GPR. In addition, the district is planning to acquire GPS receivers as well as pipe and cable locators to conduct utility investigations in-house. In addition, the district is considering acquiring RFID ball markers to inventory utility installations while the utility facility trenches are still open during construction.

District 11 officials developed a GIS-based data model to facilitate the inventory of utility installations. The current plan is for the database implementation to be in 2D. However, the district has not ruled out the possibility of migrating to 3D. Populating the database will rely on several data sources, primarily permit data and utility relocations. The initial data model, developed in Esri®'s geodatabase format, included one feature class for point features and one feature class for linear features. Differentiation among different types of utilities was by attribute, according to CAD line style attribute data. Subsequent efforts involved developing a data model in Bentley Map format, which included 19 different utility feature classes.(75) Figure 42 shows a sample of feature classes.

Underground Electric Line

Name	Display Name	Type	# chars
Status	Status	string	15
Owner	Owner	string	36
Capacity	Capacity	integer	7
Units	Units	string	3
Risk	High/Low Risk	string	9
SUEQuality	SUE Quality	string	1
DuctsNo	Number of Ducts	integer	3
DuctDia	Duct Diameter:	string	7
DuctMat	Duct Material:	string	30
CasingSize	Casing Size:	string	7
CasingType	Casing Type:	string	30
PermitNo	Permit Number:	string	20
ProjectNo	Project Number:	integer	10
YearInstalled	Year Installed:	year4	4
Comments	Comments	string	255
UserName	User Name:	string	12
DateEdited	Date Edited	string	36

Overhead Electric Line

Name	Display Name	Type	# chars
Status	Status	string	15
Owner	Owner	string	36
Capacity	Capacity	integer	7
Units	Units	string	3
Risk	High/Low Risk	string	9
SUEQuality	SUE Quality	string	1
PermitNo	Permit Number:	string	20
ProjectNo	ProjectNo	integer	10
YearInstalled	Year Installed:	year4	4
Comments	Comments	string	255
UserName	User Name	string	12
DateEdited	Date Edited	string	36

Underground Telecommunication Line

Name	Display Name	Type	# chars
Status	Status	string	15
Owner	Owner	string	36
SUEQuality	SUEQuality	string	1
DuctsNo	DuctsNo	string	3
DuctDia	DuctDia	string	30
DuctMat	DuctMat	string	30
CasingSize	CasingSize	string	7
CasingType	CasingType	string	30
PermitNo	PermitNo	string	20
ProjectNo	ProjectNo	integer	10
YearInstalled	YearInstalled	year4	4
Comments	Comments	string	255
UserName	Editor	string	12
DateEdited	Date Edited	string	36

Gasoline Line

Name	Display Name	Type	# chars
Status	Status	string	15
Owner	Owner	string	36
Capacity	Capacity	integer	7
Units	Units	string	3
Risk	Risk	string	9
SUEQuality	SUE Quality	string	1
PipeDia	Pipe Diameter	string	7
PipeMat	Pipe Material	string	3
CasingSize	Casing Size	string	7
CasingType	Casing Type	string	7
PermitNo	Permit Number	string	20
ProjectNo	Project Number	integer	10
YearInstalled	Year Installed	year4	4
Comments	Comments	string	255
UserName	Editor	string	12
DateEdited	Date Edited	string	36

Water Line

Name	Display Name	Type	# chars
Status	Status	string	15
Owner	Owner	string	36
Capacity	Capacity	integer	7
Units	Units	string	3
SUEQuality	SUE Quality	string	1
PipeDia	Pipe Diameter	string	7
PipeMatWtr	Pipe Material	string	48
CasingSize	Casing Size	string	7
CasingType	Casing Type	string	30
PermitNo	Permit Number	string	20
ProjectNo	Project Number	integer	10
YearInstalled	Year Installed	year4	4
Comments	Comments	string	255
UserName	UserName	string	12
DateEntered	DateEntered	string	32

Sanitary Sewer Line

Name	Display Name	Type	# chars
Status	Status	string	15
Owner	Owner	string	36
Capacity	Capacity	integer	7
Units	Units	string	3
SUEQuality	SUE Quality	string	1
PipeDia	Pipe Diameter	string	7
PipeMat	PipeMat	string	45
CasingSize	CasingSize	string	7
CasingType	CasingType	string	30
PermitNo	PermitNo	string	20
ProjectNo	ProjectNo	string	10
YearInstalled	YearInstalled	year4	4
Comments	Comments	string	255
UserName	Editor	string	12
DateEdited	Date Edited	string	36

Courtesy of Caltrans.

Figure 42. Diagram. Caltrans District 11—utility feature classes.(75)

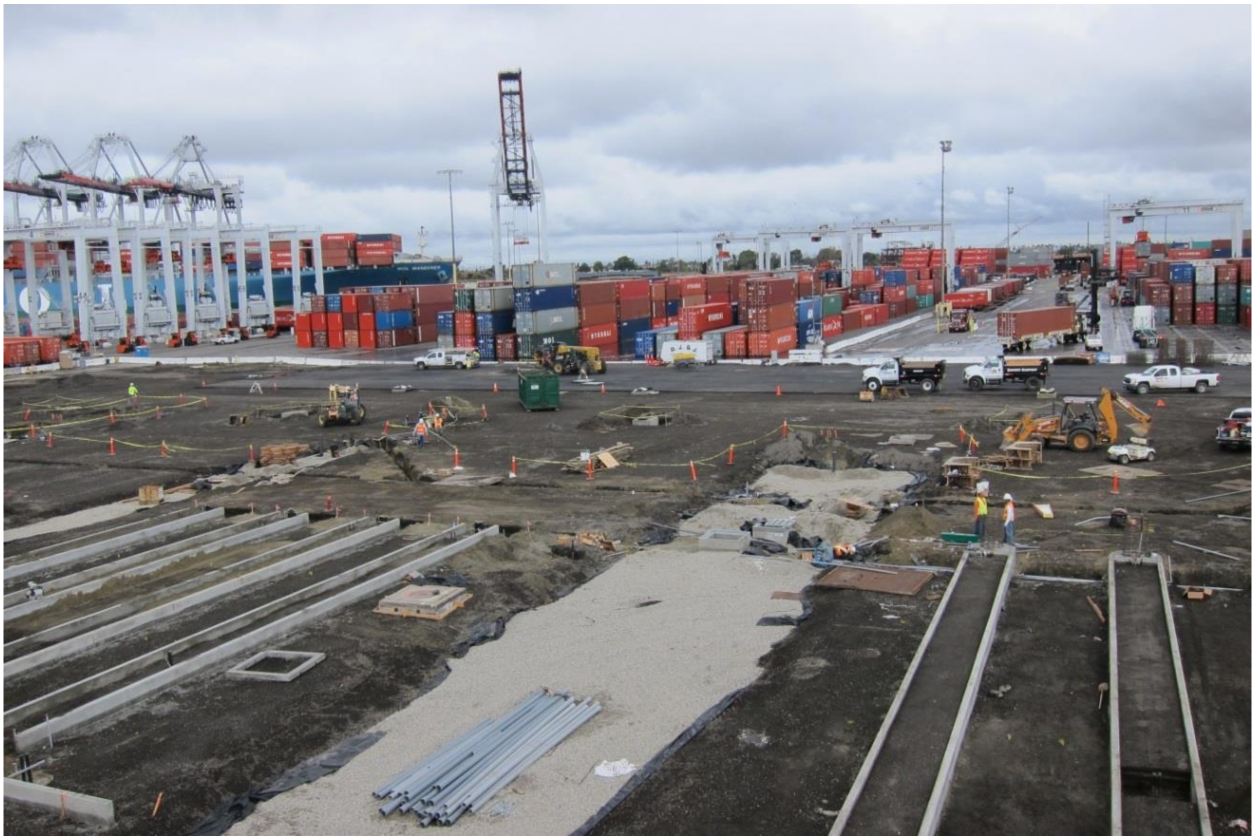
Port of Los Angeles

The Port of Los Angeles has eight major container terminals and four dockside intermodal rail yards with direct access to the 20-mi Alameda Corridor railway connecting the port-to-rail hubs in Los Angeles.(76) The $42 million Berths 144–145 Backland Improvement Project is part of the phased development of the Berths 136–147 TraPac Container Terminal Improvement Project. The ultimate goal of this program is modernization and automation of container ship and container handling operations. The Berths 144–145 Backland Improvement Project is funded partially through Caltrans under Proposition 1B, State Trade Corridor Improvement Fund.

The Berths 144–145 Backland Improvement Project consists of 21 acres of container terminal backland improvements, including installation of 4 rows of infrastructure for automatic stacking cranes infrastructure, grading, paving, storm drain, water and fire protection, rail, fiber optic conduit, electrical, and lighting. The project area of 21 acres is roughly equivalent to the right-of-way needed for 3.5 center mi (or 7-lane mi) of a 2-lane urban road having 50 ft of right-of-way width. Figure 43 and figure 44 provide a general view of the project location. The figures also show operational areas outside the project limits that are used to receive and process containers. During the design phase, the work area was also an operational port area, which gives an idea of the challenges for gathering information about existing underground installations, including utilities, before the construction started.

Source: FHWA.

Figure 43. Photo. View of the berths 144-145 Backland Improvement Project (part 1).



Source: FHWA.

Figure 44. Photo. View of the berths 144-145 Backland Improvement Project (part 2).

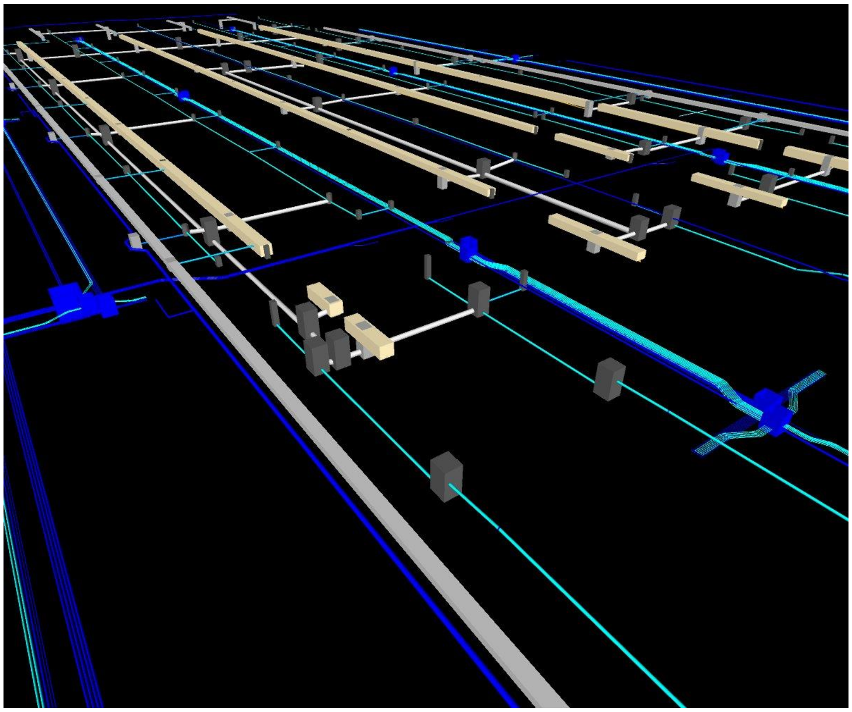
The project was a typical design–bid–build project in which the contractor received a set of construction plans from the port authority. A consultant had previously prepared those plans under contract with the port. In preparation for the construction phase, the contractor prepared a 3D model of the project surface and then added 3D models of both surface and underground installations, including drainage, utilities, and other facilities throughout the entire project (figure 45 and figure 46). The design consultant had previously provided existing utility maps based on information and records received from the port authority and, in some cases, utility companies. The berth was operational at the time the design was taking place, making it difficult for the design consultant to conduct a more thorough utility investigation.

To reduce risk and uncertainty, the contractor hired a consultant to collect GPR data to develop an inventory of underground installations. The consultant provided a 2D CAD file of horizontal locations with annotations indicating underground installation depths at locations where test holes were used. The GPR data collection took less than a week to complete. The cost was $20,000 (or $952/acre). Having a 3D surface model of the project area enabled the contractor to generate a 3D georeferenced model of existing underground facilities. The contractor also generated a 3D model of proposed underground facilities. According to contractor officials, the depth information based on the data collected by the GPR consultant was accurate and consistent with depth values the contractor obtained later during excavation activities.

The 3D model of underground installations included attributes (e.g., in the case of manholes, the attribute data included manufacturer information and other metadata). Developing a 3D model of underground installations enabled the contractor to identify many locations where there were conflicts (figure 45 and figure 46). The protocol for resolving a typical conflict was as follows:

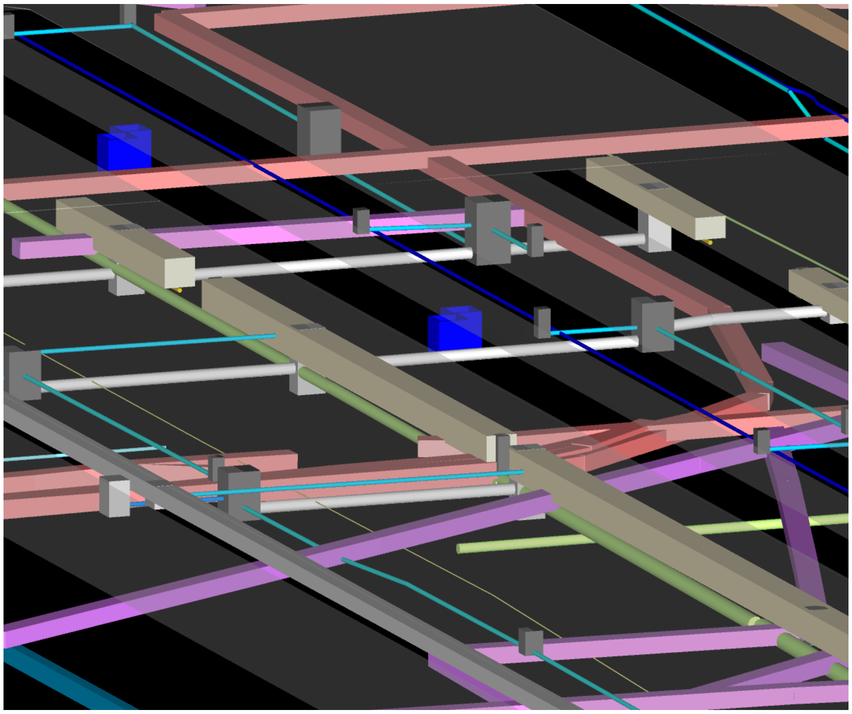
- The contractor submits an information request ticket to the port authority, using a Web-based information and document exchange application.
- The port authority forwards the request to the original design consultant with a request to address the conflict, prepare a solution, and submit the solution to the port authority.
- The port authority forwards the necessary engineering documentation to the contractor.
- The contractor implements the solution at the job site.

The contractor found this process to be effective. Nevertheless, the contractor also recognized that, ideally, it would be much more efficient and cost effective to address utility issues during the design phase. Having to manage utility conflicts during construction is not profitable.



Courtesy of Sukut Construction.

Figure 45. Screen capture. 3D model for the Berths 144-145 Backland Improvement Project (part 1).



Courtesy of Sukut Construction.

Figure 46. Screen capture. 3D model for the Berths 144-145 Backland Improvement Project (part 2).

In addition to the identification and management of conflicts in 3D, the contractor developed as-built files documenting the actual location of new and relocated underground facilities. In general, as-built information involved documenting X, Y, Z coordinates associated with specific locations and annotating that information on 2D CAD files. These locations matched the design locations within construction tolerances. In some isolated cases where there were discrepancies, the contractor worked with the port authority to develop a solution that included (as needed) rebuilding the component.

Contractor officials did not have documentation on the cost to prepare the 3D models. In their view, the experiment was highly successful, even when considering that the resident engineer who built the 3D models did not have previous experience developing 3D models (although the engineer received support from more experienced staff). The contractor shared the lessons learned with port authority officials. Although the port was not ready to embrace a change in policy to migrate fully to a 3D environment, it at least decided to make the use of GPR surveys a requirement for future projects. The port authority reimbursed the contractor for the cost of the GPR survey.

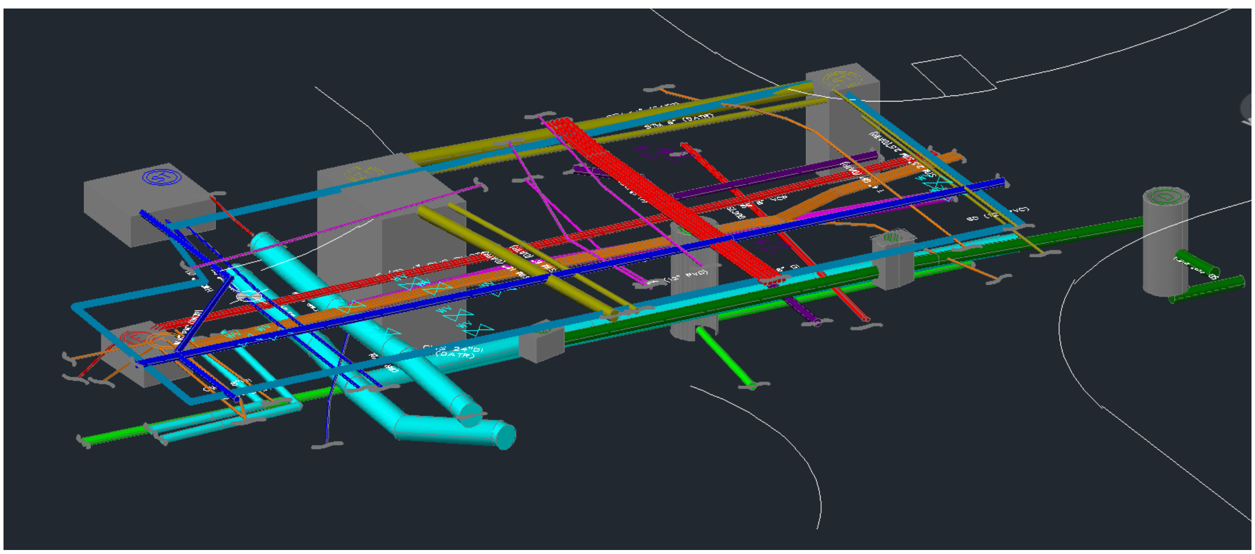
For the project, the contractor used machine control for earthwork activities. For subsequent projects, the contractor would like to augment this capability by including utilities in AMG operations. Based on the lessons learned with this project, the contractor's perception is that the process to include utilities should be easier than for earthwork because there are fewer variables.

Using Autodesk® Civil 3D® for the first time to model utility installations was a learning experience because of the need to generate many parts from scratch to develop 3D models that could be considered sufficiently realistic. The contractor recommended developing a standard library of parts for 3D models that contractors, project owners, and consultants could use for all projects, similar to what the *Standard Plans for Public Works Construction* (also called the "Greenbook") provides.(77) At the same time, the contractor advised focusing on model functionality (i.e., making sure that all the location information in the model is accurate and reliable). 3D rendering is important but only to the extent that it supports functionality goals.

Stanford University

Stanford University began the $485 million Stanford Energy System Innovations (SESI) project to replace the existing cogeneration plant powered by natural gas with a heat recovery plan powered by electricity.(78) This change also requires conversion of the campus steam distribution system to a hot water system because available heat recovery equipment can produce only hot water but not high-temperature, high-pressure steam. The cost of SESI is expected to be about $438 million, with savings expected to reach $639 million by 2050.

To evaluate the implications of replacing the campus steam distribution system, the contractor hired a consultant to develop a 3D inventory of existing utilities all over campus (figure 47). The consultant used radar tomography and other geophysical techniques to develop the 3D model. The consultant estimated that the additional cost of using tomography and building the 3D model represented approximately 30 percent of the original utility investigation cost.



Courtesy of Stanford University and GEL Geophysics.

Figure 47. Screen capture. 3D inventory of utilities at Stanford University.

CONNECTICUT

CTDOT is transitioning to a centralized digital project data storage and exchange for all transportation projects. Currently, the State uses InRoads®. If a consultant uses different CAD software (e.g., Autodesk® Civil 3D®), the department requires the conversion of all design deliverables to Bentley® format. CTDOT requires designers to submit design data in accordance with the department's electronic engineering data standard.[(79)] The department conducts about 25 percent of the design work in-house.

CTDOT is currently piloting the use of 3D modeling techniques. The department's goal is to require 3D models for both in-house and consultant design work. A justification for using 3D models is being able to provide contractors with better design information that can result in cost savings during construction. Some consultants have started using 3D models when designing projects. However, they are required to generate 2D design sheets for the preparation of deliverables to the department. A disadvantage of this approach is that, when changes are necessary, consultants frequently update their 2D sheets but not the original 3D models.

CTDOT currently does not use 3D modeling techniques for utilities. The department recognizes that obtaining accurate utility data is challenging, although it anticipates that developing 3D models for utility installations could lead to better estimates of costs and quantities associated with utility relocations.

CTDOT has not conducted estimates of the additional cost to develop 3D models. CTDOT follows a traditional approach for negotiating design projects that involves reaching an agreement on the price per sheet. Partly because of this practice, it would be difficult to separate costs associated with digital modeling.

Recently, CTDOT completed a five-legged roundabout, which used 3D models for both visualization and design. The use of the 3D models during the design stage enabled better estimates of quantities and costs. During construction, the contractor imported the 3D model into its survey GPS tools to improve construction quality and accuracy. Using a similar method, the CTDOT inspector was able to check the progress of the construction against the 3D model for a more effective construction QC. The 3D model also enabled the inspector to generate as-built documentation.

As part of the I-95 New Haven Harbor Crossing Corridor Improvement Program, CTDOT used 3D and 4D modeling techniques, primarily for visualization and construction management. The I-95 program is a $2 billion multimodal transportation improvement program that includes public transit enhancements and roadway improvements along 7.2 mi of I-95 between Exit 46 (Sargent Drive) in New Haven and Exit 54 (Cedar Street) in Branford.

The I-95 project was the first major project in which CTDOT used 3D and 4D modeling extensively. To facilitate public outreach, CTDOT hired a consultant to prepare 3D and 4D models, which involved conversion of 2D plans and profiles to a 3D visualization platform that included enhancement of simple 3D surface models through surface scanning for a more realistic effect. The modeling effort did not include utilities. To verify and control modeling costs as well as train CTDOT staff, CTDOT asked the consultant to relocate a modeling specialist to Connecticut. As a result, the total modeling cost was probably higher than it would have been otherwise. The department anticipates costs to decrease in the future as procedures and requirements for the production of 3D and 4D deliverables are standardized. CTDOT has spent roughly $500,000 on 3D modeling so far. For a specific modeling effort that included modeling eight traffic shifts, each one with multiple modeling views, the total cost was $277,000. As a reference, the total cost of the design for the entire program was about $95 million, including design during construction.

According to CTDOT officials, the 3D and 4D visualizations have benefited the department's public outreach efforts significantly. For example, the public was able to understand the project and the associated traffic impact better, which resulted in less pressure and stress for department officials. The modeling effort also helped CTDOT to identify construction staging errors and inefficiencies that otherwise might have resulted in construction delays and more traffic impact. There were also "non-routine" applications (e.g., modeling the temporary location of an incident management camera that had to be relocated because of construction activities). The positive experience with this effort led the ITS group to consider similar 3D modeling activities for other incident management cameras along the corridor.

Partly because of the 3D and 4D modeling initiative, the improvement program realized project delivery time and budgetary savings. Realizing the benefit of the 3D and 4D models, a contractor who was originally not receptive to the 3D concept requested 3D models to use during construction. CTDOT also decided to spend more money on the use 3D and 4D modeling techniques on construction management.

FLORIDA

Several design–build projects at FDOT have been designed and built using 3D technologies, including AMG. From anecdotal evidence, the agency knows that this technology results in increases in efficiency and cost savings. However, the current contracting framework for design–build projects gives considerable freedom to developers on how to manage their contracts. As a result, FDOT does not have access to sufficient information to determine which specific aspects of the technology translate into productivity increases or cost reductions.

Nevertheless, based on what FDOT learned from the design–build process and feedback from other States, the agency decided to implement an initiative to migrate conventional design–bid–build projects to a 3D design environment. Part of this initiative was the publication of the *FDOT2014 Civil 3D State Kit* to provide additional resources for the production of 3D design deliverables to the department.(80) For drainage and utilities, the process includes a workflow for creating LandXML files for importing these files into Civil 3D®.

FDOT has also released guidelines for mobile LIDAR applications, which are based on the Caltrans *Surveys Manual*.(81,82) In addition, FDOT is developing surveying prequalification requirements for remote sensing activities, including technologies that gather aboveground, underground, or subaquatic 3D data. FDOT has an enterprise GIS framework and an electronic document management system. However, the current implementation is geared toward 2D applications.

It is common to collect QLB and QLA data in situations where there are drainage or geometric improvements. The FDOT *Plans Preparation Manual* provides guidance on timing and use of utility investigations.(83) According to this manual, existing record data collection and QLB data collection should be complete by 30-percent design, depending on the type of utility conflicts. QLA data collection should be complete at about 60-percent design. QLB and QLA deliverables are typically CAD drawings in state plane coordinates.

FDOT has used GPR arrays for utility investigations for several years. In a typical application, GPR arrays enable the production of 2D and 3D imagery that analysts use in conjunction with conventional utility investigation techniques to prepare plans that include plan views, profiles, and test hole reports. As an illustration, figure 15 through figure 18 show a sample of 2D images using GPR arrays for a project on Route A1A in Palm Beach, FL. According to the consultant, GPR arrays have reduced the need for test holes by 90 percent. In general, the consultant pre-scans locations with 2D radar randomly to make sure the area is favorable to the use of GPR arrays.

FDOT started a pilot initiative to examine the feasibility of extending the functionality of GPR arrays to enable the production of utility data products in 3D. The scope of the project includes using radar tomography to collect data in the field, process the raw data to generate 3D imagery, and produce 3D lines, shapes, and models. The expectation of vertical infrastructure locations is up to a maximum of 10 ft deep from the surface in optimum GPR conditions. The horizontal and vertical accuracy expectation is 0.5 ft, using as a point of reference the center and/or top crown of all lines, pipes, or objects.

The pilot initiative involves using GPR arrays in two capacities: standalone and in combination with conventional utility investigation techniques. In standalone mode, the objective is to determine to what degree GPR arrays can detect underground facilities without any additional piece of information. Conventional utility investigations following the CI/ASCE 38-02 standard, including minimally intrusive verifications, are also used to validate and augment the quality of the information.(1) For the initiative, districts were asked to suggest construction projects that needed utility investigations that were not extremely complicated. Because the data collection was in the context of actual project needs, all deliverables had to meet FDOT’s standards and requirements for utility investigations.

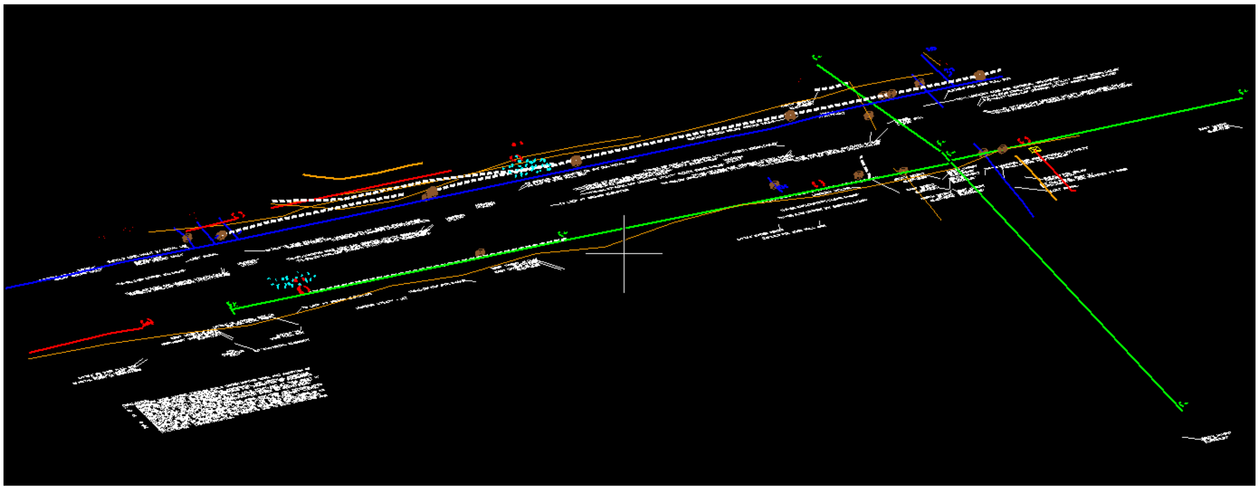
For a project on State Route 46 in Seminole County, FL, the utility data collection involved the designation of slightly more than 41,000 ft of utilities.(84) An initial assessment had indicated the possibility of approximately 29,000 ft of utilities needing designation. The GPR array was generally adequate, with penetration depths up to 8 ft below the ground surface. Initially, a dielectric value of 9.0 was used to estimate the depth of observed features. However, average dielectric calculations based on depths measured at test hole locations ranged from 2.4 to 9.5, for an overall average of 6.0 across the project. These actual dielectric values were then used, and depth values were adjusted. Some extrapolation was necessary outside the contour plot bounded by the test holes.

In several instances, installations were found with EMI locators but not with the GPR array. In other instances, the depth obtained with either EMI locators or GPR array was off compared with the depth measured at test holes. Overall, the consultant concluded that the GPR 3D imagery provided an adequate backbone for the development of the 3D deliverable but that all data collection methods used contributed to a more reliable deliverable than would have been possible with each method on its own. Table 7 shows a sample of points comparing the vertical accuracy of the GPR array and the EMI locator.

Table 7. State Route 46 Project GPR array versus EMI locator vertical accuracy.

Point Number	Test Hole Number	Depth/Cut (ft)	EMI Locator Depth (ft)	GPR Array Depth (ft)	Best Depth Estimator
CTH7	TH8	2.41	1.5	2.2	GPR array
CTH8	TH9	1.99	2.0	2.4	EMI locator
GCSH1	39A	1.75	2.1	2.1	Same
GCSH8	26	2.50	2.7	4.8	EMI locator
GCSH21	41	4.85	2.9	4.4	GPR array
GCSH18	TH25	2.10	3.0	1.7	GPR array
ECSH1	43	2.40	3.1	2.4	GPR array
GCSH17	43A	3.20	3.2	2.2	EMI locator
GUNK21	TH16	3.38	3.2	2.2	EMI locator
DTH10	TH16A	4.49	3.3	4.2	GPR array

For a project on State Route 60 in Hillsborough County, FL, the utility data collection involved the designation of almost 32,000 ft of utilities.[(85)] The data collection process was similar to that completed on State Route 46, although there were some differences in project characteristics. Along with the GPR array, data collection included an EMI locator complemented by test holes at critical locations. The deliverable included a 3D model of utility features (figure 48). Notice that the 3D model only used points and lines to represent utility features. It did not fully render those features in 3D. One of the reasons was that the data collection equipment did not always enable a positive confirmation of pipe diameters or cross sections, which would be necessary to develop a full 3D model.



Courtesy of Cardno.

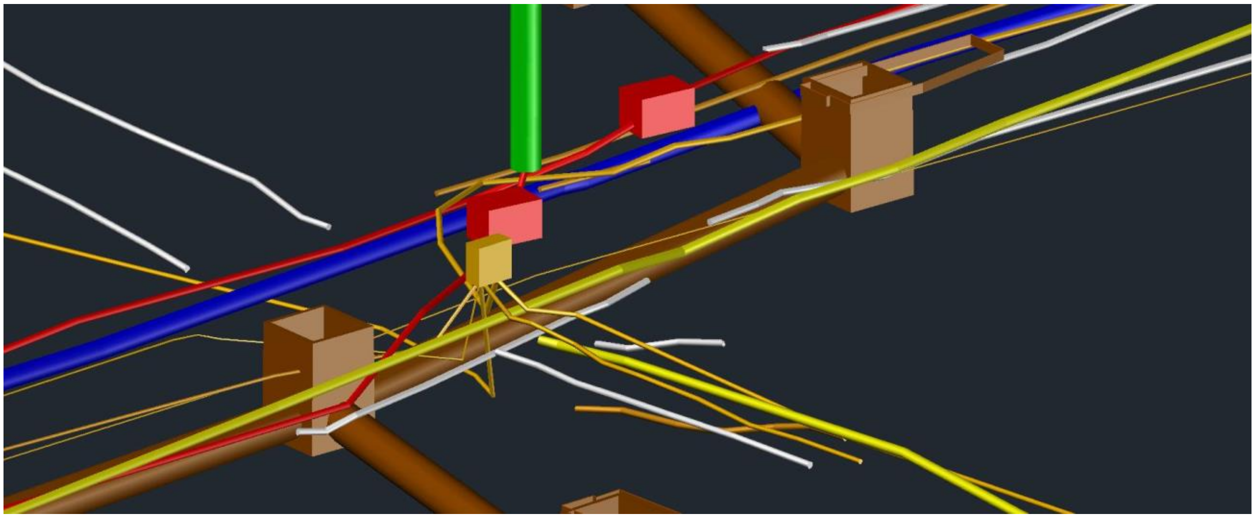
Figure 48. Screen capture. Views of 3D model for utility investigation on State Route 60.

Overall, the GPR array produced more reliable depth measures than the EMI locator. Table 8 shows a sample of points comparing the vertical accuracy of the GPR array and the EMI locator. In several instances, installations were found with EMI locators but not with the GPR array. Overall, the GPR array was able to detect approximately 58 percent of the 32,000 ft of utilities that were mapped, ranging from 24 percent in the case of fiber optic lines to 99 percent in the case of gas lines.

Table 8. State Route 60 Project GPR array versus EMI locator vertical accuracy.

Point Number	Test Hole Number	Depth/Cut (ft)	EMI Locator Depth (ft)	GPR Array Depth (ft)	Best Depth Estimator
UFCSH3	TH1-4	6.75	5.33	6.9	GPR array
UFCSH4	TH1-1	6.58	4.08	7.1	GPR array
UFCSH6	TH1-5	1.95	2.50	1.9	GPR array
UFCSH7	TH1-8	3.96	4.67	4.1	GPR array
UFCSH8	TH1-7	3.72	2.92	4.1	GPR array
UFCSH9	TH1-9	3.70	6.17	3.7	GPR array
UGBT3	TH1-18	3.56	3.42	2.9	EMI locator

For a project on State Route 189 in Fort Walton Beach, FL, the utility data collection involved the designation of utilities in area that was approximately 31,000 ft^2 in size.[86] The utility investigation included a visual assessment of existing utility appurtenances; scanning of the project area with EMI and GPR equipment; excavation of several test holes and slit trenches; surveying of designating marks, utility appurtenances, and scan area; and creation of a DTM surface model. The deliverable also included a 3D model of utility features (figure 49).



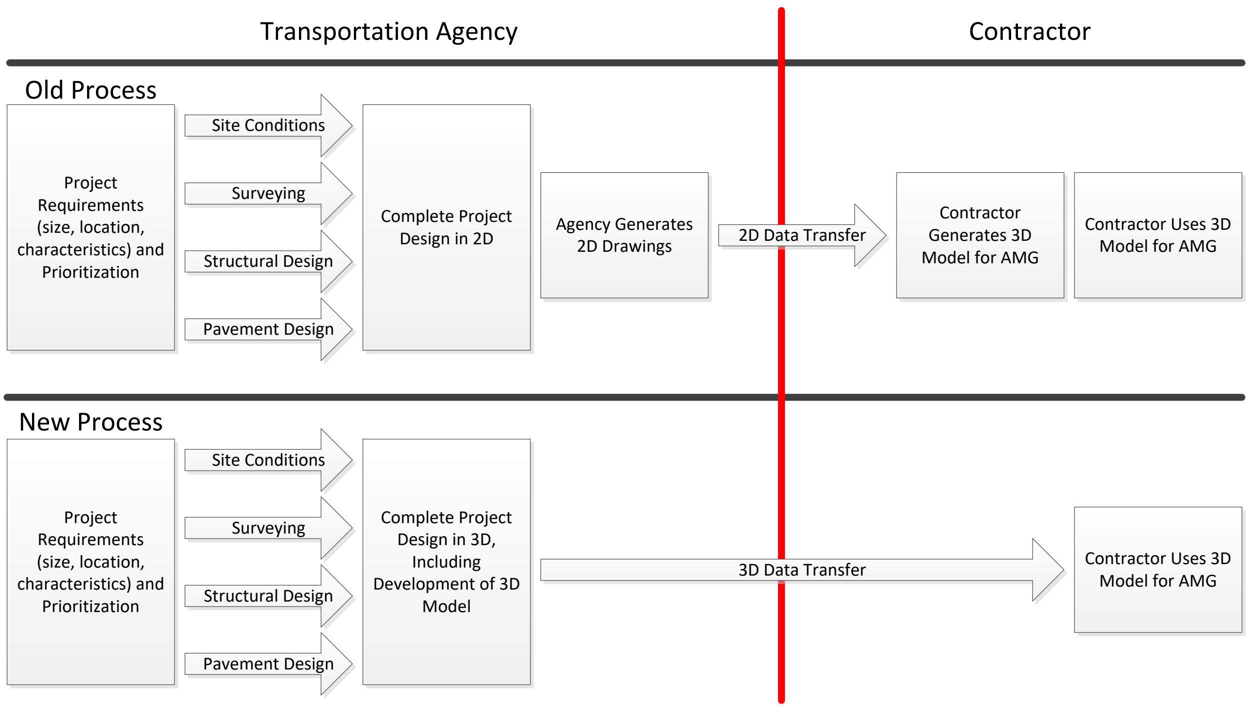
Courtesy of Cardno.

Figure 49. Screen capture. 3D visualization of existing aboveground and underground infrastructure on State Route 189.

IOWA

The Iowa Department of Transportation (Iowa DOT) has migrated its design environment to 3D, although some projects are still designed in a 2D environment. What started as an experimental initiative in the mid-2000s to provide data needed by contractors to automate their machine control guidance process has now evolved into a 3D environment in which the roadway design is fully executed in 3D with the exception of drainage structures and bridges.

Figure 50 illustrates the change in business process at Iowa DOT with respect to 3D modeling practices. In the mid-2000s, the agency met with representatives of the construction community to discuss strategies on how to make the construction process more efficient. What emerged was recognition that the transfer of 2D plans from the agency to the contractor at the beginning of the construction phase was a source of inefficiency and higher costs. Until then, a contractor would receive the 2D plans and then develop a 3D model from scratch for AMG purposes. The question was whether the agency could prepare the 3D model during the design phase and provide this model to the contractor. There were legal hurdles. For example, the official design document is still a set of design plans signed and sealed by a registered professional engineer (PE). Under these circumstances, a strategy emerged in which the agency develops the 3D design; prepares a set of traditional plans, profiles, and cross sections views from the model; and then prints, signs, and seals the plans. The 3D model is then transferred to the contractor with a waiver that the model is for information only and that any model the contractor uses that is derived from designer's 3D model must conform to the hard-copy plans. Otherwise, the contractor must use the 2D plans to develop its own 3D model.



Source: FHWA.

Figure 50. Diagram. Change in business process to provide 3D models to contractors in Iowa.

The first pilot project was in 2006. For this project, Iowa DOT made it mandatory to use machine-guided construction. The project was a 9-mi machine-controlled grading project divided into four segments that were awarded to three contractors. Two of the contractors used Trimble® equipment and the third one used Topcon equipment. Over time, Iowa DOT has completed more than 70 machine-controlled grading projects and more than 20 machine-guided paving projects, involving 27 contractors.

Iowa DOT is at the forefront on the use of 3D models for automated machine grading and paving guidance applications. Figure 51 shows construction equipment with AMG capabilities used at the IH 80 and US 6/US 65 Interchange Project in Des Moines, IA. It is worth noting that, although this project involved 3D modeling during design, the design used an older process that does not represent the agency's current 3D design practices (which are used for new projects under development).

Source: FHWA.

Figure 51. Photo. Construction equipment with AMG capabilities.

Initially, Iowa DOT used 2D cross sections to prepare the 3D models. Now all the design is completed in a 3D environment. In addition, Iowa DOT initially provided the data post letting. However, after about a year of this process, bidders began requesting all the 3D documentation as part of the bidding package to prepare more competitive proposals.

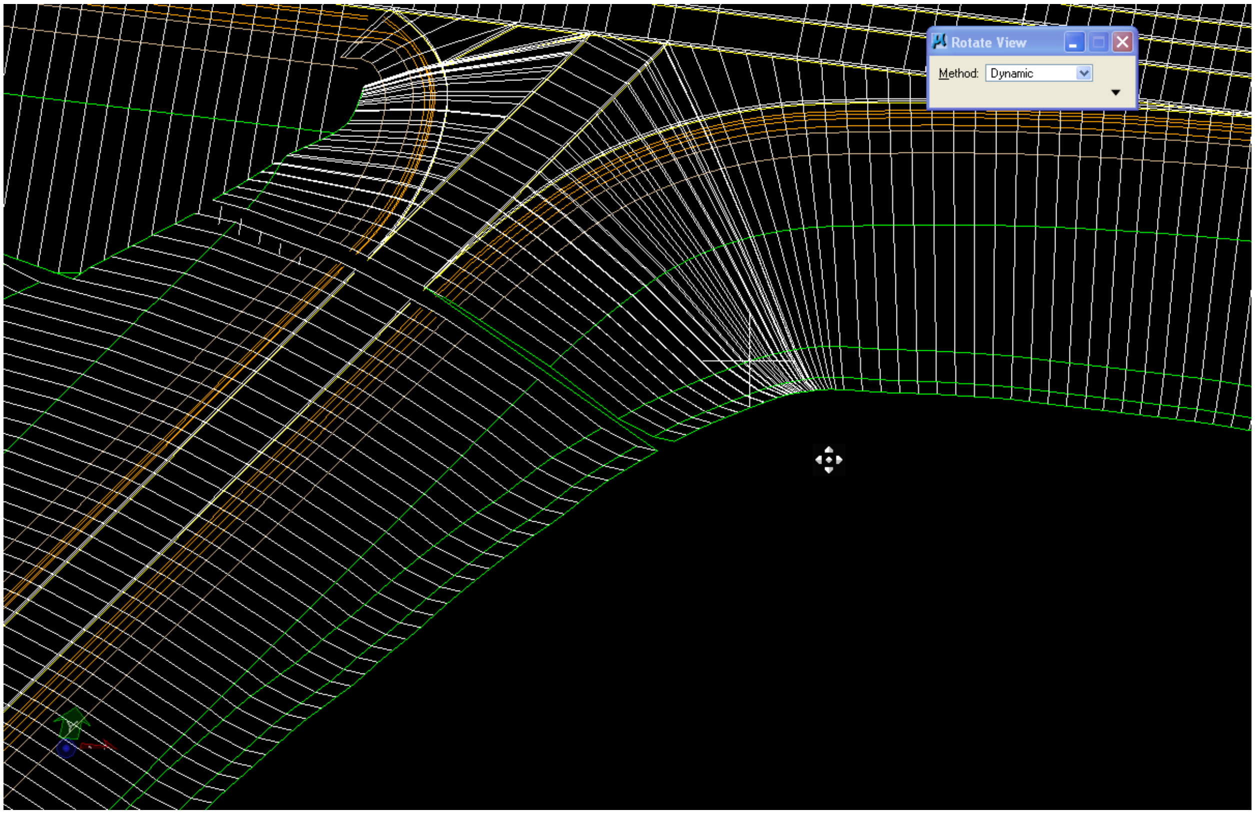
Iowa DOT uses a general supplemental specification that includes provisions for AMG.[87] This specification was used internally for 3 yr and then released in October 2013 as a general supplemental specification to the agency's 2012 series standard specifications for highway and bridge construction.

Iowa DOT designs 50 to 70 percent of projects in-house. The agency uses Bentley® GEOPAK® tools for roadway design and has no plans to switch to AutoCAD® Civil 3D®. The agency has not noticed a significant increase in the cost to design projects in a 3D environment. However, particularly during the initial transition, Iowa DOT did notice that additional time was needed to complete the design in 3D (e.g., 5 to 10 percent additional time for simple projects and more for complex projects).

Because designing in 3D is now part of the standard process, Iowa DOT does not have separate estimates for the cost to develop 3D models. The agency and the contractors recognize that, as contractors become accustomed to the technology, 3D modeling becomes an integral part of the cost of doing business. Nevertheless, although the agency provides a basic 3D model during the letting phase, if contractors need to modify the existing model or create new models because of construction requirements, there is an allocation for it in the bidding documents. The agency currently includes two separate bid items that include 3D modeling costs: a GPS machine controlled grading item and a paving 3D machine control item.

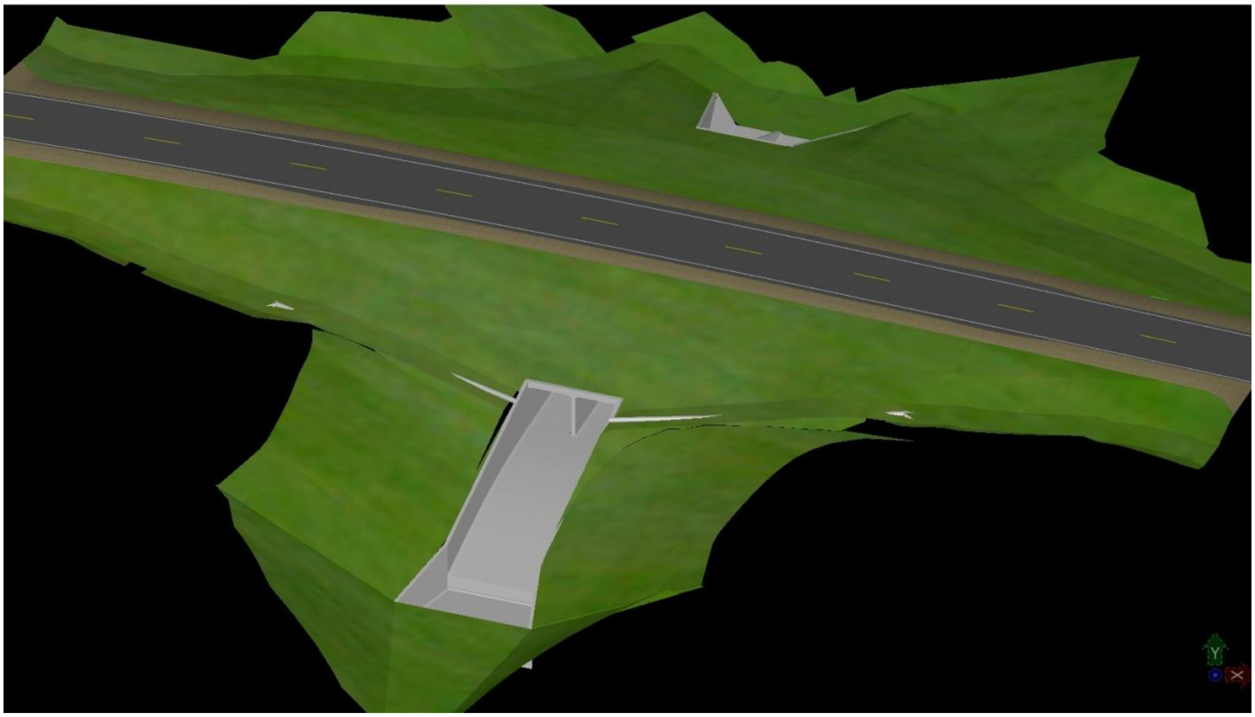
Iowa DOT uses LIDAR in multiple applications. A few years ago, the agency finished a planning-level LIDAR scan of the entire State. Because of the extent of that application, the level of detail was limited. The agency also has contracts with LIDAR service providers for aerial LIDAR scans at the project level. The agency has its own static and mobile LIDAR equipment that it uses as needed (e.g., to generate drive-through renderings and develop line strings of specific features in 3D format).

As mentioned previously, the driving force behind 3D design is the need to provide a 3D model to contractors for grading and paving. Contractors have not expressed a strong desire to receive drainage or bridge design data in 3D. As a result, Iowa DOT does not incorporate these elements into a 3D environment unless there is a specific reason (e.g., for public outreach). As an illustration, figure 52 shows the 3D model of a roadway with a gap that represents the location where a drainage structure will be built. This a typical practice. Figure 53 illustrates a situation where a drainage structure that had been designed in 2D was then modeled in 3D for inclusion in a 3D rendering.



Courtesy of the Iowa Department of Transportation.

Figure 52. Screen capture. 3D model of roadway with gap for a drainage structure.



Courtesy of the Iowa Department of Transportation.

Figure 53. Screen capture. Drainage structure included in 3D rendering.

Lessons learned by Iowa DOT officials from the transition from a 2D environment to a 3D environment include the following:

- **Just-in-time training is critical**—This means making sure that designers are trained at a time when they will be able to start modeling right away. Staff interest and effectiveness decreases substantially as the lag between training and implementation increases.
- **3D design requires designers to think differently than with traditional 2D design**—This makes it critical to enable adequate time for that transition.
- **Transition to a 3D design environment is not "plug-and-play"**—Depending on the process followed to transition to a 3D environment, it may be necessary to make adjustments, including making sure to review the existing process to identify steps that can be eliminated or enhanced.
- **The first pilot must be mandatory for AMG to control the bidding process and subsequent outcome throughout the construction phase**.
- **Close coordination between contract administration personnel and contractor personnel is necessary to make sure both parties are relying on the same kind of information for all communications**.
- **Start small**—It is easier to achieve buy-in within the agency if success is demonstrated on small projects.

Iowa DOT does not model utilities in 3D. For most projects, the agency collects utility data based on existing as-built drawings or utility company records as well as surveys of visible utility appurtenances. These data are not certified at QLD or QLC. Depending on the situation, project managers request test holes or the use of noninvasive geophysical techniques. For some projects, aboveground utility features, such as poles and overhead lines, are shown on roadway models based on the survey data. However, underground utilities are not included because of the extensive time and survey effort they would require.

NORTH CAROLINA

NCDOT uses 3D modeling occasionally for bridge projects and smaller projects. Most 3D modeling efforts have focused on surface models. A standard procedure at the agency is to generate a DTM for every project. Design plans and earthwork estimates are generated based on DTMs. However, NCDOT typically does not provide a copy of the models to contractors. As a result, contractors must recreate the surface models themselves based on their survey or the design plans and profiles provided by the agency.

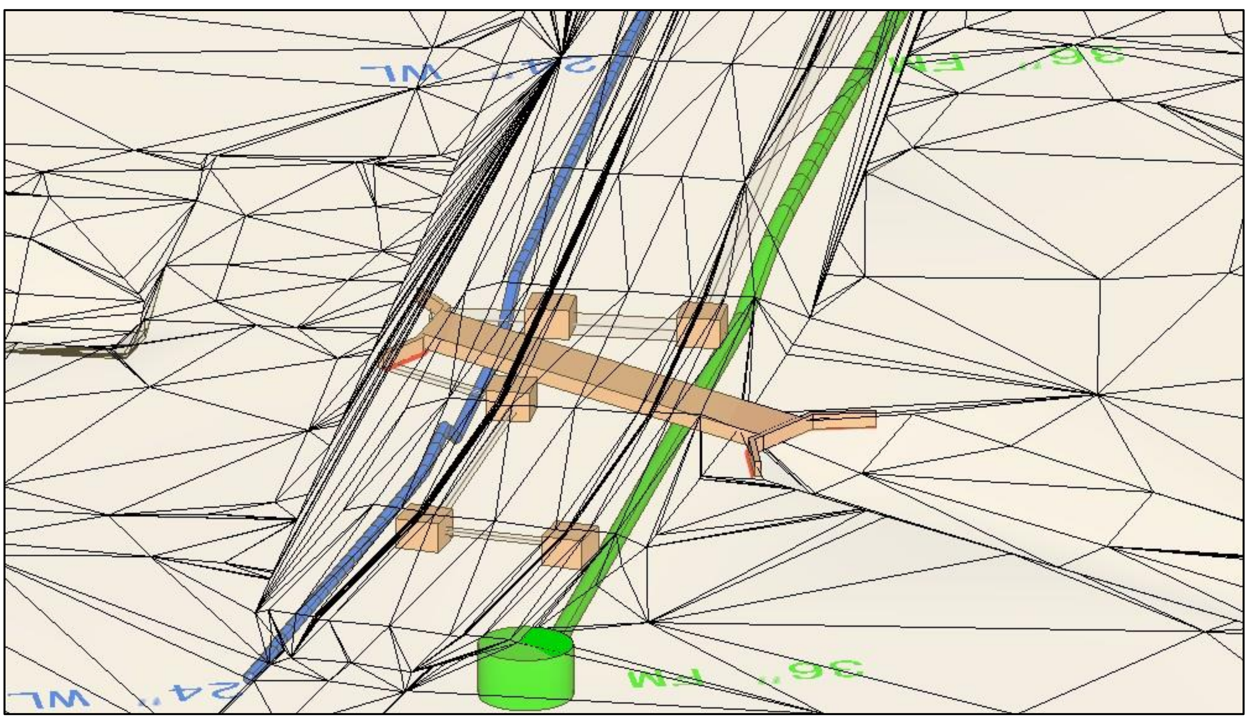
To promote the use of 3D models, NCDOT established a 3D committee that includes representatives of functional areas such as roadway design, construction, geotechnical, and utilities. Currently, NCDOT is focusing on promoting the use of 3D models for roadway design. The agency also has plans to use 3D models for hydraulic and storm drainage design and later for utility relocations.

For utility relocations, the standard practice is to generate 2D plans, profiles, and cross sections. In the past, NCDOT required profiles only for water lines that were larger than 16 inches in diameter. Currently, the agency requires profiles for all utility lines with a diameter of 4 inches or larger.

From a 3D modeling perspective, the agency considers building 3D models for new utility facilities to be straightforward. By comparison, it would be difficult to develop 3D models for existing utilities because of the lack of accurate 3D location information for typical underground utility installations.

One of the concerns in addressing this limitation is the anticipation of a high cost to collect reliable data in the field because of the large number of test holes that would be necessary given that depth information from QLB data normally does not exist or is not reliable. The agency is also concerned about requiring the collection of Z data before a data collection standard for Z data is developed.

NCDOT has experimented with 3D visualizations of underground utility facilities, primarily for outreach purposes. For example, figure 54 shows a 3D visualization that NCDOT used for discussions with local officials to illustrate a proposed design concept. The visualization was generated in-house from 2D plans and profiles and did not include the surface because it was anticipated that a more detailed DTM would be available later in the process. NCDOT did not have estimates of the cost to develop a 3D model of this type.



Courtesy of the North Carolina Department of Transportation.

Figure 54. Screen capture. Sample 3D visualization of underground utility facilities.

Many projects at NCDOT involve QLB and QLA utility investigations. Test holes are particularly common for large projects. In most cases, utility investigations at NCDOT are provided by a preselected pool of consultants under limited services agreements. Based on a review of cost data associated with a sample of QLB and QLA utility investigations from 13 prequalified firms, NCDOT estimated average utility investigation costs as follows:

- QLB services for projects that have the following characteristics:
    - Less than 10,000 ft: $1.01 to $1.60 per linear foot (average: $1.41/ft).
    - 10,000–50,000 ft: $0.84 to $1.32 per linear foot (average: $1.09/ft).
    - More than 50,000 ft: $0.77 to $1.13 per linear foot (average: $0.95/ft).

  These costs do not include mobilization costs.

- QLA services for projects with the following characteristics:
    - Fewer than 10 test holes: $798 to $1,229 per test hole (average: $989 per test hole).
    - Ten or more test holes: $602 to $952 per test hole (average: $762 per test hole).

These costs do not include mobilization costs. For test holes deeper than 6 ft, there is an additional cost per additional foot of depth.

Recently, the agency estimated that the additional cost to develop a 3D model for existing utilities could be about $16,000/mi. That estimate was highly preliminary, based on the assumption that the model would rely on available utility information.

TEXAS

TxDOT implemented comprehensive development agreements (CDAs) to enable private development of transportation corridors by sharing the risks and responsibilities of design and construction with the private sector in ways that the traditional design–bid–build process did not allow.[(88)] CDAs provide considerable flexibility, including financing and private investment. The ultimate goal of these delivery tools is to streamline the process to deliver projects.

Project handoff to developers in a CDA typically occurs after the environmental decision-of-record has been issued and very little, if any, design work has been completed. (Note: A CDA might be executed before the environmental decision-of-record is in place, but the notice to proceed is only issued afterward.) Types of CDAs include design–build projects and concession development agreements. For design–build projects, TxDOT secures funding for the project and owns the future toll income. These projects encourage innovation in a number of ways, including finding opportunities for cost savings (which are split between TxDOT and the developer). For concession development agreements, TxDOT receives a stipend for each vehicle accessing the facility over the lifetime of the transportation facility. These projects encourage developers to complete projects as fast as possible to start generating revenue and profits for their investors. Although cost containment is a priority, the emphasis is not necessarily identifying cost saving opportunities.

Differences between design–build projects and concession development agreements have an impact on the way utility relocations, and therefore utility data collection and utility conflicts, are managed during project delivery. For design–build projects, TxDOT conducts QLB (and some QLA) utility investigations and provides this information to prospective developers as a strategy to reduce the level of risk to the agency in the hope that developers might be able to offer more favorable prices. Depending on the project, TxDOT's expectation is also that bidders might not have to collect much more additional utility data. Because of the way design–build projects are structured, there is a very strong incentive for developers to reduce the need for utility relocations (and their impact) because of the possibility of realizing significant cost savings. For concession development agreements, TxDOT does not collect QLB data under the assumption that the developer absorbs and manages all the risks involving utilities during design, construction, operation, and maintenance of the transportation facility.

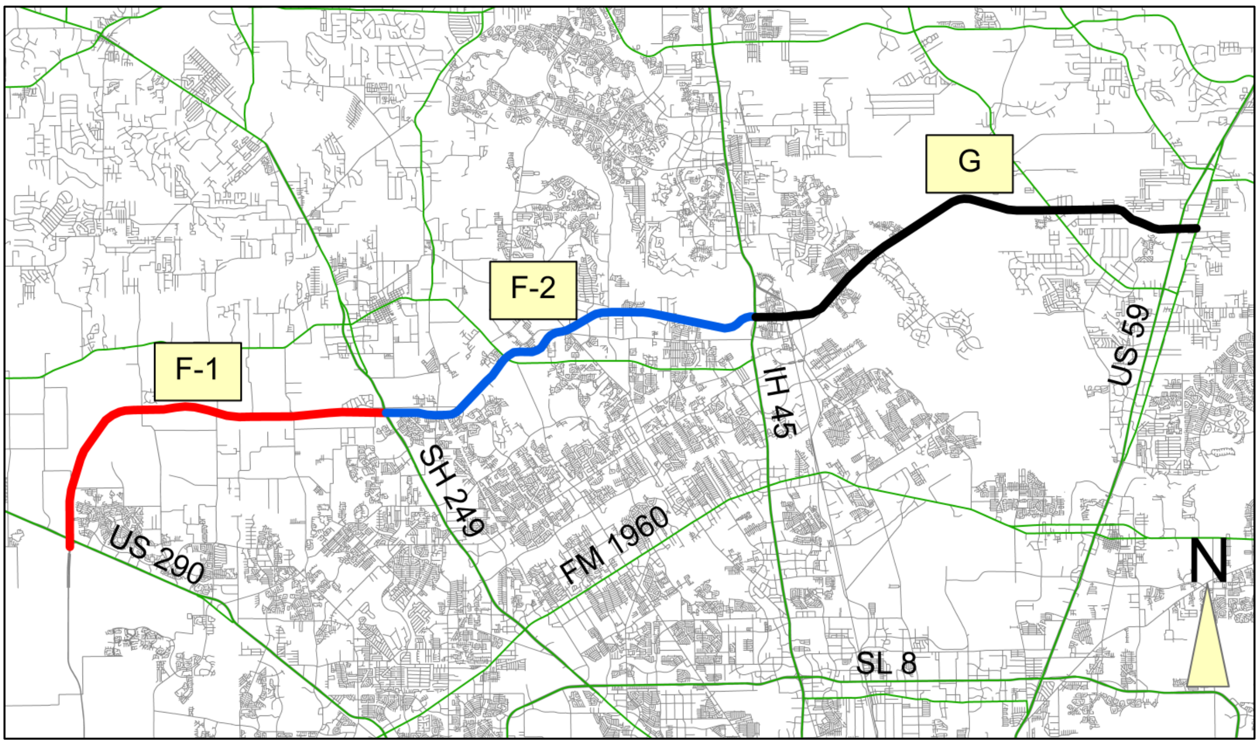
The utility process for design–build projects is performance driven rather than procedure driven as in traditional design–bid–build projects. For design–build projects, developers work with utility owners to make sure that relocations are completed in a timely manner. TxDOT provides oversight and limited coordination, which includes reviewing reimbursable cost estimates and signing utility agreements. TxDOT's role in reviewing cost estimates and agreements is crucial because developers frequently do not have the necessary expertise to verify compliance with all procedures, rules, and regulations, including the utility accommodation rules (UAR) and the TxDOT *Utility Manual*.(89,90) TxDOT executes all agreements as a third-party beneficiary. As an incentive to execute utility agreements in a timely fashion, design–build contracts have a provision that utility agreements must be approved within 10 d. Otherwise, there is a penalty for each additional day. If there is a need for additional information, TxDOT has to return the agreement within 10 d to the developer listing the required changes.

In 2013, TxDOT modified CDA contract provisions to support the use of 3D models.(88) A technical provision covers 3D design and visualization. The provision includes a requirement to prepare a 3D model of existing conditions that comprises ground surface features and underground features such as drainage structures, bridge and wall foundations, and utility installations. It also includes a requirement to prepare 3D design features for existing and proposed elements of work, including underground features. For project discussions with TxDOT and other stakeholders, the provision requires the use of software that enables interactive 3D visualizations of project elements, including the capability to visualize and navigate through existing and proposed elements of the project and detect conflicts among features.

TxDOT has also started a process to transition from 2D to 3D for regular design–bid–build projects. The agency engaged the services of a consultant to build the business case for the transition. TxDOT has also begun to plan how to train TxDOT staff on the process to build 3D models internally for design and visualization purposes. The goal is to develop 3D models with a focus on basic functionality, not sophisticated rendering. The current plan is to include roadway surface and drainage features such as storm sewers and storm drains. If utility features are displayed, they would be displayed as broken lines on the surface if the Z data for utility features are not available.

TxDOT is actively using LIDAR as an effective mechanism to accelerate data collection. The agency is now able to collect aboveground georeferenced data much faster than with other methods such as GPS or traditional surveying. TxDOT recently acquired terrestrial-based LIDAR equipment. In addition, numerous consultants use mobile- and helicopter-based LIDAR equipment for data collection activities at the agency.

State Highway 99, also called the Grand Parkway, is a proposed 184-mi circumferential highway traversing seven counties and encircling the greater Houston region. Some sections on the west, southwest, and east segments have been completed. In 2013, TxDOT awarded a design–build contract for segments F-1, F-2, and G, from US 290 to US 59 on the north side of the Grand Parkway in Harris and Montgomery counties (figure 55).(88) This $1.1 billion design–build project is 38.4 mi long and is expected to open to traffic in late 2015.



Source: FHWA.

Figure 55. Map. Grand Parkway Project—segments F-1, F-2, and G.

The developer is designing and building this project in 3D. The developer is using Bentley® InRoads®. Before the project was awarded, TxDOT had collected QLB (and some QLA) data, which TxDOT made available to the developer in 2D CAD files. As part of the design–build project, the developer and its engineer generated a 3D model for existing and proposed utility installations. This iterative process involved activities such as the following:

- Review all previous utility information, including QLB data (obtained using traditional geophysical equipment and techniques) and QLA data received from TxDOT at the beginning of the project. The original information included plan views and profiles. Initially, the 3D modeler wanted to use this information to develop the 3D model of utility facilities without any changes, but the team's utility coordinator highlighted the need for additional analysis, interpretation, and data collection.

- Collect additional QLB data to supplement the data received during the bidding phase. This was critical at many locations where there were communication lines, particularly lines that had been installed after the initial QLB data collection was completed. To help pinpoint where additional QLB data would be needed, the utility coordinator requested records from TxDOT's UIR permitting system (see chapter 2). As part of this process, the team's utility coordinator and TxDOT implemented a protocol so that new utility permit applications received through UIR had to be routed to the developer's team for review. To address the issue of poor information quality, the protocol included a requirement for new permit applications within the project limits to include detailed plans and profiles signed and sealed by a registered PE. In situations where this was not feasible or practical (e.g., a regular permit application not tied to a reimbursable utility relocation), the protocol included a requirement for the permit application to include detailed plans and profiles that were subject to the project team's review and approval. In addition, the team would inspect the installation as it was taking place in the field and take survey measurements to prepare a set of as-built files. For this project, utility relocations were 50 percent reimbursable. However, the developer agreed to pay 100 percent of the utility relocation design work and 50 percent of the utility relocation work in the field, which facilitated the implementation of the requirement to have plan views and profiles in utility permit applications signed and sealed by a registered PE.

- Add test hole data to the GEOPAK® files. Where geophysical data provided some indication of the depth of a utility facility, the utility coordinator included that information along with a label to the effect that the depth information was approximate. Overall, the utility coordinator provided depth data every 50 ft along straight alignments and every 10 to 15 ft at other locations.

- Build the 3D model of existing utilities in InRoads® using the information described in the previous bullet and additional judgment based on feedback provided by subject matter experts who had considerable field experience installing utility facilities.

- Integrate this information with the main 3D model for the project and run "hard" clash detections to identify locations where there were conflicts between existing utilities and project features. The utility coordinator also ran "soft" clash detections using buffers to check for restrictions according to the Texas UAR.[89]

- Collect additional QLA data at critical locations based on the information resulting from the clash detection analysis. This data collection was emphasized at three major areas along the project that the developer identified as critical for project scheduling purposes. This protocol for collecting additional QLA based on the results of the clash detection analysis was a sound, cost-effective strategy because it reduced the need for too many test holes at the beginning of the project.

- Conduct additional clash detections in the 3D software as additional design information becomes available. This is critical because throughout design and construction, there may be design changes (e.g., roadway features, drainage features, traffic control features, and so on) that could have an impact on existing and/or proposed utility installations. It is also critical because the project schedule is highly compressed. An issue that utility coordinators noticed was access to up-to-date project information. Although different team members have access to the latest online version of the project files, team members do their work with a version that may be obsolete by the time they are finished (because a file needs to be checked out and, in the meantime, the file owner might continue editing the master file).

With the results of the clash detection analysis, the developer was able to determine which strategies to follow to resolve utility conflicts. To manage utility conflicts, the utility coordinator used the utility conflict matrix that had been developed as part of the SHRP2 R15B project.(2) In addition, the utility coordinator developed a spreadsheet to define and manage groups of utility relocation activities. A utility relocation activity group represents a logical association of utility relocation activities in the field. A group could have one or more utility conflicts associated with it. For consistency, each group has a unique identification (ID) (e.g., E1-14) that corresponds to a specific line segment in MicroStation®, which is labeled with the same unique ID. In general, a group can only be associated with one utility owner. However, a utility owner could have one or many activity groups. For example, a utility owner that has a unique code of E1 in the database could have several groups of utility relocation activities (e.g., E1-1, E1-14, and so on). A utility agreement could also have one or many activity groups, but the relationship between utility owners and utility agreements is not one-to-one. A utility owner could have one or many utility agreements.

WASHINGTON STATE

WSDOT has experimented with 3D design on several projects. WSDOT has also used 3D data collection technologies such as LIDAR during project delivery. For example, The I-90 Mount Baker Tunnel and Mercer Island Lid Programmable Logic Controllers system replacement project involved using LIDAR to scan hundreds of miles of electrical conduits, fire suppression piping, and HVAC, as well as the production of an entire structural as-built.

A significant project is the $4 billion Alaskan Way Viaduct and Seawall Replacement Project in downtown Seattle (figure 56). The purpose of the project is to replace the Alaskan Way Viaduct, which was damaged in the 2001 Nisqually earthquake, with a tunnel and other related improvements to ensure safe and efficient transportation within and through the project corridor. The overall project includes more than 20 projects involving WSDOT, King County, the City of Seattle, and the Port of Seattle.

Most of the preliminary engineering effort involved the use of traditional 2D techniques, with cross sections where applicable. MicroStation® was used for all roadway and associated elements for compatibility with WSDOT standards. AutoCAD® was used for the utility work to ensure compatibility with the City of Seattle’s design and GIS systems and standards.

The preliminary engineering phase involved an evaluation of several alternatives based on cost, construction sequence and impacts, feasibility, and functionality. Utility issues were a highly critical aspect of the project given the terrain (gravity sewer issues) and presence of major electric transmission and distribution lines, storm and combined sewer outfalls, and fiber optic services. Areas of surface impacts (generally depicted by the solid red lines in figure 56) were mapped (topographic survey and utility installations) to provide the base conditions for subsequent design. Mapping covered the city right-of-way and acquired property and generally extended to a block on either side of the alignment. The utility inventory also included an assessment of available utility and city GIS records for use in assessing potential settlement impacts associated with the tunnel alignment (shown as a hashed black line in figure 56).

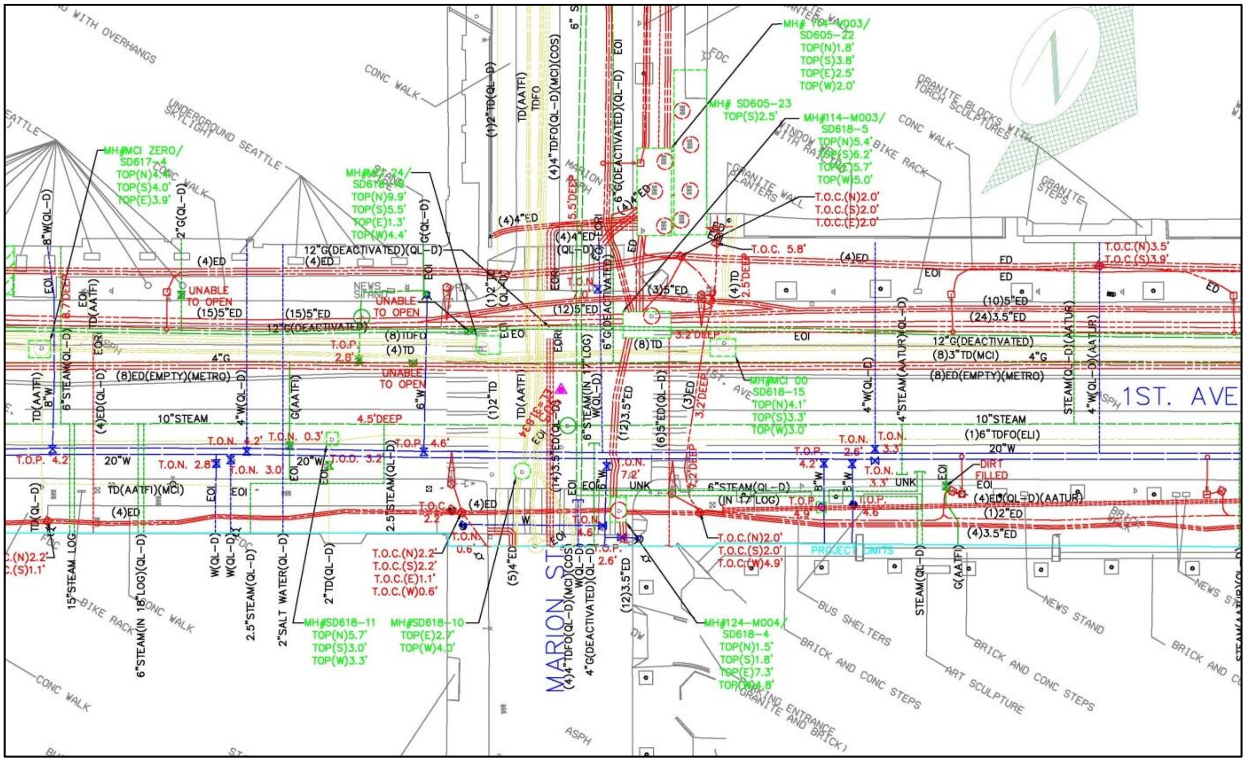
Source: FHWA.

Figure 56. Map. Alaskan Way Viaduct and Seawall Replacement Project in Seattle, WA.

Preparation for the design phase involved mapping existing utilities according to the CI/ASCE 38-02 guideline.(1) This included mapping straight-run gravity sewers at QLC between structures and gathering QLB for other underground utilities. The utility investigation also included measuring inverts at accessible manholes and electrical vaults to provide improved Z data, accessing and documenting utility vaults, and accessing and inspecting building basements for utilities entering the building walls. Utility types, depths, sizes, and material types were calculated and documented where they entered the buildings. All utility valve boxes and hand holes were accessed, and the depths to piping were measured and documented where possible.

All utility poles within project limits were inventoried for types of utilities, ownership of poles, and appurtenances on them.

The utility investigation covered approximately 10 mi of surface streets. The total linear miles of utilities (mains, services, empty conduits, multiple non-encased conduits) mapped is estimated at 150 mi. To make future modeling easier, the CAD deliverables depicted all utility facilities more than 12 inches in width or diameter at their actual scaled size. Figure 57 shows an example of the utility mapping deliverable.



Courtesy of So-Deep.

Figure 57. Map. Example of utility investigation deliverable.

The cost of the QLB investigation and initial CAD deliverables was approximate $2.5 million, which translates to about $3/ft of utility investigated. This cost was approximately 30 percent higher than for typical State transportation department projects. The higher cost of the QLB utility investigation was the result of a combination of factors, including the following:

- The work largely took place in Seattle’s central business district, which had a high density of utilities in a busy city environment with heavy traffic.
- It was critical to conduct a comprehensive inventory of existing utilities to minimize risks and the possibility of project delays. This also involved a relatively high project management cost factor. The result was a utility inventory with no significant errors or omissions, other than a few unrecorded out-of-service facilities found during excavation.

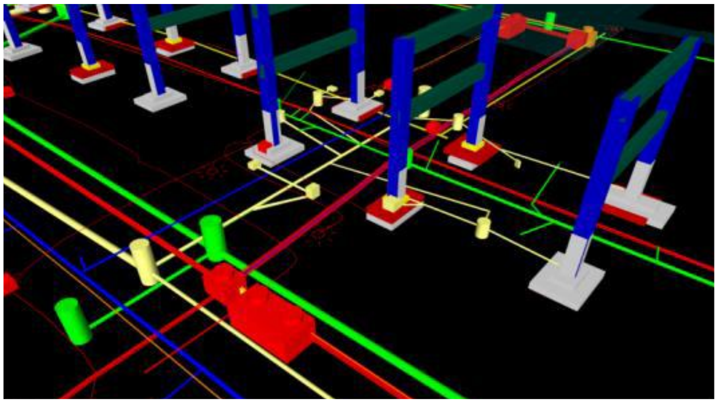
- The area was developed and redeveloped over 150 yr, and the age of utilities (some more than 100 yr old) and reliability of records over the years was questionable.
- The utility data collection was not continuous causing multiple mobilizations and travel expenses.
- The utility mapping took place over several years as the project evolved. Previously mapped project areas needed to be continuously evaluated for newly installed utilities and changes to existing utilities.

The utility investigation spanned 5 yr. During this time, there were frequent changes to underground utilities within the project limits. Especially pervasive was a city program to increase closed-circuit television coverage. Hundreds of new cameras attached to poles and buildings were installed with duct runs directionally drilled throughout the project area. Most of these new systems did not have available design records. Previous pole inventories proved critical in spotting these new installations. Utilities that changed because of project activity were included in as-built drawings.

The need to keep track of these frequent changes resulted in a protocol to evaluate the project every 6 mo, each time requiring a two-person crew about 2 weeks to perform the evaluation. The protocol was as follows:

- Review all utility-related construction permits from the previous update time period. It was eventually discovered that more than 75 percent of changed utility conditions did not involve a permit from the city. City-owned utilities, blanket utility owner permits, and unpermitted construction were the cause.
- Review all one-call tickets within the project area and screen them for construction that might possibly involve utility changes.
- Contact utility owners and request information on any known changes.
- Walk the project site and visually scan the area for evidence of new construction.
- Indicate the results of the previous four steps on field sheets, and conduct a field investigation with designating equipment in those separate areas. Any discovered changes to the utilities were updated into a new version of the base mapping, available and managed through ProjectWise®.

Project managers decided to develop 3D utility models for discrete portions of the project where complex utility relocations were likely to take place (figure 58). Project managers also decided to collect QLA data at locations such as tunnel entrances and exits and ventilation areas.

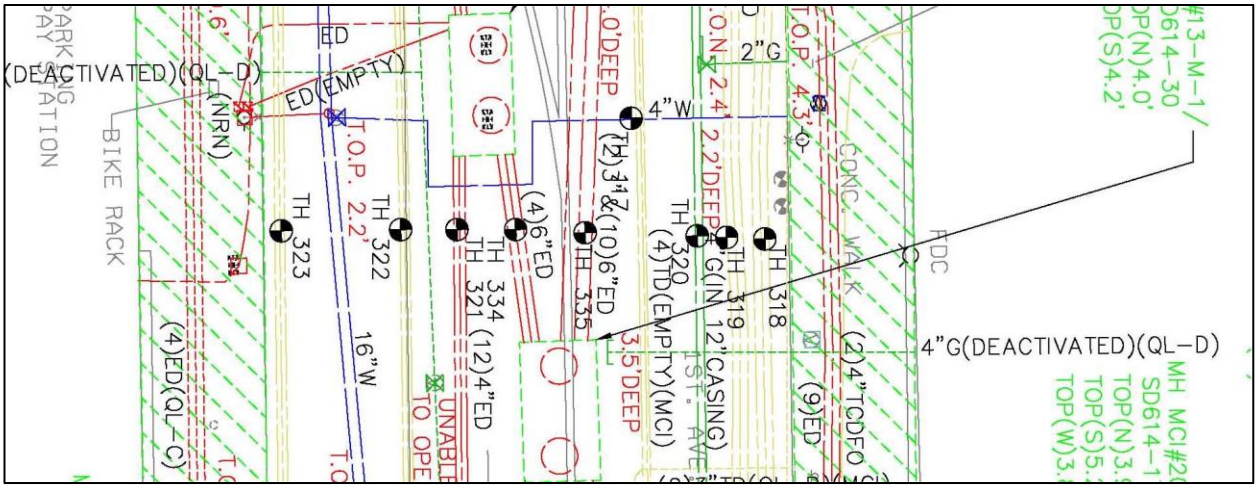


Courtesy of the Washington State Department of Transportation.

Figure 58. Screen capture. 3D utility visualization for the Alaskan Way Viaduct and Seawall Replacement Project, Seattle, WA.[91]

It was critical to measure utility Z data given the sheer magnitude and complexity of the utility systems within the project limits. Relying on the depth functions of the pipe and cable locators for measuring Z data was not an option because of quality assurance requirements and the variability in electromagnetic field data at any given point. At the same time, the ideal number of test holes necessary for this effort would have been too expensive. This resulted in a plan for obtaining spot utility elevations without mass exposure, which involved the following activities:

- From the existing depth information at singular points developed through basements, vaults, valves, and record information, spot utility elevations were calculated using the DTM of the surface features.
- Utility subject matter experts used their judgment in coordination with utility company representatives to estimate general elevations of utility facilities between the measured spot elevations. They then coordinated with CAD technicians to input this utility data into Autodesk® Civil 3D® as shape files. A similar process was used to model the utility vaults.
- Where additional information was important, especially in places where utility elevations changed significantly over distance to weave through the maze of intersection utilities, QLA data were gathered through air-vacuum test holes (figure 59).
- These data were analyzed against the original 3D model, and adjustments were made in an iterative process. In addition to utility elevations, measurements on encasement size proved valuable in determining utility shape file dimensions.



Courtesy of So-Deep.

Figure 59. Map. QLA data points at selected locations.

The cost to convert the 2D utility data to the 3D model is difficult to quantify. First, there was a significant learning curve for using the 3D modeling software and adapting business practices to the new process. Second, subject matter experts and CAD personnel were performing many different unrelated tasks during this time, making the identification of the cost to develop the 3D model difficult. An educated guess is that the QLA data, utility experts, and CAD personnel may have added up to $0.50/ft of designated utility for those utilities that were developed into shape files. After a specific design was selected, an additional $2 million was spent on QLA data at points of tunnel entrances and exits and ventilation areas.

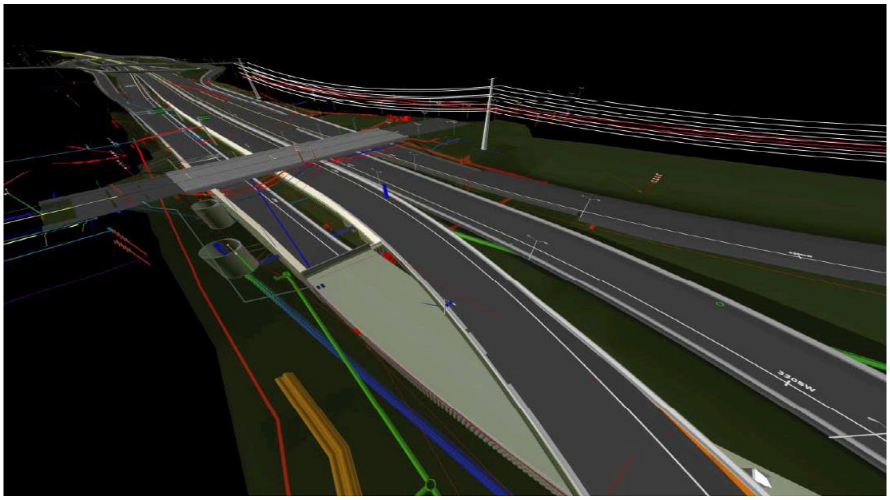
WSDOT officials indicated that the choice to use 3D data, either by gathering through State survey teams or consultants, is decided at the project development team level. A reason for not using 3D is not being able to justify the upfront expenditure. Currently, State policy does not mandate requirements or give specific direction on when or at what level 3D should be implemented.

Officials also indicated that a centralized database for utilities would be beneficial. Benefits would include time savings realized by not redoing work each time a project overlaps an area that has been documented, access to data without having to go through another office, and retention that would not end up in an archive and inaccessible in a timely manner when programs change. At the same time, barriers to implement a centralized database would include budget restrictions, a mechanism to transfer data currently stored in a functional (although primitive) database in such a way as to capture thousands of records without losing pertinent data, and how to update the data once the system is in place.

WISCONSIN

WisDOT's South East Freeways group has used 3D modeling techniques on several projects, including visualizations, conflict detection, 4D modeling, and with rovers for inspection and contract administration.[92] WisDOT has also provided 3D surface models to contractors for AMG applications, and has begun to integrate mobile, static, and aerial LIDAR with other survey tools. The use of 3D modeling techniques has ranged from the production of 3D models for construction purposes based on an existing 2D design (e.g., the $294 million Mitchell Interchange project along the $1.9 billion I-94 North–South Corridor project) to an integrated 3D design process (e.g., the Zoo Interchange that is part of a $1.7 billion highway reconstruction and expansion project in Milwaukee County).

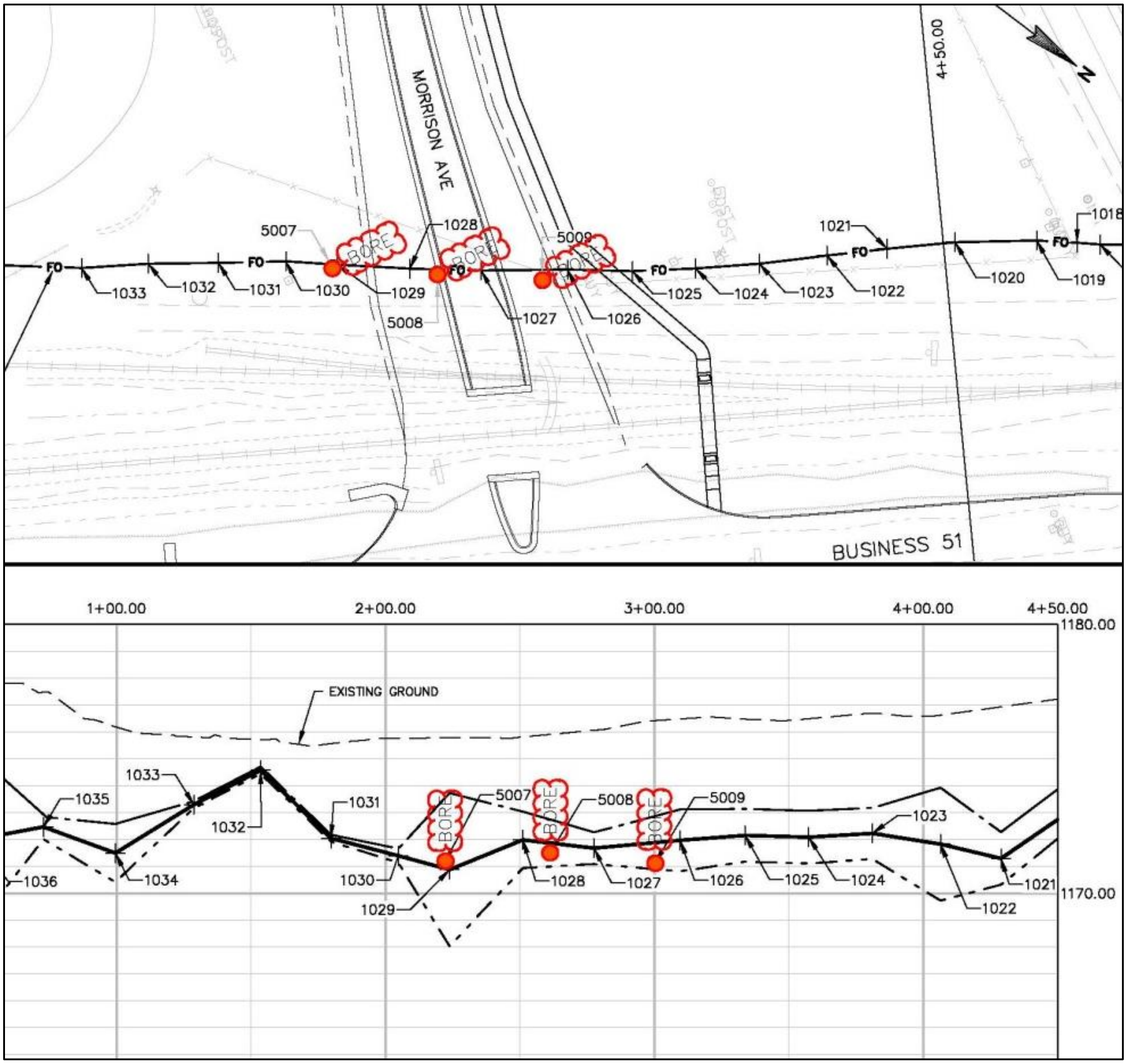
For the Mitchell Interchange project, WisDOT converted 4,500 plan sheets to a 3D environment and developed a 4D simulation to evaluate the sequencing of construction phases based on a work schedule that contained nearly 2,700 tasks. WisDOT also modeled utilities and clash detection in 3D, as shown in figure 60.



Courtesy of the Wisconsin Department of Transportation.

Figure 60. Screen capture. Mitchell Interchange Project with existing and proposed utilities.[93]

Recently, WisDOT identified five projects throughout the State (one per region) to conduct a pilot 3D utility survey implementation. The pilot implementation involved the use of GPR and a dual-antenna EMI device capable of measuring depth, in conjunction with test holes at critical locations to check Z values. In addition to X, Y, Z data, the EMI device provides horizontal and vertical error values, which enable the production of one-sigma error bands. As an illustration, figure 61 shows the plan and profile of a telephone line with an indication of the one-sigma error band at different points along the line. Also shown is the location of test holes that provided a visual confirmation of the actual X, Y, Z coordinates of the telephone line. As figure 61 shows, the actual depths at the locations where the telephone line was exposed were within the one-sigma error band.



Courtesy of the Wisconsin Department of Transportation and Utility Mapping Services.

Figure 61. Screen capture. Telephone line and vertical error band.[(23)]

CHAPTER 4. ISSUES, STRATEGIES, BARRIERS, AND ROI ANALYSIS

INTRODUCTION

This chapter summarizes the analysis completed to identify issues that State transportation departments encounter in collecting, storing, and maintaining utility location data; strategies to address those issues; as well as barriers that might block the implementation of those strategies. Although the focus of the research was the collection, storage, and maintenance of 3D utility data, the material in this chapter also addresses issues related to the collection of utility data at any point during project delivery, whether the data are 2D or 3D. As explained in the literature review in chapter 2 and the case studies in chapter 3, the reason is that the collection, depiction, and use of utility data is cumulative and progressive during the various phases of project delivery.

To facilitate the discussion of issues, strategies, and implementation barriers, this chapter is divided into the following four main sections:

- Utility data collection and management.
- Utility process in a 3D environment.
- Benefits of a reliable, accurate inventory of 3D utility data.
- Costs and ROI.

UTILITY DATA COLLECTION AND MANAGEMENT

Table 9 provides a summary view of commonly encountered issues related to the collection and management of utility data. The list of issues includes a description of common causes and consequences affecting project delivery. The table also includes a list of solutions to address the issues as well as anticipated challenges for the implementation of those solutions. The material provided is the result of feedback from State transportation departments and other stakeholders, the literature review in chapter 2, and the collective prior experience of members of the research team.

The solutions listed in table 9 through table 20 include a mix of project-level solutions and program-level solutions. Responsibility for implementation of those solutions ranges from State transportation department-level to State legislative or regulatory levels. At a project level, it is possible to group the solutions in table 9 through table 20 into a set of 10 common strategies to address the collection and management of utility data. Table 21 lists these strategies along with a description of challenges to implement them.

Table 9. Issues and solutions for collecting, storing, and maintaining utility location data: 2D utility data may not be reliable.

Topic	Description
Causes	• Records are not complete. • One-call and survey are not comprehensive or accurate.
Consequences	• Unnecessary relocations. • Unplanned utility conflicts. • Overdesign. • Utility damages. • Extra cost and time associated with these issues.
Solutions	• Use CI/ASCE 38-02 to conduct utility investigations.(1) • Obtain accurate utility as-built files for newly installed or relocated utilities within the right-of-way.
Challenges to implement solutions	• Lack of as-built standards. • Inadequate inspections. • Need for legislative changes at the State level. • Need for changes to permitting processes. • Lack of training on utility investigation procedures. • Increase in up-front costs expecting project savings during construction.

Table 10. Issues and solutions for collecting, storing, and maintaining utility location data: utility data might not have a known reliable depth or elevation attribute.

Topic	Description
Causes	• Utility owners do not have or are not willing to provide Z data. • Utility mapping firms are reluctant, unwilling, or unable to furnish Z data. • State transportation departments are not willing to absorb the cost to obtain Z data.
Consequences	• Overuse of test hole excavations. • "Fabrication" of data to fill in missing gaps. • Unnecessary relocations. • Unplanned utility conflicts. • Overdesign. • Utility damages. • Extra cost and time associated with these issues.
Solutions	• Document utility data using CI/ASCE 38-02 along with best judgment interpretation for documenting Z data.(1) • Obtain accurate utility as-built files for newly installed or relocated utilities within the right-of-way. • Develop risk-based standards for populating the missing Z data. • Strengthen permitting requirements to measure and submit accurate depths on all utilities exposed for maintenance or repair activities.
Challenges to implement solutions	• Lack of as-built standards. • Inadequate inspections. • Need for legislative changes at the State level. • Need for changes to permitting processes. • Lack of training on utility investigation procedures. • Increase in up-front costs expecting project savings during construction. • Lack of adequate consultant prequalification criteria.

Table 11. Issues and solutions for collecting, storing, and maintaining utility location data: utility data once collected are not updated with changes to the utility information.

Topic	Description
Causes	• Permits for new installations do not contain robust information. • Permits are not easily accessible by relevant agency departments. • Utility owners do not inform State transportation department of changes. • State transportation departments or utilities do not update project plans after initial utility mapping.
Consequences	• Project surprises during construction. • Utilities relocated more than once per project. • Utility damages during construction. • Incorrect one-call marks because utility locators have outdated records. • Contractor change orders and delays. • Designers using outdated data for late-stage design decisions.
Solutions	• Assign someone to the project with the duty to be aware of and update project plans with any new or changed utility information on the project as the project develops. • After the project ends, implement a solution to track any changes to utility data within the original project limits.
Challenges to implement solutions	• Changes to permitting protocols and systems. • Need for legislative or administrative changes to the relationship between State transportation department and the one-call system. • Lack of trained personnel to update utility changes within the right-of-way for all previous projects.

Table 12. Issues and solutions for collecting, storing, and maintaining utility location data: changes in utility data are not communicated to project designers in a timely manner, at all, or in a useful fashion.

Topic	Description
Causes	• No staff or group is responsible to notify project designers of any utility changes that may affect them. • Silos of information affect interdepartment communications. • Changes are not documented well enough for designers to know exactly the nature and scope of the impact.
Consequences	• Designers ignore vague or broad descriptions of utility changes. • Designers receive change information too late during project development. • Utilities that could be abandoned remain on the plans and considered as a potential conflict.
Solutions	• Identify any changes to a utility location or status and update plans accordingly. • Use new or updated plans to replace existing working plan sets for affected project designers. • Send e-mail notification to affected designers with a written description of the changes, along with a visualization of the changes on the working drawings.
Challenges to implement solutions	• No availability of staff to be responsible for this action. • Lack of software systems to prepare and deliver the visualization component.

Table 13. Issues and solutions for collecting, storing, and maintaining utility location data: 3D software for risk-based utility analysis and visualizations is not sufficiently robust.

Topic	Description
Causes	• Software developers are not sufficiently familiar with utility processes at State transportation departments. • There are software bugs or limitations in populating or managing Z data. • There is limited support for UAR.
Consequences	• No representations of data reliability are easily visualized.
Solutions	• Improve 3D software to strengthen utility data management. • Implement risk-based algorithms to facilitate utility clash detection and resolution of utility conflicts.
Challenges to implement solutions	• Lack of interest by State transportation departments and designers in risk-based approaches to manage utility issues during project delivery. • Inability of software developers to provide full support to risk-based utility analyses.

Table 14. Issues and solutions for collecting, storing, and maintaining utility location data: lack of commonly used utility database architecture.

Topic	Description
Causes	• There is an array of competing existing data models, some of which are used for purposes not entirely compatible with State transportation department needs.
Consequences	• Database implementations do not fully serve the purpose for which they are intended. • Data may be useless or incomplete.
Solutions	• Develop standardized data model that meets most State transportation department needs regarding utility mapping. • Upgrade LandXML to provide strong support for utility features during project delivery.
Challenges to implement solutions	• Lack of a knowledgeable, diverse, and experienced consensus body to develop national standard. • Lack of expertise at State transportation departments to incorporate utility data needs into IT strategies and programs.

Table 15. Issues and solutions for collecting, storing, and maintaining utility location data: significant gaps in utility data because projects are not in contiguous segments.

Topic	Description
Causes	• Projects are of various sizes, locations, and timing throughout the State transportation department.
Consequences	• Utility information trickles in from various projects in bits and pieces at various levels of completeness, accuracy, and documentation.
Solutions	• Develop and maintain a project polygon tracking system, with metadata on the exact nature, extent, completeness of all utility investigations. • Use standards-based, agencywide utility data collection protocols.
Challenges to implement solutions	• Lack of staff and other resources to coordinate data across projects.

Table 16. Issues and solutions for collecting, storing, and maintaining utility location data: archived utility data do not have meaningful value for design purposes because there is no 100-percent assurance that all changes to utility data have been captured since the last complete mapping.

Topic	Description
Causes	• Adequate metadata documenting the characteristics, accuracy, and precision of the old data are lacking. • A process to update database with changes since the last complete mapping is lacking. • Engineers' data are only certified for a particular project, preventing a future engineer from using a previous engineer's data without excessive liability if things go wrong.
Consequences	• Extra costs and delays are incurred during project delivery because of the need to collect new utility location data for every project.
Solutions	• Develop and implement utility inventory system that includes appropriate mechanisms and protocols to update the database whenever there are changes, e.g., through the utility permitting process.
Challenges to implement solutions	• High implementation costs. • Perception of low value to the agency because most of the need and benefit in collecting utility location data is during project delivery, not throughout the lifecycle of all facilities that occupy the right-of-way.

Table 17. Issues and solutions for collecting, storing, and maintaining utility location data: storage of utility data once collected is not easily available for future retrieval.

Topic	Description
Causes	• Data storage is in separate project files. • Data storage is in CAD file format without linkages to a database.
Consequences	• Data may not be available when needed.
Solutions	• Develop central database of utilities within the right-of-way referenced to a common and easily retrievable datum. • Link utility location data to utility attribute data in a database environment.
Challenges to implement solutions	• Information technology costs to create and manage database. • Investment and effort to convert existing data to a database environment. • No standardized utility database model commonly accepted.

Table 18. Issues and solutions for collecting, storing, and maintaining utility location data: there is a lack of continuity in funding because State transportation departments plan their budgets on a project-to-project basis.

Topic	Description
Causes	• There is a limited maintenance budget to manage utility issues after construction projects are completed.
Consequences	• Utility data within the right-of-way are obsolete or incomplete.
Solutions	• Enable utility permitting fees that take into consideration the actual cost to manage the accommodation of utility facilities within the right-of-way, including developing and maintain accurate, comprehensive utility inventories. • Obtain accurate utility as-built files for newly installed or relocated utilities within the right-of-way.
Challenges to implement solutions	• Need for potential legislative changes. • Need for changes to permitting processes. • Personnel availability limitations. • Budgetary limitations.

Table 19. Issues and solutions for collecting, storing, and maintaining utility location data: State transportation departments do not want to be responsible for obtaining accurate location information for utilities they do not own.

Topic	Description
Causes	• Obtaining accurate, comprehensive information about utility facilities is expensive. • Utility owners are responsible for managing records about the facilities they own and operate.
Consequences	• Utility conflicts that are discovered during construction result in unnecessary delays and project cost overruns. • Many utility relocations are unnecessary. • Information about utility facilities within the right-of-way is incomplete and inaccurate.
Solutions	• Update policies and procedures to focus on managing the right-of-way based on the requirement to obtain accurate location of all the assets within that right-of-way. • Establish programs that emphasize effective data exchange agreements with utility owners.
Challenges to implement solutions	• Unwillingness to change the current practice. • Right-of-way management practices that focus on section objectives instead of program and agency objectives.

Table 20. Issues and solutions for collecting, storing, and maintaining utility location data: utility issues are spread among several business areas that operate with little communication.

Topic	Description
Causes	• Different units within the State transportation department coordinate with utility owners with little coordination. • Some utility owners consider all data about utility installations within the right-of-way proprietary or sensitive. • Utility owners ignore the State transportation department's responsibility for managing the right-of-way. • There is a lack of societal consensus on acceptable levels of data access by authorized stakeholders.
Consequences	• There are silos of information that make data exchange difficult. • Accurate, complete information about existing utility facilities is not available to project designers.
Solutions	• Assign the responsibility to track all utility locations and data to just one department or unit within the State transportation department. • Develop spatial databases to manage all underground installations within the right-of-way that meet the same standards and datum. • Implement interoffice and interagency agreements to provide effective, reliable access to each other's data. • Develop secure log-in and credentialing systems similar to banking transactions for different levels of read/write privileges.
Challenges to implement solutions	• Lack of adequate financial resources to develop reliable utility inventories. • Unwillingness to adopt a comprehensive asset management approach to manage the right-of-way. • Lack of an appropriate legislative framework that facilitates data access to authorized users.

Table 21. Strategies and challenges for utility data collection, depiction, and management.

Strategy	Challenges to Implement Strategy
Allow or require utility owners to draw their facilities on project plan sets	• Not all utility owners are local, requiring long-distance collaboration. • Not all utility owners have possession or knowledge of a State transportation department's CAD system, digital database, or GIS formats. • State transportation department personnel have to collate many different drawings into one composite product. • There are no elevation or depth values. • Some utilities may refuse to furnish this service. • There is no control over the knowledge and experience of the utility personnel performing the task. • There is no control over the timing of the information coming back from the utility owners. • There is no opportunity to capture records' additional data for quality assurance information, such as age of records, type of records, presence of notes on records, conflicting records, etc. • Only active facilities may be depicted. • There may be no attributes on size, material, encasement, or number of direct buried cables. • There may be utilities or other infrastructure for which there are no records or known contact persons. • The records may be incorrect and incomplete.
Use utility owner records and assign someone else to draw records on plan sets	• This process is time consuming for State transportation department personnel. • The learning curve for interpreting utility owner records may be significant, especially in the case of telecommunication records. • Researching, requesting, obtaining, and evaluating legacy project design installation drawings to find elevation data at the time of design or actual installation can be time consuming. Utilities may not be willing to perform this record search for the State transportation department or its consultants.
Transfer data directly from a utility owner's spatial database to a State transportation department database	• Utility owner GIS data rarely have a Z attribute. • There is a lack of interoperability regarding common data formats, data models, symbology, or attribute data among utility owners. • Utility owners, particularly small ones, may not have a GIS to manage utility data. • Most State transportation departments do not manage utility data in a database environment. • Utility owners may not want to share GIS information. • Utility owners may require significant assurances and technology to prevent unwanted data viewing by other than necessary project personnel. • Accuracy of utility location data in existing databases is questionable or unknown.
Use the one-call system to get marks placed on the ground for subsequent survey	• Only a few States allow the use of one-call design tickets. Currently, one-call is used primarily for damage prevention purposes right before excavation takes place. • Unavailability of State transportation department or consultant personnel to survey one-call marks and transfer the data to an acceptable format. • Large projects are a challenge for one-call responses. Markings trickle in over a period of weeks, making the survey of those marks inefficient and costly. • There is a lack of statutory penalties for omissions or errors associated with one-call markings. • Not all utilities are required to respond to a one-call design ticket. • There is a lack of utility depth information in one-call responses. • One-call markings may not include empty conduits intended for future utility use. • One-call markings may not include unknown or privately-owned utilities.

Strategy	Challenges to Implement Strategy
	• One-call markings may not indicate attributes such as ownership, size, material, or age.
Correlate records to represented topographic and utility features	• The topographic survey must be completed first. • Although rare, utility appurtenances may be misidentified. • In municipal areas, valve boxes and manhole covers are frequently paved over and hidden. • As with spot excavations, utility appurtenances only provide reliable information at that single location. • Coordination with utility owners for inspection can be time consuming. • It is difficult or there is a lack of interest in accessing valve boxes, manholes, and vaults to obtain Z data. • Valve boxes may be filled with dirt. • Vaults may be filled with water. • Valve boxes may be too tight to measure to the top of the pipe. It may only be possible to measure to the top of the operating nut. There must be a knowledgeable person evaluating this action in the field. • There is a lack of interest in accessing basement walls where utilities enter buildings. Gathering this type of data is time consuming and requires participation of property owners for right of entry. In some cases, only service lines are visible, which might be of little value to the project.
Use surface geophysical methods to indicate potential utilities' existence and location	• There is a lack of equipment, training, or professional experience at most State transportation departments to perform these activities. Consultants usually perform these activities, but the cost to conduct utility investigations is frequently a reason not to pursue this type of studies. • There is a lack of understanding at many State transportation departments about the benefits of using surface geophysical methods to gather information about existing utility installations. • With few exceptions, both horizontal and depth values must be evaluated in the field at time of survey, and transferred to datasets in the office.
Expose and measure utilities using test holes	• Frequently this is an expensive option with the least amount of data gathered, although the data may be of the highest reliability. • Data gathered only apply to the location where the excavation takes place. • Traffic disruptions occur at the location where test holes are taking place. • There is a risk of utility damages during excavation. • There is a risk of road surface integrity if the lag between test hole and construction is too long. • It is difficult to identify a utility owner or type of utility installation. • There is a lack of participation by utility owners in exposure costs or activities. • There is a risk of dry holes, leading to unnecessary costs and road damages.
Survey utilities at the time of installation	• A survey crew is required on site during utility construction. • A permitting policy change and rigorous enforcement is required. • A written procedure on survey details and accuracy requirements is required. • A procedure is required on where and how to store data from the newly surveyed utility.
Install RFID markers on utilities at the time of installation or utility exposure	• A survey crew is required on site during utility construction. • A permitting policy change and rigorous enforcement is required. • A written procedure on survey details and accuracy requirements is required. • A procedure is required on where and how to store data from the newly surveyed utility. • A procedure on RFID installation is required.

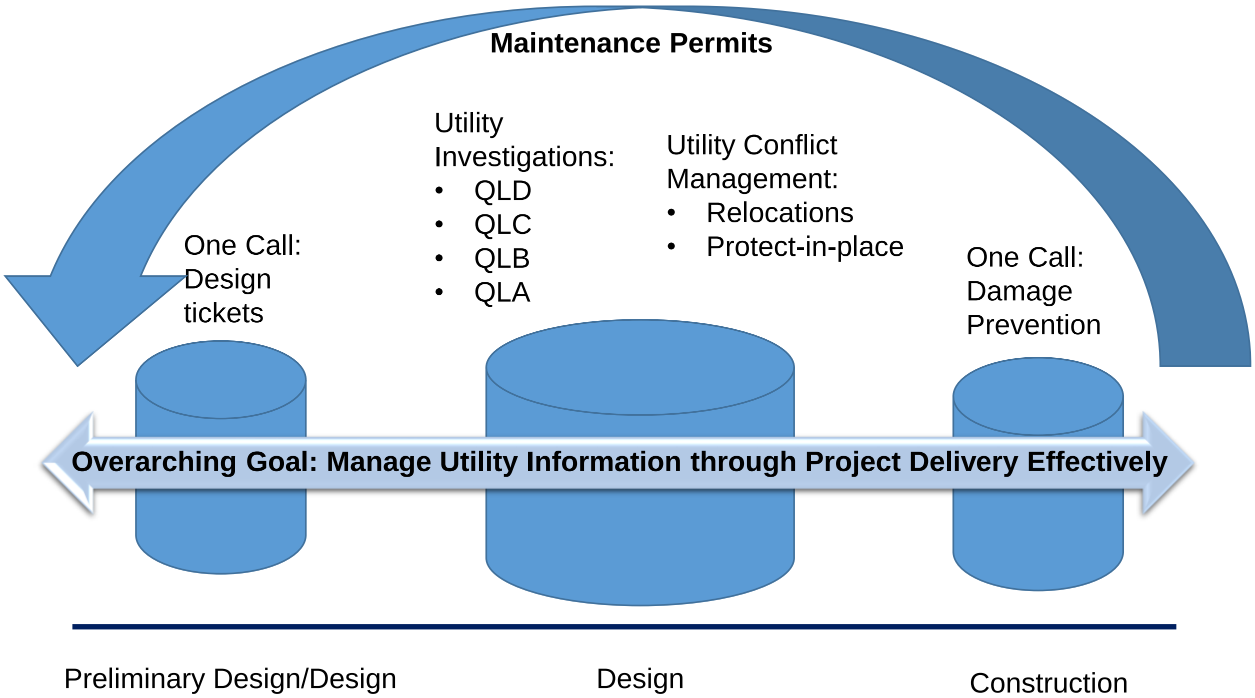
Strategy	Challenges to Implement Strategy
Note changes to existing utility information and update the utility database	• A permitting policy change and rigorous enforcement is required. • This process is time consuming for State transportation department personnel. • The learning curve for interpreting utility owner records may be significant.

UTILITY PROCESS IN A 3D ENVIRONMENT

Collecting and managing utility data is not an isolated activity within project delivery. Utility activities span most phases of project delivery and include five interconnected, multi-stage processes:(2)

- **Utility investigation**—This process involves the application of technologies to detect, identify, and map existing utilities within the project limits.
- **UCM**—This process involves the systematic identification and resolution of conflicts between transportation project features or phases and existing or proposed utility facilities.
- **Utility coordination**—This process involves planning and managing the communication and interaction between the transportation agency and all the utility stakeholders.
- **Utility design**—This process involves conducting all engineering activities to design utility relocations as well as protect-in-place measures for existing facilities that will remain in place.
- **Utility relocation management**—This process involves monitoring, inspecting, and surveying utility relocations as they place at the job site, as well as the collection and mapping of utility as-builts.

The goal is to improve the quality of utility information as the project delivery progresses. Figure 62 illustrates this concept by emphasizing the improvement in utility data completeness and accuracy as the project advances from preliminary design to design and construction. In practice, effective utility data quality practices should span the entire lifecycle of transportation and utility facilities with the highway right-of-way. Figure 62 illustrates this concept by emphasizing that quality utility data should also be captured through the maintenance permitting process.



Courtesy of TTI.

Figure 62. Diagram. Effective lifecycle utility data management.

Knowing the location of existing utility facilities and applying effective UCM techniques have tangible economic benefits.(2,3) For example, in Maryland, use of the UCM approach at one of the pilot projects resulted in the determination that relocating a gas line was not necessary, saving stakeholders $500,000 and 4 to 6 mo in project delivery. In Georgia, for a bridge project that affected many utility facilities, it was recognized during construction that slightly modifying the horizontal alignment of the bridge would have avoided utility impacts without affecting the right-of-way or the construction phase. The affected utility facilities were relocated at a cost of $5 million, which could have been avoided. In Georgia, for an interstate highway project, widening the highway required raising the embankment by 50 to 60 ft. The Georgia Department of Transportation expected significant soil settlement, which would have affected existing major gas and water facilities in the area. The agency was able to avoid costly utility relocations by using a foam layer and a concrete cap to protect the existing utility installations in place. In a rural area in South Dakota, a conflict with an existing 69-kilovolt corner pole was detected at the 30-percent design point. Relocating the pole would have cost about $60,000. Timely coordination and redesign of the transportation facility around the pole made it unnecessary to relocate the pole. The total cost, which included building an approach to the pole for maintenance purposes, was $3,000 (which the utility owner paid).

The five interconnected processes outlined above can be applied to any project, whether project delivery occurs in a 2D or a 3D environment. Using the lessons learned from the case studies in chapter 3, it is possible to outline a few recommended activities for projects being designed and constructed in a 3D environment, including the following:

- Review all previous utility information, including any existing QLB or QLA data. The original information might include plan views and profiles. The project's 3D modeler might want to use this information to develop a 3D model of existing utility facilities without any additional verification. Therefore, it is critical for the project utility coordinator to highlight the need for additional analysis, interpretation, and data collection as appropriate.

- Collect new or additional QLB data to supplement existing utility location data. This may be critical at locations where additional utility facilities have been installed after the initial utility data collection was completed. To help pinpoint where new or additional QLB data are needed, the utility coordinator should rely on a variety of data sources, including paper or online utility permit records at the agency.

- Implement a protocol so that any new utility permit application within the project limits is routed to the project team for review. The protocol should include a requirement for any new permit application within the project limits to include plan views and profiles signed and sealed by a registered PE. In situations where this is not feasible or practical (e.g., a maintenance permit application not tied to a reimbursable utility relocation and, therefore, the utility owner considers the PE requirement too onerous), the protocol should include a requirement for the permit application to include detailed plans and profiles that are subject to the project team's review and approval. In addition, the project team should inspect the installation as it is taking place in the field and take survey measurements. In the future, as 3D modeling becomes more pervasive, it might be possible to require utility permit applications to include utility files in a compatible 3D file format.

- Where existing test hole data are available, add that information to the project files. Where geophysical data provide some indication as to the depth of a utility facility, the utility coordinator should include that information along with a label to the effect that the depth information is approximate.

Recommended activities for building and using the 3D model of utility installations include the following:

- Build the 3D model of existing utilities using the information above and additional judgment based on feedback provided by subject matter experts who have considerable field experience installing utility facilities.

- Integrate this information with the main 3D model for the project.

- Run hard clash detections to identify locations where there are conflicts between existing utilities and project features. The utility coordinator should also run soft clash detections using buffers to check for restrictions according to existing UAR and regulations. In coordination with project designers, additional clash detections could or should be run to identify potential construction sequencing conflicts. Given the state of the practice in 3D modeling technology, this might require manually generating virtual features of different shapes around specific utility features of interest.

- Collect additional QLA data at critical locations (as determined by the project manager in coordination with the utility coordinator (e.g., at locations where there may be a significant project scheduling impact)) based on the information resulting from the clash detection analysis. One of the reasons for using the results of the clash detection analysis to evaluate the need for additional QLA data collection is that it may be possible to reduce substantially the number of test holes that are needed for the project.

- Conduct additional clash detections in the 3D software as additional design information becomes available. This is critical because throughout design and construction, there may be design changes (e.g., roadway features, drainage features, traffic control features, and so on) that could have an impact on existing or proposed utility installations. Utility coordinators should keep in mind that they might be conducting clash detections using project files that are not necessarily up-to-date if the files that they check out to do the analysis continued to be updated by the file owner but this information is not conveyed to the utility coordinator.

- With the results of the clash detection analysis, determine which strategies to follow to resolve utility conflicts using the methodology developed in the SHRP2 R15B and R15C projects.[2,3]

Recommended activities for keeping the 3D utility information current throughout project design and construction include the following:

- As utility facilities are relocated in the field, implement an inspection and as-built production protocol that includes surveying and documenting X, Y, Z coordinates associated with actual locations on the ground and transcribing that information to 3D files to generate an as-built 3D model. Depending on the contract requirements, it might also be necessary to prepare official 2D as-built files.

- Implement an efficient electronic communication protocol between the contractor and the project owner (and/or its representative) to identify, resolve, and manage utility conflicts that arise during construction. To maintain the integrity of the data, all stakeholders involved in this coordination should work on the same (or compatible) 3D environment.

- Implement a protocol to evaluate the project at regular intervals (e.g., every 6 mo) to check for any changes in utility installations within the project limits. The protocol should involve activities such as, but not limited to, the following:

    - Review all utility-related construction activity from the previous updating cycle. This is particularly critical for projects in urbanized areas in which multiple jurisdictions (e.g., city, county, State) operate and in situations that do not involve a permit (e.g., city-owned utilities), blanket utility owner permits, or unpermitted construction.

    - Review all one-call tickets within the project area and screen them for construction that might possibly involve utility changes.

- Contact utility owners and request information on any known changes.
- Walk the project site and visually scan the area for evidence of new construction.
- Indicate the results of the previous four sub-steps on field sheets and conduct a field investigation with designating equipment in those separate areas.
- Update the utility map based on any discovered changes to utility installations in the field.

BENEFITS OF A RELIABLE, ACCURATE INVENTORY OF 3D UTILITY DATA

Feedback from State transportation department representatives indicates that a reliable inventory of utility facilities in 3D during project delivery would provide benefits such as the following:

- Depth and elevation of utility facilities are available throughout the project.
- Integration with aboveground 3D project data.
- Possibility of generating cross sections at any desired location.
- 3D representation of underground environments with a high concentration of utility installation within a limited space.
- Full 3D design and analysis of utility clash or conflict detection.
- Acceleration of project delivery and fewer delays.
- Accessibility of and less effort to find utility data.
- More accurate utility data.
- Increased safety, lower risk, and less damage to utilities.

A significant challenge for implementing 3D inventories of utilities is likely to be the lack of consensus among project managers and designers regarding the benefits or need to conduct utility investigations for specific projects beyond the traditional review of existing records and survey of visible appurtenances. Reasons include the following:

- Lack of hard data documenting benefits under a variety of project types and local conditions.
- Lack of ownership in the final product (because of the handoff that usually takes place when a transportation project progresses from design to construction).
- Perception that utility installations are a utility owner problem, and public money should not be used to address them.

A 2012 survey of State transportation departments conducted by Caltrans was consistent with these observations. Survey participants indicated that they use 3D modeling techniques for reconstruction and grading projects as well as intersection improvements, culvert replacements, storm sewer and drainage improvements, and bridge replacements.(94) Respondents reported a range of benefits related to the use of 3D modeling techniques although for the most part were unable to quantify the benefits. Examples of benefits include the following:

- Time savings—3D visualization leads to faster decisionmaking. Profiling is simpler, and faster calculations for earthwork are possible. The design process is more effective, and it is easier to spot and correct problems earlier in the design process.

- Cost savings—There is a potential for lower bids, lower survey costs, and less rework; more accurate estimates; and fewer change orders and field modifications.

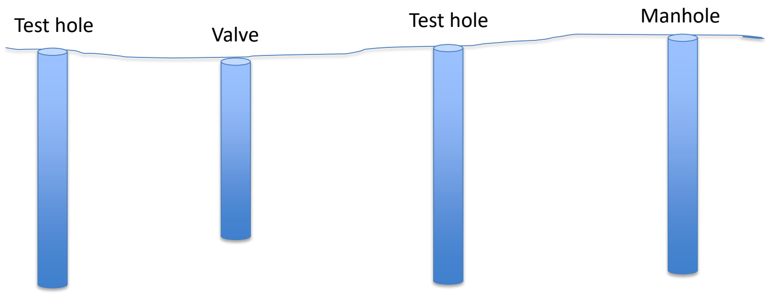
- Quality—3D visualization increases the ability to catch avoidable mistakes. Conflicts can be more easily resolved before the letting process. Earthwork calculations are more realistic and accurate.

- Improvements in customer relations—3D modeling builds belief in the design and confidence in the engineer-client relationship.

Examples of challenges that State transportation departments face for developing utility inventories, particularly in a centralized setting, include but are not limited to the following:

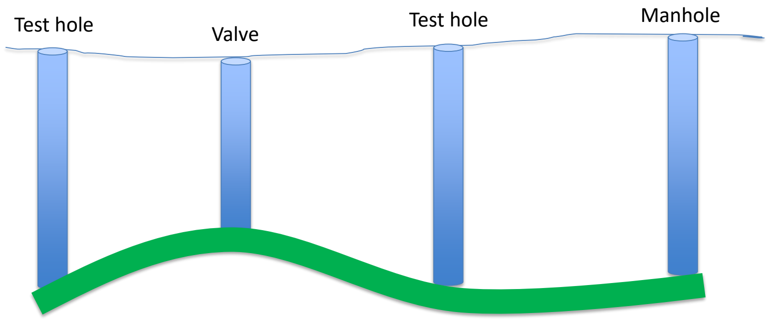
- Cost of development or lack of funding and resources.
- Concerns about maintenance, updates, or monitoring of the database.
- Concerns about data security, access, and privacy.
- Lack of staff and/or equipment.
- Utility owners that do not want to participate or provide data.
- Concerns about data accuracy.
- Concerns about liability.
- Data that are the utility owner's responsibility.

A major challenge that State transportation departments face is the difficulty of gathering reliable data, particularly in the case of existing underground facilities. Collecting reliable data is challenging in a 2D design environment. In a 3D design environment, it is even more challenging because of the added difficulty of determining how to handle and manage Z data in situations where there is no clarity about where the infrastructure is actually located. To illustrate this issue, figure 63 shows the location of four points where QLA data collection enabled a positive determination of the depth of an underground pipe. Figure 64, figure 65, and figure 66 show three potential interpretations about the vertical alignment of that pipe. Making a determination of the vertical alignment is a critical requirement for building a 3D model of the pipe. Without the support of proper data collection and processing technology and professional judgment, making that determination can be a challenge.



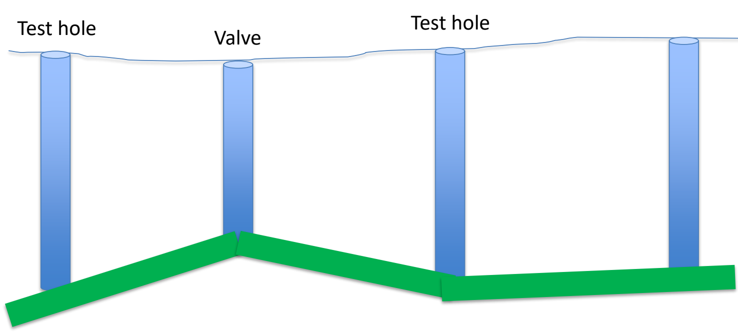
Courtesy of TTI.

Figure 63. Diagram. Locations where QLA data were collected.



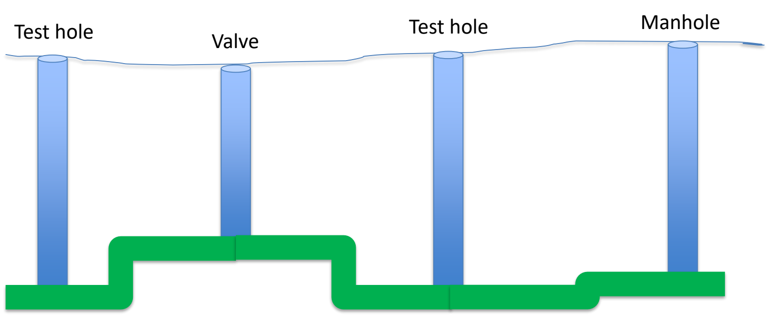
Courtesy of TTI.

Figure 64. Diagram. Assumed curved vertical pipe alignment between QLA points.



Courtesy of TTI.

Figure 65. Diagram. Assumed straight vertical pipe alignment between QLA points.



Courtesy of TTI.

Figure 66. Diagram. Assumed horizontal alignment between mid-points.

As mentioned earlier, 3D data collection and image processing tools increasingly provide the capability to generate vertex points and line work in 3D (and sometimes shapes such as pipes). The technology is not at the point yet to enable a consistent measurement of pipe diameters (or sometimes depth). However, the technology has evolved to the point where it can provide the backbone for preparing 3D deliverables as long as other data collection methods are also used to produce a more reliable deliverable than what would be possible with each separate method on its own. Analytical tools and risk-based algorithms to provide a quantitative assessment of location uncertainty are also not available yet.

A significant challenge that prevents the use of 3D utility data, particularly during construction, is that 3D design and construction processes throughout the country are geared to support AMG grading and paving applications. AMG is now an accepted practice, and 3D modeling is used to improve the design process, with the primary goal to provide data that contractors can use directly to facilitate critical project activities such as grading and paving. Data exchange standards such as LandXML facilitate the AMG process. However, as mentioned in chapter 2, current data exchange standards do not provide adequate support for utility 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 capability to use LandXML to document existing or proposed utility installations in ways that could fully support all related 3D applications during design and construction. Further, existing 3D CAD platforms provide support for LandXML import and export operations, but the degree to which data interoperability across platforms is achievable on a consistent basis is unknown.

An important reason preventing a more pervasive use of geophysical techniques to obtain 3D utility data is the inadequate level of technical expertise at many companies that provide utility investigation services. Due, in part, to the high demand for test holes at State agencies and municipalities, many providers derive a significant portion of their revenue from test holes, which require lower labor and training costs than that for conducting geophysical investigations. Another reason is the consultants’ need to limit their liability because of contractual clauses that hold the consultants responsible for errors in data interpretation and reporting, particularly in the case of Z data for which there is usually more uncertainty than for X, Y data. Those clauses limit the consultant’s ability to exercise appropriate professional judgment and, consequently, deliverables are usually limited to providing 2D utility information.

COSTS AND ROI

For the most part, efforts to gather direct, comprehensive information about the cost to develop 3D utility inventories were unsuccessful. The research team used a variety of strategies to gather this information, including requesting information about typical costs to develop 3D models in general as well as attempting to use typical costs to conduct utility investigations to estimate the cost to develop a 3D inventory of utilities. Likewise, there was only limited, mostly anecdotal information about economic benefits in connection with 3D modeling efforts. As a result, the analysis evolved into an indirect assessment of costs and benefits. Overall, the analysis suggests that the cost to develop 3D utility inventories is primarily a function of the cost to collect reliable, comprehensive utility data in the field because the actual cost to develop the 3D model is relatively minor once the data have been collected.

Use of 3D Models in Design and Construction

Although there are differences among States depending on how prevalent the use of 3D modeling is, the main observation is that State transportation departments and practitioners now see 3D modeling as having reached a point where the cost to develop 3D models is a normal component of the cost of doing business. This means that (1) it is difficult to separate the cost to develop 3D models from other business costs, (2) the cost to develop 3D models is relatively minor, and (3) 3D modeling will only become more pervasive over time. In some cases, State transportation departments reimburse contractors for the cost to collect 3D data or to facilitate AMG, but this tends to be on a case-by-case basis for specific applications. In general, State transportation departments control costs by focusing on basic 3D model functionality, not on sophisticated renderings (which tend to increase costs dramatically).

As an illustration, the Iowa DOT has not noticed a significant increase in the cost to design projects in a 3D environment. However, particularly during the initial transition, the agency did notice that additional time was needed to complete the design in 3D (e.g., 5- to 10-percent additional time for simple projects and more for complex projects). Because designing in 3D is now part of the standard process, the Iowa DOT does not have separate estimates for the cost to develop 3D models. Nevertheless, although the agency provides a basic 3D model during the letting phase, if contractors need to modify the existing model or create new models because of construction requirements, there is an allocation for it in the bidding documents. The agency currently includes two separate bid items that include 3D modeling costs: a GPS machine-controlled grading item and a paving 3D machine control item.

Because of the lack of reliable benefit and cost data, State transportation departments that are migrating to a 3D design environment have not yet prepared formal ROI assessments. 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.(5) Further, as shown in table 22, using BIM resulted in a reduction in construction change order amounts from about 18 percent to 4 to 10 percent of the construction contract amount. Overall, using BIM resulted in 8 to 14 percent in project cost savings.

Table 22. Benefits of using BIM on roadway projects in Norway.(5)

Project	Contract Type	Contract Amount ($M)	Contract Method	Number of Change Orders	Change Order Amount ($M)	Change Order Percent Cost
RV 150—E03; Ring 3 Ulven-Sinsen	Unit price	38.9	Traditional	680	7.4	18.9
E6 Skaberud—Kolomoen	Unit price	60.8	Traditional	385	11.0	18.1
RV 150—E22; Ring 3 Ulven-Sinsen	Unit price	68.8	BIM	491	6.7	9.8
E6—Nordre, Trondheim	Turnkey	34.0	BIM	80	2.6	7.6
Fv. 456 Vågsbygdveien, Auglandsbukta-Flødemelka	Unit price	5.7	BIM	86	0.2	4.2
Joint Project E6—Dovrebanen	Unit price	232.9	BIM	178	19.3	8.3

Some examples documenting ROI assessments of the use of 3D technologies in vertical construction may be relevant. The Letterman Digital Arts Center, located on a 23-acre site in the Presidio National Park, San Francisco, CA, was completed in 2005 at a cost of about $350 million.(6) The decision to use BIM was made after most of the design had already been completed in 2D (the design was 60-percent complete at that point). The initial goal was to use BIM for visualization purposes, but the focus evolved so that BIM became a management tool during construction and for the production of an as-built 3D model.

The BIM was updated weekly and posted to a server where all team members could access it. Having the latest version of the model always available minimized the need for requests for information during construction. Nevertheless, a challenge encountered was staying ahead of the construction process because, in some cases, changes were made at the job site that were not necessarily reflected immediately in the BIM.

Use of BIM at this project enabled the determination of some 200 design and construction conflicts, most of which were corrected before construction, resulting in an estimated savings of more than $10 million (or almost 3 percent of the total project cost). To estimate the savings, the project managers undertook design coordination variance cost studies to determine the impact if the conflicts had not been identified using BIM (e.g., the cost to make corrections later if concrete had already been poured). Not included in the savings was the funding that was allocated to the general contractor for the purchase of the 3D CAD software, training for contractor and subcontractor personnel, and the cost to build and maintain the 3D model.

The project managers also used BIM in a 4D capacity (i.e., to simulate construction sequences in a 3D environment). This enabled the production of time-based animations. A lesson learned from this exercise was the need to coordinate closely with all stakeholders on naming conventions both for the 3D model and the scheduling software.

The University of Southern California's School of Cinematic Arts complex was completed in 2010 at a cost of $165 million. BIM was used for design and construction.(7) According to project managers, using BIM led to more integrated design and delivery, cohesive teamwork, and expedited project schedules. As a result, the first phase of the project was completed 2 mo ahead of the original schedule, and the second phase of the project was completed 3 mo ahead of the original schedule. Estimated cost savings were $6.4 million (or almost 4 percent of the total cost of the project).(95)

Use of 3D Models for Utility Investigations

It is difficult to develop a generalized estimate of the cost to conduct QLB and QLA utility investigations. A rule of thumb is to assume 1 percent of the total design and construction cost for a project (or 10 percent of the total design cost) to gather QLB data throughout the project and QLA data in sufficient locations to identify important utility conflicts.(1) However, there could be significant variations from these percentages (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).(8,9) ROI estimates for conducting traditional QLB and QLA utility investigations range from 3.42:1 (Ontario, Canada, study), to 4.62:1 (Purdue University study), to 22:1 (PennDOT study).(8–10)

A review of utility investigation costs in North Carolina produced an average cost of $0.77 to $1.60 per linear foot of mapped utility feature for QLB investigations and $602 to $1,229 per test hole for QLA investigations. These costs did not include mobilization costs. Test holes deeper than 6 ft involved an additional cost per additional foot of depth. For the Alaskan Way Viaduct and Seawall Replacement Project in downtown Seattle, the cost of the QLB utility investigation was approximately $2.5 million (or about $3/ft of mapped utility feature). This cost was higher than normal because of a combination of factors, including, but not limited to, complexity of the utility mapping effort and length of the project (which involved implementing a multiyear protocol for maintaining the utility inventory up-to-date at regular intervals). For this project, there was also 3D modeling of utilities at some locations. Although specific cost numbers were not available, a consultant who was involved in the project estimated that the QLA data, utility experts, and CAD personnel needed for this effort might have added up to $0.50/ft per designated utility for those utilities that were developed into shape files.

Assuming for simplicity an ROI of 4:1 (which could be higher based on the trends described in previously) 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 a savings of about 4 percent of the total project cost. Table 23 summarizes this concept.

Table 23. 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

Using GPR or EMI arrays adds to the cost of conducting utility investigations. However, 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, particularly in relation to the larger utility investigation effort. For example, for a hypothetical four-legged intersection in an urbanized area, assuming 200 ft/approach, a consultant who specializes in utility investigations estimated that the cost of a conventional QLB and QLA utility investigation could be $50,000 to $70,000. For the same location, the cost of using GPR or EMI arrays could be $30,000 to $50,000 (i.e., from 42 to 100 percent of the conventional utility investigation cost). However, if the larger utility investigation effort had been for a corridor improvement project covering five signalized intersections but with only one requiring the use of GPR or EMI arrays, the relative increase in cost by using advanced geophysics would be 8 to 20 percent of the conventional utility investigation cost.

These 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 investigations. Given the high ROI values associated with conventional QLB and QLA investigations mentioned previously (3.42:1 to 22:1), it is reasonable to assume that adding advanced geophysics to the menu of options for conducting utility investigations will still result in high positive ROI values for projects that use those techniques. Further, lessons learned from the use of BIM strongly suggest that the use of 3D modeling for transportation projects is likely to result in 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. Table 23 summarizes this concept.

CHAPTER 5. USE OF RFID TECHNOLOGY

INTRODUCTION

This chapter summarizes the results of a literature review and an analysis of the use of RFID technology to mark and manage underground utility installations. The analysis includes lessons learned from the implementation of RFID ball markers in Virginia along with a discussion of benefits and costs.

BASIC CONCEPTS AND TERMINOLOGY

RFID technology is a wireless sensor technology that relies on the detection of electromagnetic signals. A typical RFID system includes three components: a transceiver (equipped with a decoder), an antenna, and an RFID tag that is programmed with unique information. The antenna establishes the communication between the transceiver and the RFID tag. Commercial readers typically include the transceiver, the decoder, and the antenna as part of the same assembly.

Depending on data storage capability, there are read-only RFID tags and read/write RFID tags. Operationally, there are passive RFID systems and active RFID systems. With passive RFID systems, the RFID tags do not have an internal power supply. The small electrical current induced in the tag by the incoming radio frequency signal from the antenna provides just enough power for the integrated circuit in the tag to power up and transmit a response back to the antenna. Depending on the implementation, the response can include just the tag ID number or, in addition, relevant attribute data that had been previously recorded onto the tag. The range of application of passive RFID tags is usually very limited, from a few inches to a few feet.

With active RFID systems, the RFID tags have their own internal power source, which is used to power the integrated circuits in the tag and to broadcast the response signal to the reader. The range of application of active RFID tags is much wider than that for passive RFID tags, reaching to the hundreds of feet. Depending on the implementation, batteries for RFID tags could last for several years. Active tags can usually store more information than passive tags but tend to be bigger and considerably more expensive.

The type of application determines what part of the electromagnetic spectrum RFID systems use. Generally, lower frequencies are associated with less signal absorption by moisture, less impact from metal interference, shorter signal range, and slower reading. Higher frequencies are associated with more metal interference, longer signal range, and higher speed. Table 24 summarizes typical frequencies used for RFID applications.

Table 24. Typical uses of RFID in the electromagnetic spectrum.

Frequency Range	Type	RFID System	Typical Range
125–134 kHz	Low frequency	Passive	18 inches
13.56 MHz	High frequency	Passive	5 ft
433–956 MHz	Ultra-high frequency	Active/passive	Tens to hundreds of feet
2.45 GHz	Ultra-high frequency	Active	Tens to hundreds of feet

GHz = gigahertz.

RFID MARKETPLACE

The use of RFID technology in transportation applications, particularly in the case of passive RFID tags, is increasing. Examples mentioned in the 2007 Transportation Research Circular E-C114 (which interestingly did not mention utility applications), include the following:[96]

- **Construction**—Asphalt concrete truckload tracking, equipment and material tracking on construction sites, and supply chain tracking for critical components.
- **Infrastructure management**—Bridge inspection and inventory of roadway signs and other infrastructure assets.
- **Safety and security**—Hazardous material monitoring, port security, customs, and border crossings.
- **Supply chain management**—Inventory control, electronic payment and automated transactions, access control, theft prevention, and counterfeit detection.
- **System operations**—Electronic tolling and traffic management, automatic vehicle identification, transit control, and commercial vehicle clearance.

The use of RFID technology to mark underground utility installations is a niche market. Examples of commercial products in the United States include 3M™'s Dynatel™ and Berntsen®'s InfraMarker®.[97,98] 3M™ has a dominant share of the utility RFID market both in the United States and abroad. The company states that there are more than 25 million 3M™ markers buried worldwide. 3M™ has a patented system in which the RFID tag floats in a liquid encased in a plastic round ball. 3M™ ball markers are available in seven different colors, according to the American Public Works Association color code.[99] They are detectable up to 5 ft in depth, and can be simply thrown into the trench. Each of the seven balls emits a different signal, enabling an operator to know the ball color from the ground surface. Many pipe and cable locator manufacturers now include antennas that can detect these ball markers, but without the proprietary 3M™ detector, the pipe and cable locator antennas cannot read the data stored in the RFID tag.

Prior to burial, operators program the markers with information about each location. Each marker has a unique, factory-assigned serial number that is stored in the tag. The markers can also store up to 24 bytes of custom data. In the field, it is possible to develop customized data dictionaries for individual ball markers. In addition to ball markers, 3M™ offers near-surface RFID markers, which are small cylinders that can be deployed through hard surfaces and are readable up to 2 ft in depth.

Berntsen®'s InfraMarker® uses a combination of permanent magnets for location and RFID chips for identification. It is possible to program the RFID chip with information fields about that specific utility element, differentiating one element from all the others in an area. Burial detection depth is about 2 ft. The inclusion of a magnetic detection device provides an alternative mechanism to identify a utility location. This may be valuable for field personnel such as surveyors, who may not have an RFID reader but usually carry a flux-gate magnetometer for finding property corner pins. Omni-ID provides RFID tags for the InfraMarker® system. The company states that its RFID tags include a proprietary arrangement of metal layers that reflect and boost the signal from the RFID reader, enabling the tag to be read even when placed on metal or immersed in a liquid.

USE OF RFID TECHNOLOGY TO MANAGE UTILITY INSTALLATIONS

Damage Prevention

A typical justification for deploying RFID markers is to protect and prevent damage to utility installations during construction or maintenance activities. A secondary (usually lower priority) objective is to facilitate the development of underground asset inventories. There are not too many examples of application of RFID technology for utility installations in the United States, partly because of the perception that deployment of this technology is expensive, and independent ROI assessments are not yet available. Nevertheless, the number of applications continues to grow. Examples of locations where RFID markers have been deployed include the City of Charlotte, FL; Lawrence Livermore Laboratory, CA; Atlanta International Airport; Baltimore BWI Airport; Heathrow Airport in London, United Kingdom; Village of Thiensville, WI; and Sacramento Area Sewer District.

Agencies have begun to develop standards and specifications for the deployment of RFID markers. For example, a multi-agency specification in southern Nevada that includes Clark County Reclamation District, Boulder City, City of Henderson, City of Las Vegas, and City of North Las Vegas has the following requirements for RFID markers along sewer facilities:(100)

- At uniform intervals not exceeding 25 ft along curvilinear sewer segments.
- At uniform intervals not exceeding 50 ft and at changes in horizontal or vertical alignment above each force main in dual force main installations.
- At uniform intervals not exceeding 50 ft and at changes in horizontal or vertical alignment above pressurized water reuse lines.
- At upstream ends of stub-outs and at uniform 10- to 25-ft intervals along stub-outs longer than 25 ft.
- Above each lateral connection to the main sewer and above the upstream end of each lateral.
- For adjacent or crossing pipelines, offset markers from one another by 25 ft.
- At least 3 ft below finish grade but not more than 5 ft below finish grade.

Utility Investigations

During QLA utility investigations, sometimes passive RFID ball markers are placed in the test holes to assist in future asset management activities (e.g., by enabling the use of GIS files and ball marker locators to respond quickly to excavation requests by contractors without the need to mobilize survey crews). In this situation, a utility investigation requirement might include designating all underground utility facilities; excavating test holes at line beginnings and endings, changes of direction, tees, intersections, at set intervals on curves, and set intervals on straight line sections; and surveying the positions of all designated underground facilities and the ball markers. Data programmed into each RFID ball marker would include agency name, utility type, diameter, invert elevation, and utility material.

Oxford Electromagnetic Solutions Limited

Most RFID systems are standalone systems in that the reader is not connected to any remote server and, therefore, cannot upload data collected or generated in the field or download data such as maps or other data that might be needed in the field. A new system in the United Kingdom called Oxford Electromagnetic Solutions Limited (OXEMS) provides that capability.(101) With the OXEMS system, all data collected or generated by the reader is wirelessly uploaded to a central server, along with other supporting data such as pictures. OXEMS RFID markers are tied to the pipe during installation. Placement of these markers at the appropriate points on the pipe during installation or during exposure for maintenance allows an electronic reader above the pipe to identify the location and display the type and data associated with the tag. If the reader has an associated GPS unit, it is possible to assign coordinates to the marker location. The resulting positional accuracy obviously depends on the positional accuracy of the GPS receiver. Other data elements include utility type, diameter, depth, material, and type of fitting. Another difference between the OXEMS system and systems such as 3M™ Dynatel™ and Berntsen® InfraMarker® is that the OXEMS RFID markers store no attribute information other than the marker unique ID. All other information associated with the specific marker location and underground facility resides in the central server database, where it is available for downloading on demand.

OXEMS resulted from the commercialization of one of the products of the MTU research program in the United Kingdom (see chapter 2). During the MTU phase 1, research focused on the development of a low-cost RFID passive system that could be mounted on pipes. Research also focused on the development of a passive system that could be placed within the wall of a pipe and that could resonate when scanned using GPR. During phase 2, further development was conducted to bring the research products closer to commercialization. OXEMS is the result of that effort.

Intelligent Trench

Similar to OXEMS, Intelligent Trench is a system recently deployed in the United Kingdom. that provides integration to the deployment of RFID markers and the collection and management of marker data within the environment of a centralized database of underground assets.(102) Intelligent Trench is a joint venture of 3M™, Exor (which was recently acquired by Bentley®), Trac-ID, and Infotec. With Intelligent Trench, users deploy markers following the same procedure as described previously for regular 3M™ Dynatel™ ball markers. A critical difference is that the handheld data collector provides the capability to access and upload information online.

Intelligent Trench records are also available through LinesearchbeforeUdig, which is a free Web-based system that any company or private individual can use to inquire about the location of underground installations.[103] LinesearchbeforeUdig users are able to see online where Intelligent Trench records are available in the United Kingdom. The service provides a single point of contact for all inquiries relating to facilities owned by underground asset owners that are subscribers to the service. The only difference between LinesearchbeforeUdig and one-call systems in the United States is that the system notifies utility owners that a user is inquiring for utility information, but it does not generate a ticket for marking utility installations in the field.

Virginia Department of Transportation

The application of RFID technology at VDOT's Northern Virginia District is unique among State transportation departments. At the Northern Virginia District (which accounts for some 40 percent of all construction projects at VDOT), VDOT has undertaken an aggressive program to deploy passive 3M™ Dynatel™ ball markers to mark utility installations that have been relocated as part of VDOT construction projects.[11] VDOT has also used RFID markers on a few projects in the Fredericksburg District. The district routinely obtains comprehensive QLB data early in the design phase (at about 10-percent stage). However, utility installations within the project limits continue to change during the life of the project, which may be several years. There are invariably utility relocations needed before and during project construction. Utility owners may also need to install new facilities within the project limits as part of their normal business activities. VDOT also installs its own underground installations during this process. In addition to QLB data becoming out-of-date, significant errors in one-call markings are a common phenomenon before excavation during project construction.

Technology and Protocols

VDOT started the RFID program to mark newly installed utility installations in an effort to reduce the level of uncertainty with respect to these facilities and, more specifically, as a damage prevention strategy. The RFID marker deployment protocol includes deploying RFID ball markers at the following locations:

- Every 25 ft along straight utility facility alignments (figure 67).
- At (significant) horizontal and vertical changes in direction.
- At critical utility crossings, tees, and service connections.
- On appurtenances that are important to the utility owner.
- On out-of-service facilities when they are encountered or uncovered in the field.

This level of spatial disaggregation provides a point-to-point X, Y, Z picture of new utility installations and enables managers to generate an inventory of those facilities. In practice, project managers had to achieve a workable balance between the need for spatial information and ball marker density (e.g., in the case of crossings, which in some cases, could be only 3 ft apart).

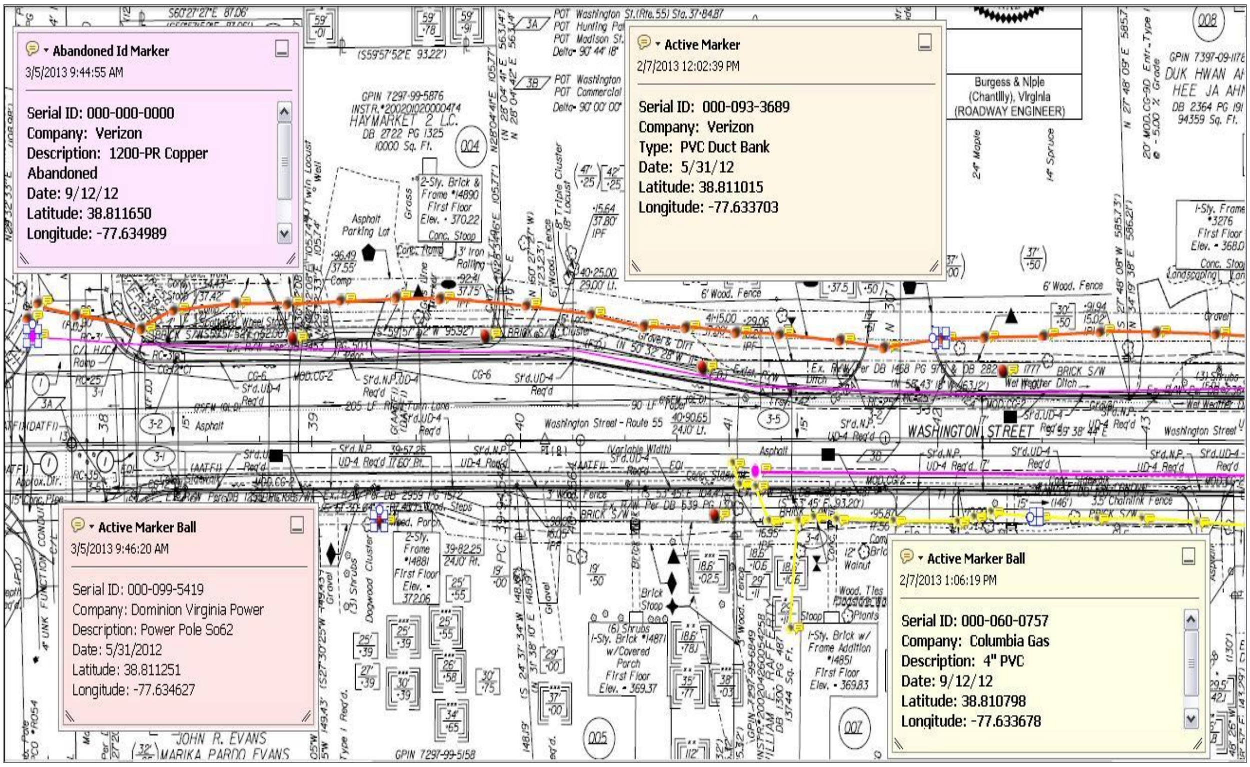
Source: FHWA.

Figure 67. Photo. RFID markers next to the trench.

During installation, operators store relevant information—such as utility owner, utility type, pipe diameter, horizontal coordinates, and type of feature associated with the ball marker (e.g., tee, service connection, or change in direction)—on the RFID tag. In practice, VDOT has developed several variations of the data dictionary depending on the type of installation.[11] Operators program the ball markers in the field using primarily laptop connections, although in some situations, they can also program some basic information using the 3M™ locating wand. Depending on the purpose for a specific RFID marker, operators use one of several data dictionaries. As a result, the actual list of attributes stored in the tag could vary. For example, markers located along straight project alignments include a station attribute. Markers associated with service lines have an address attribute. Markers associated with out-of-service lines have a verification attribute.

According to VDOT officials, the positional accuracy of the horizontal coordinates is about 2 ft because they use a mapping level GPS receiver. Likewise, officials first place the marker in the trench and then take the GPS coordinate reading to ensure the coordinates correspond to the actual horizontal location of the utility installation, not a location on the surface next to the trench.

After gathering the information in the field, VDOT makes this information available through Google® Earth™. VDOT also generates as-built polylines that provide a visual representation of the utility alignment and prepares PDF files that users can click and query to display RFID marker information (figure 68). During utility construction, VDOT provides a copy of these files to utility owners on a monthly basis so that they can update their records accordingly in a timely manner.



Courtesy of VDOT.

Figure 68. Map. VDOT RFID tag attributes.[11]

The current protocol also includes deploying decals to inform field crews about the existence of RFID markers (figure 69). In addition, the Virginia Underground Utility Marking Standards now includes a requirement to indicate the letters "RF" over the approximate location of the RFID marker.[104]

Courtesy of VDOT.

Figure 69. Photo. RFID marker decal.[11]

For quality and risk management purposes, VDOT is currently retaining control of the ball marker installation and program functions. This could change in the future, as QC and quality assurance protocols are developed to allow other stakeholders (e.g., utility owners and contractors) to participate in those functions.

VDOT is considering requiring the installation of ball markers in test holes excavated by utility investigation consultants or utility owners. Installation protocols, pricing, and data storage and delivery issues had not been established at the time of this report.

VDOT is also exploring other applications of RFID technology, including the identification of right-of-way elements. Using RFID to mark the borders of various project rights-of-way (e.g., existing, proposed, and temporary construction) provides an easy way for constructors to know these limits, especially when other visual references, including stakes, are hidden or have been obliterated during construction.

Comparison With One-Call Markings

VDOT has also had the opportunity to build a growing case study on the reliability and positional accuracy of one-call locates. Although contractors have had issues with one-call locates for years, VDOT has been able to catalog many cases of mismarks by comparing one-call locates and RFID marker-derived locations. Figure 70 shows one of those cases where there was a significant discrepancy between the one-call locates and the location of the RFID marker.

Courtesy of the VDOT.

Figure 70. Photo. Discrepancy between one-call locate and RFID marker location.[11]

Sample Projects

VDOT provided information about the deployment of RFID markers in connection with four projects at the Northern Virginia District.[105] Table 25 provides a summary of each project and relevant RFID marker deployment information.

Table 25. Sample VDOT projects with RFID marker deployments.

Item	Description
Project	**Widening and Intersection Improvements in Merrifield, Fairfax County**
Summary	Project No.: State: 0029-029-119, C508; Federal: STP-5401 (097) The project widened Route 29 from two to three through lanes in each direction between Merrilee Drive and I-495 (about 0.6 mi), widened Gallows Road from two to three through lanes in each direction between Gatehouse Road and Prosperity Avenue (about 0.8 mi), constructed a 6-ft sidewalk on the westbound side of Route 29 and a 5-ft sidewalk on the eastbound side, constructed a 10-ft asphalt shared-use path on the west side of Gallows Road and a 6-ft sidewalk on the east side, installed dual left-turn lanes on Route 29 at Gallows Road, and landscaped medians on both approaches.
Statistics	Project cost: $110 million, including the following: • $76 million for 70 right-of-way parcels and extensive utility work to move seven underground fuel tanks, with a separate $8 million project to relocate and upgrade major water mains. • $10.6 million for preliminary engineering. • $23.4 million for construction. Construction start/end dates: 2010–2012.
Utilities and RFID Data	Utilities: Natural gas, telephone, power, cable television, two water authorities, sanitary sewer, 13 separate fiber optic companies, and out-of-service facilities. RFID work status: Complete. RFID installation limits: Entire project limits. RFID markers installed: 700. RFID installation cost: $10,000. Cost per ball marker installed: $10,000/700 = $14.29. Utility relocation and RFID installation start/end dates: 2008-2010.
Project	**I-66/Route 29/ Linton Hall Road Interchange in Gainesville**
Summary	Project No.: State: (FO)0066-076-113, Federal: HPD-0660N The project involved construction of an overpass carrying Route 29 over the Norfolk Southern Railroad, construction of another overpass carrying Linton Hall and Gallegher roads over the railroad and Route 29, widening of Route 29 to six lanes, and elimination of driveway entrances and two traffic signals between I-66 and Virginia Oaks Drive.
Statistics	Project cost: $267 million. Construction start/end dates: June 2010–December 2014.
Utilities and RFID Data	Utilities: Water and sewer, joint build duct system, and out-of-service facilities. RFID work status: Complete. RFID installation limits: Entire project limits. RDID markers installed: 350. RFID installation cost: $7,500. Cost per ball marker installed: $7,500/350 = $21.43. Utility relocation and RFID installation start/end dates: 2007–2010.
Project	**Route 7100 (Fairfax County Parkway) Interchange at Route 7700 (Fair Lakes Parkway) from South of I-66 to North of Route 750 (Rugby Road)**
Summary	Project No.: State: (FO) 7100-029-353, Federal: STP-5401 The project widened Fairfax County Parkway from four to six lanes from south of I-66 to north of Rugby Road (more than 3 mi). Signals were eliminated, and entrance and exit ramps were constructed to and from the Fairfax County Parkway, Fair Lakes Parkway, and Monument Drive. Shared-use paths and sidewalks enhanced pedestrian access at the interchange and to the Rocky Run Stream Valley Park trail system.

Item	Description
Statistics	Project cost: $69.5 million • $8.9 million for preliminary engineering • $2.6 million for right-of-way acquisition and utility relocations • $58.2 million for construction Construction start/end dates: 2010–2013
Utilities and RFID Data	Utilities: N/A. RFID work status: Complete. RFID installation limits: Entire project limits. RFID markers installed: 550. RFID installation cost: $9,000. Cost per ball marker installed: $9,000/550 = $16.36. Utility relocation and RFID installation start/end dates: N/A.
Project	**Stringfellow Road (Route 645) from Fair Lakes Boulevard (Route 7735) to Lee Jackson Memorial Highway (Route 50)**
Summary	Project No.: State: 0645-029-384, C-501 Project Improvements: This project involved widening Stringfellow Road to four lanes, separated by a 16-ft concrete center median, between Fair Lakes Boulevard and Route 50. The first phase of the project began in October 2010 and focused on moving major utilities.
Statistics	Project cost: $63 million. Construction start/end dates: March 2013 to July 2015.
Utilities and RFID Data	Utilities: Petroleum pipeline, fiber optic system, water and sewer, and out-of-service facilities RFID work status: Complete. RFID installation limits: Fair Lakes Boulevard to Route 50 (approximately 2 mi). RFID markers installed: 2,500. RFID installation cost: $40,000. Cost per ball marker installed: $40,000/2,500 = $16.00. Utility relocation and RFID installation start/end dates: N/A.

For the 4 projects listed in table 25, the total number of RFID markers installed was 4,100 and the total cost of installation was $66,500, for an overall average of $16.22/marker installed. These costs included the cost for purchasing the markers; programming, installing, inspecting, and surveying activities; providing CAD and database support; and providing as-built information to stakeholders. It is unclear whether these costs included overhead costs. Unit costs ranged from $14.29/marker on the Route 29/Gallows Road project to $21.43/marker on the Gainesville project. For the Gallows Road project, fewer staff hours were involved compared with the other projects. For the Gainesville project, more staff hours were involved on certain steps, which increased overall costs.

Benefits

Benefits that VDOT officials noted from the implementation of the RFID marker program include the following:

- Availability of georeferenced utility segment information that can be used to establish a zone of protection for that specific utility installation when construction equipment is equipped with GPS-enabled digging trigger mechanisms. Another benefit is the availability of as-built information that highway contractors can use for test hole planning purposes. The result is a reduction in safety hazards, delays, and costs commonly associated with conflicts with underground utilities in highway construction.

- Improvement in the horizontal and vertical accuracy of utility facility information.
- Linkages between attribute data associated with each RFID marker with georeferenced coordinates for mapping and locating purposes.
- Reliable utility inventory system that provides comprehensive information for future use by contractors, locators, and designers.
- Production and conveyance of reliable, as-built utility information to utility owners, locators, excavators, and design engineers. A related benefit is increased coordination among stakeholders.
- Improved effectiveness of utility inspections by helping inspectors to verify that actual utility locations on the ground are consistent with design documentation. As a QC measure, VDOT inspectors who oversee the installation of RFID markers also verify that the data programmed into the marker are accurate and consistent with the utility installation on the ground. One of the results is more productivity in the inspection process. Inspectors can now collect data from about 180 markers (or about 4,500 ft) per day, which is a significant improvement compared with prior practice.
- Improved coordination with other VDOT officials, including construction inspectors, for any utility-related issues that might arise during construction.
- No conflict with one-call laws or regulations.
- Installation of RFID markers in proximity to existing gas markers without interference.
- Reduction in the risk of confusion between active line and out-of-service lines.

ROI Analysis

As mentioned previously, the cost in place for RFID markers on the four VDOT projects ranged from $14.29 to $21.43/marker, for an overall average of $16.22/marker. The impact on utility relocation costs depends on the type of utility installation. For example, according to VDOT officials, the average cost to install a 24-inch water main in Virginia is approximately $145/ft of pipe. Assuming RFID markers every 25 ft, the additional cost is $16.22/25 = $0.65/ft of pipe, which translates to a relative increase of 0.45 percent. The relative impact increases for smaller diameter pipes. For example, for a 12-inch pipe that costs $60/ft of pipe, the relative increase would be 1.1 percent. Similarly, for a 4-inch pipe that costs $40/ft of pipe, the relative increase would be 1.6 percent.

Most of the benefits mentioned in the previous section are difficult to quantify in terms of fewer delays or lower project costs. The research team requested change order data to determine whether the use of RFID markers had resulted in fewer change orders or utility claims. Because most of the RFID implementations have been in the Northern Virginia District, the goal was to compare cost data for a sample of projects in this district with cost data for a sample of projects in other districts. Unfortunately, VDOT only maintains aggregated change order information, which made it impossible to determine which, if any, change orders could have been related to the lack of adequate utility information during construction.

VDOT officials provided anecdotal information about specific damage prevention benefits. For example, for a project along Route 50, VDOT relocated approximately 700 ft of an 8-inch gas line for a proposed sound wall. VDOT installed RFID markers over the relocated gas line for mapping and identification purposes. To build the sound wall, it was necessary to remove existing street light foundations. The relocated gas line was close to these foundations. The one-call marks on the ground that the contractor requested before construction corresponded to the location of the old main, which was far away from the street light foundations. With this information, the contractor started removing the light foundations. VDOT officials happened to be on site that day and advised the contractor that the location of the relocated gas line was very close to where the work was taking place. VDOT also provided markings on the ground identifying RFID marker locations showing where the new gas main was actually located.

Quite likely, a disaster was avoided. This event took place on a Friday afternoon in the middle of two highly traveled roadways. There were also approximately 50 townhouses near this location. If the contractor had damaged the relocated gas main, both roadways might have been closed and the residents of the townhouses would have been evacuated. The gas company would have had to send crews to repair the damage, and emergency services would have been deployed to manage the event. Depending on the magnitude of the damage, lives might have been lost.

In another instance, a VDOT environmental contractor was performing investigative borings to find the perimeter of a plume of contaminated soil along Gallows Road in Falls Church. The borings were taking place in the middle of Gallows Road at night. VDOT officials were onsite that night performing inspections for a duct bank installation when they noticed the environmental contractor performing a bore at a location where an 8-inch gas line had been relocated. One-call feedback to the contractor had indicated that the gas line was located along the existing sidewalk. VDOT located the RFID markers showing the actual gas line location, providing confirmation to the contractor where not to perform the boring.

These are not isolated incidents considering national trends. According to data compiled by the Common Ground Alliance (CGA), 236,810 underground facility damage events were reported in 2012, of which 1,188 occurred on State or interstate highways.[106] Statistics were not broken down by State, but assuming a uniform distribution, this number would translate to 24 damage events on State or interstate highways per State every year on average. Nationwide, 17 percent of events were the result of nonsufficient locating practices. The most commonly reported subgrouping within this category was nonsufficient facility marking or location (63 percent), followed by facility not located or marked (24 percent). For damage events for which the cause was nonsufficient location practices, the majority (61 percent) had visible but incorrect markings, and 30 percent had markings that were not visible. In other words, nationwide, some 10 percent of damage events can be due to visible but incorrect markings, and an additional 5 percent of damage events can be due to markings that were not visible. CGA statistics include the number of events that resulted in utility service interruptions and contractor downtime hours but no information about total costs to all affected stakeholders (such as, but not limited to, highway and utility contractors, emergency services and hospitals, nearby communities and businesses, commuters, and utility rate payers).

Sometimes, contractors find out-of-service utility facilities. In these cases, it is necessary to contact the utility owners to verify the status of the facilities on the ground. In practice, this can take from a few hours to a couple of days. In some cases, the utility owner official goes to the site but does not confirm the status of the facility to VDOT or its contractor. In these situations, VDOT has had to pay the contractor for downtime and any related inefficiencies. With the RFID protocol, if a cable or pipeline is out of service, VDOT asks the utility contractor to cut the facility in the area of potential conflict and install an RFID marker at the exact location of the cut cable or pipeline. This allows the contractor to excavate at that location and find proof that the facility is indeed out of service, saving VDOT time and money.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Two critical factors contribute to inefficiencies in the management of utility issues—the lack of accurate, complete information about utility facilities that might be in conflict with the project and the resolution and overall management of those conflicts. These inefficiencies can result in problems, including, but not limited to, construction-site disruptions when utility installations are encountered unexpectedly, damage to utility installations leading to environmental concerns and safety risks, project delays, and unnecessary utility relocations.

The objective of this research was to document issues associated with State transportation departments asserting their responsibility to manage utility installations within the highway right-of-way, with a focus on the use of 3D techniques to assist in that management. More specifically, the research addressed the following topics:

- Feasibility of having State transportation departments as the central repository of utility data within the State highway right-of-way.
- Potential benefits of having accurate utility data available during the project delivery of highway projects.
- Barriers that State transportation departments may encounter in collecting, storing, and maintaining utility location data, as well as recommendations on how to overcome these barriers.
- Potential cost to State transportation departments to collect and maintain 3D utility location data, as well as to mark utilities with 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 selected case studies.
- Conducted an analysis of strategies, barriers for implementation, and ROI.
- Reviewed the use, benefits, and costs of using RFID technology to mark underground utility installations.

FEASIBILITY OF STATE TRANSPORTATION DEPARTMENTS AS THE CENTRAL REPOSITORY OF UTILITY DATA

State transportation departments must 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 the State transportation department’s goal to collect, map, and store utility facility data systematically and reliably. State transportation departments are typically interested in just a few utility data items they need to manage the right-of-way but 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 (mainly, State transportation departments manage the right-of-way but external entities own the utility infrastructure), it is currently not feasible for State transportation departments to be the unique, centralized repository of all authoritative information that exists about utility facilities within the State highway right-of-way.

According to AASHTO guidelines that are the basis for utility accommodation policies around the country, it is in the public interest to accommodate utility facilities on the highway right-of-way provided there is no negative impact on highway safety, construction, maintenance, or operations.(107,108) This statement of public interest is also a provision in 23 Code of Federal Regulations (CFR) 645.205.(109) However, the same AASHTO guidelines place the responsibility for managing records describing facilities, use, size, material, location, and other characteristics on utility owners. These owners are expected to provide as-built information at the completion of construction, and the as-built information should be accessible to other utilities and transportation agencies. In other words, utility accommodation policies assume that utility owners are responsible for managing all the data associated with the facilities they own and operate. In practice, State transportation departments are usually not aware of the exact location of most underground utility facilities in the highway right-of-way. If information about those facilities is needed for a particular reason (usually in the context of an active transportation project), State transportation departments request that information. However, the quality and completeness of this information depends on the utility owner's standards and procedures for record keeping, which are frequently inadequate to satisfy the needs of a typical State transportation department highway design and construction project.

State laws give utility owners the right to build, operate, and maintain their facilities within the highway right-of-way. Occupancy of this right-of-way is usually by permit, easement, lease, or some other legal instrument. Further, with some exemptions, State laws require utility owners to participate in and provide information about their facilities to one-call notification centers for damage prevention purposes. However, there is no formal requirement for utility owners to provide accurate, comprehensive copies of their utility facility records to agencies that own or are responsible for the right-of-way where the utility facilities are located. Even for one-call applications, some utility owners intentionally degrade the quality of the spatial information they provide to the notification centers. Utility owners are generally opposed to the idea of allowing others access to their information. Reasons include commercial concerns, homeland security concerns, and a lack of societal consensus on acceptable levels of data access by authorized stakeholders.

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

- **Use utility data model**—This strategy involves using 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 utility permitting requirements**—This strategy involves strengthening 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**—This strategy involves updating agency policies and procedures to achieve the goal of managing the right-of-way effectively based on 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 within the highway right-of-way. It also includes establishing reliable protocols to identify, map, and document recorded and nonrecorded utility facilities within project boundaries throughout the highway project delivery process. Updating AASHTO 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

In the current practice, it is common to depict utility lines and appurtenances on utility layouts after collecting the data. These drawings are typically labeled utility drawings, files, or maps. However, this information is not necessarily shown or referenced on all relevant plan views or cross sections. As a result, critical design files frequently lack utility-related information (e.g., in the case of files showing ITS or signalized intersection infrastructure, noise walls, or structure foundations).

Utility lines and appurtenances are frequently not shown on PS&E assemblies (although it is common to include utility certifications in these assemblies listing utility relocations that are still pending). In addition, utility installations that are relocated before or during the construction phase (and associated attribute data) do not normally appear on construction plans, or changes to the operational status of previously documented existing installations are often not updated. In addition, if changes are made in the design phase, project task designers might not be aware of them.

In general, project-related information tends to follow paper-era guidelines for document retention. In some cases, State transportation departments have implemented procedures to scan as-built information into image files, which could then be stored as PDF file plan-of-record repositories. The as-built information could be based on CAD files or paper drawings that were marked up during construction. Increasingly, State transportation departments are interested in exploring strategies to keep the original CAD files or at least to generate PDF files directly from the CAD environment instead of losing the wealth of project data by first generating an image representation of the as-built conditions.

There is a growing demand at State transportation departments for the use of 3D modeling to support project design and construction. By comparison, only a few agencies are using 3D technology for utility installations, clearly indicating that this is a new area for most agencies. In most cases, States might collect utility data in 3D but then develop 2D information products to document the existence of utility installations for inclusion in other aspects of project delivery.

A reliable inventory of utility facilities that includes using 3D techniques to assist in that effort would provide benefits such as availability of depth and elevation of utility facilities throughout the project, integration with aboveground 3D project data, and 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, lower risk, and less damage to utilities, as well as less utility exposures for absolute proof of utility installation existence, location, and attributes.

This feedback is consistent with general perceptions of benefits associated with the use of 3D modeling techniques found in the literature. For example, according to a 2012 survey, State transportation departments highlighted the following benefits related to the use of 3D modeling techniques (although, for the most part, they were unable to quantify the benefits):(94)

- 3D visualization leads to faster decisionmaking. Profiling is simpler, and faster calculations for earthwork are possible.
- There is a potential for lower bids, lower survey costs, and less rework; more accurate estimates; and fewer change orders and field modifications.
- 3D visualization increases the ability to catch avoidable mistakes. Conflicts can be more easily resolved before the letting process. Earthwork calculations are more realistic and accurate.
- 3D modeling builds belief in the design and confidence in the engineer-client relationship.

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 monitoring the submission of utility data to maintain systemwide 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 in participating; 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 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 take the following into consideration:

- Focus on how a 3D design environment actually works because this environment requires designers and coordinators to approach things differently compared with a traditional 2D design environment.

- Conduct webinars to introduce the subject at any time but only conduct detailed training when the agency is committed to start designing in 3D. The reason is that staff interest and effectiveness decreases substantially as the lag between training and implementation increases. Another reason is that transition to a 3D design environment is not plug-and-play. Depending on the process followed to transition to a 3D environment, it may be necessary to make adjustments in the business process.

- Start small. It is easier to achieve buy-in within the agency if success is demonstrated on small projects.

BARRIERS AND SOLUTIONS FOR COLLECTING AND MANAGING UTILITY LOCATION DATA

Collecting accurate utility data from utility owners can be challenging. Typically, agencies send project drawings to utility owners with a request to mark up those drawings with relevant utility information. In some cases, utility owners request electronic copies of those drawings in CAD format. Sometimes, utility owners provide electronic as-built files. In practice, these files are rarely scaled or georeferenced and follow a variety of formats, making it necessary to convert the files to a usable format and adjust their scale and alignment to match the project files.

One-call systems started in the 1970s as a mechanism to prevent damage to underground utility installations. Depending on the level of urgency, one-call notification centers often have different categories of job tickets (e.g., routine, priority, or emergency). Although most tickets are associated with imminent excavation activities, survey or design tickets are also possible. Most one-call systems do not allow designers or State transportation departments to call for information during the project design phase. For the few States that allow survey or designer tickets, there are significant shortcomings in getting utility installations marked accurately, comprehensively, and in a timely manner. Nevertheless, although the data provided through the one-call process are typically not accurate or complete enough to make design decisions, the data do provide valuable information about some utility installations at earlier stages of the project development process. However, agencies that rely exclusively on one-call information during project design often experience significant utility issues as projects progress.

Questions about the completeness and quality of existing utility as-built information prompted the emergence of the CI/ASCE 38-02 standard guideline for the collection and depiction of existing underground utility installations.[(1)] Collecting data from existing records or oral recollections and surveying and plotting visible utility appurtenances is a routine practice at State transportation departments. However, this practice tends to miss many existing underground installations. QLB and QLA data collection practices vary substantially across the country. Some agencies collect these data routinely, while other agencies do it only on a case-by-case basis or not at all.

When applied correctly, QLB and QLA utility investigations can find 80 to 90 percent of all underground utility installations that were suspected to exist in the area and, in any case, considerably more than traditional investigations at the QLD or QLC level. Unfortunately, many agencies still do not recognize the benefits of conducting thorough utility investigations. One of the reasons is the lack of a tool that provides not just information about the benefits but also provides specific guidelines on how or where to use QLB and QLA utility investigations, as well as a quantitative assessment of the risks agencies assume 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.

AMG is now an accepted practice, and 3D modeling is being used to improve the design process, with the primary goal to provide data that contractors can use directly to facilitate critical project activities such as grading and paving. However, a significant issue affecting the implementation of 3D utility applications is data exchange. Over the years, it has been possible to exchange 2D CAD files in their native formats as well as XML formats. However, the same level of interoperability has not yet translated to the 3D environment. Data exchange standards such as LandXML facilitate the AMG process. However, current data exchange standards do not provide adequate support for utility 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 capability 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. Further, existing 3D CAD platforms provide support for LandXML import and export operations, but the degree to which data interoperability across platforms is achievable on a consistent basis is unknown.

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, 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 support for project scheduling, quantity and cost management and control, and construction supply chain management.

A variety of geophysical methods are available to detect underground utilities, including EMI methods, GPR methods, optical methods, infrared (or thermal) methods, magnetic methods, inertial methods, and elastic wave methods. In general, 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. At the same time, no single technology is available to detect utility installations under all conditions. Because of factors such as variability in soil characteristics and moisture content, as well as utility facility material and other properties, a large toolbox of equipment and techniques is frequently necessary to identify and map utility installations in a reliable, comprehensive manner. New GPR and EMI array technologies that use multiple sensors to produce 3D imagery of underground facilities are at the point where they 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.

In Europe, surface geophysical methods are frequently considered adequate for the production of fairly or sufficiently accurate X, Y, Z data for design purposes. As a result, 3D utility mapping information is more common in European countries than in the United States. A common practice in those countries is to represent a utility facility by a 3D polyline with X, Y, Z attributes at every vertex, where the X, Y, Z data represent the crown of the buried utility facility as determined by surface geophysical instruments and/or physical exposure.

A generalized utility process that was developed as part of the SHRP2 R15B and R15C research projects applies to a wide range of projects whether design and construction occurs in a 2D or a 3D environment.[2,3] 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 keeping the 3D utility information current throughout project design and construction. Recommended activities prior to building a 3D model of existing utility installations include the following:

- Review all previous utility information, including any existing QLB or QLA data. It is critical for the project utility coordinator to highlight the need for additional analysis, interpretation, and data collection as appropriate.

- Collect new or additional QLB data to supplement existing utility location data. This may be critical at locations where additional utility facilities have been installed after the initial utility data collection was completed.

- Implement a protocol so that any new utility permit application within the project limits is routed to the project team for review. The protocol should include a requirement for new permit applications within the project limits to include plan views and profiles signed and sealed by a registered PE. In situations where this is not feasible or practical (e.g., a maintenance permit application not tied to a reimbursable utility), the protocol should include a requirement for the permit application to include detailed plans and profiles that are subject to the project team’s review and approval. In addition, the project team should inspect the installation as it is taking place in the field and take survey measurements.

- Where existing test hole data are available, add that information to the project files. Where geophysical data provides some indication of the depth of a utility facility, the utility coordinator should include that information along with a label to the effect that the depth information is approximate.

Recommended activities for building and using the 3D model of utility installations include the following:

- Build the 3D model of existing utilities using the information described in previous bullets and additional judgment based on feedback provided by subject matter experts who have considerable field experience installing utility facilities.

- Integrate this information with the main 3D model for the project.

- Run hard clash detections to identify locations where there are conflicts between existing utilities and project features. The utility coordinator should also run soft clash detections using buffers to check for restrictions according to existing UAR and regulations.

- Collect additional QLA data at critical locations based on the information resulting from the clash detection analysis. One of the reasons for using the results of the clash detection analysis to evaluate the need for additional QLA data collection is that it may be possible to reduce substantially the number of test holes needed for the project.

- Conduct additional clash detections in the 3D software as additional design information becomes available. This is critical because throughout design and construction, there may be design changes (e.g., roadway features, drainage features, traffic control features, and so on) that could have an impact on existing or proposed utility installations.

- With the results of the clash detection analysis, determine which strategies to follow to resolve utility conflicts using the methodology developed in the SHRP2 R15B and R15C projects.[(2,3)]

Recommended activities for keeping the 3D utility information current throughout project design and construction include the following:

- As utility facilities are relocated in the field, implement an inspection and as-built production protocol that includes surveying and documenting X, Y, Z coordinates associated with actual locations on the ground and transcribing that information to 3D files to generate an as-built 3D model.

- Implement an efficient electronic communication protocol between the contractor and the project owner (and/or its representative) to identify, resolve, and manage utility conflicts that arise during construction.

- Implement a protocol to evaluate the project at regular intervals (e.g., every 6 mo) to check for any changes in utility installations within the project limits. The protocol should involve activities such as the following:

  - Review all utility-related construction activity from the previous updating cycle.

  - Review all one-call tickets within the project area and screen them for construction that might possibly involve utility changes.

  - Contact utility owners and request information on any known changes.

  - Walk the project site and visually scan the area for evidence of new construction.

    - Indicate the results of the previous four sub-steps on field sheets and conduct a field investigation with designating equipment in those separate areas.
    - Update the utility map based on any discovered changes to utility installations in the field.

- Implement an automated CAD-based protocol to evaluate the project at regular intervals (e.g., monthly or bimonthly) to check for any changes in project design, construction sequence, or other relevant project characteristics that might have an impact on the status of already cleared utility conflicts.

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

- **Use standards-based utility data collection and reporting protocols**—This strategy involves using standards-based, agency-wide utility data collection and reporting protocols, including appropriate surveying, CAD, and GIS standards and specifications. Using standards-based data collection protocols includes 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 began an initiative to develop a standard for recording and exchanging utility infrastructure data.

- **Include mechanisms to update database in response to changes**—This strategy involves developing and implementing 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). To achieve this goal, it is important to establish effective communication channels within the agency, including, but not limited to, assigning the overall responsibility for tracking all utility locations and data to just one department or unit within the State transportation department.

- **Integrate 3D utility conflict management process**—This strategy involves promoting 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. This training should include the three groups of recommended activities to support utility 3D design and construction activities: 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 keeping the 3D utility information current throughout project design and construction. Part of the process will involve developing and disseminating model design and construction specifications for utility 3D modeling techniques.

COST TO COLLECT AND MAINTAIN 3D UTILITY DATA AND MARK UTILITIES WITH RFID TECHNOLOGY

Cost and ROI of Using 3D Models for Utility Investigations

Efforts to gather reliable, comprehensive information about the cost to develop 3D utility inventories were largely unsuccessful. The research team used a variety of strategies to gather this information, including requesting information about typical costs to develop 3D models in general as well as attempting to use typical costs to conduct utility investigations to estimate the cost to develop a 3D inventory of utilities. Although the data gathered were incomplete, the analysis indicates that the cost to develop 3D utility inventories is primarily a function of the cost to collect reliable, comprehensive utility data in the field because the actual cost to develop the 3D model is relatively minor once the data have been collected.

Although there are differences among States on how they use 3D modeling for design and construction, State transportation departments and practitioners now generally see 3D modeling as having 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. However, examples documenting economic benefits from the use of 3D modeling and BIM for vertical construction are beginning to appear in the literature. For example, the Letterman Digital Arts Center at the Presidio National Park, San Francisco, CA, was completed in 2005 at a cost of about $350 million.(6) BIM was used initially for visualization purposes, but then, it became a management tool during construction and for the production of an as-built 3D model. Use of BIM in this project enabled the determination of some 200 design and construction conflicts, most of which were corrected before construction, resulting in an estimated savings of more than $10 million (or almost 3 percent of the total project cost). Similarly, the University of Southern California’s School of Cinematic Arts complex was completed in 2010 at a cost of $165 million.(7) BIM was used for design and construction. The first phase of the project was completed 2 mo ahead of the original schedule, and the second phase of the project was completed 3 mo ahead of the original schedule. Estimated cost savings were $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 (or 10 percent of the total design cost) to gather QLB data throughout the project and QLA data in sufficient locations to identify important utility conflicts. However, 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 in the literature for conducting traditional QLB and QLA utility investigations are usually from 3:1 to 6:1. 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.

Recently, a review of utility investigation costs in North Carolina produced an average cost of $0.77 to $1.60 per linear foot of mapped utility feature for QLB investigations and $602 to $1,229 per test hole for QLA investigations. These costs did not include mobilization costs. Test holes deeper than 6 ft involved an additional cost per additional foot of depth. For the Alaskan Way Viaduct and Seawall Replacement Project in downtown Seattle, the cost of the QLB utility investigation was approximately $2.5 million (or about $3/ft of mapped utility feature). This cost was higher than normal owing to a combination of factors, including, but not limited to, complexity of the utility mapping effort and length of the project (which involved implementing a multiyear protocol for maintaining the utility inventory up-to-date at regular intervals). For this project, there was also 3D modeling of utilities at some locations. Although specific cost numbers were not available, a consultant who was involved in the project estimated that the QLA data, utility experts, and CAD personnel needed for this effort might have added up to $0.50/ft of designated utility (or 17 percent) for those utilities that were developed into shape files.

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. Further, 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 include developing a catalog of projects that use 3D modeling techniques for utility facilities during project delivery. The purpose of developing this catalog is 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.

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

A typical justification for deploying RFID markers is to protect and prevent damage to utility installations during construction or maintenance activities. A secondary (usually lower priority) objective is to facilitate the development of underground asset inventories. There are not too many examples of application of RFID technology for utility installations in the United States, partly because of the perception that deploying this technology is expensive. Nevertheless, the number of applications continues to grow.

The application of RFID technology at VDOT's Northern Virginia District is unique among State transportation departments. At the Northern Virginia District (which accounts for some 40 percent of all construction projects at VDOT), VDOT has undertaken an aggressive program to deploy RFID markers to mark utility installations that have been relocated as part of VDOT construction projects.(11) VDOT has also used RFID markers on a few projects in the Fredericksburg District. VDOT started the RFID program to mark newly installed utility installations in an effort 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 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. Likewise, the relative increase is 1.6 percent for a pipe that costs $40/ft to install.(11)

VDOT has realized benefits ranging from the availability of georeferenced 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. The reason is that available project cost data, including change orders, are not sufficiently disaggregated to enable a reliable determination of economic benefits. Nevertheless, VDOT officials provided information about specific 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 showing where the new gas main was actually located. Quite likely, a disaster was avoided.

In another instance, a VDOT environmental contractor was performing investigative borings along Gallows Road in Falls Church. VDOT officials noticed the environmental contractor performing a bore 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 located the RFID markers showing the actual gas line location, providing confirmation to the contractor where not to perform the boring.

These are not isolated incidents considering national trends. According to data compiled by the CGA, some 10 percent of underground utility damage events nationwide can be due to visible but incorrect markings. CGA statistics include the number of events that result in utility service interruptions and contractor downtime hours but no information about total costs to all affected stakeholders (such as highway and utility contractors, emergency services and hospitals, nearby communities and businesses, commuters, and utility rate payers). However, from the experience reported by VDOT, 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 as the result of incorrect utility markings.

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

- **Promote the use of RFID technology to mark utilities**: This strategy involves promoting 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. This 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.

- **Assess total cost of damage to underground utilities**. This strategy involves developing a systematic assessment of the total cost associated with the damage to underground utilities during project construction to complement the statistics that CGA compiles, which currently include the number of events that result in utility service interruptions and contractor downtime hours but no information about total costs to all affected stakeholders.

ADDITIONAL RECOMMENDATIONS

Most strategies described in the previous sections are readily implementable at the Federal and/or State levels. Their feasibility depends on the availability of funding and the identification of agencies, units within agencies, or trade organizations that could agree to champion their implementation. A separate, standalone implementation plan provides specific information and recommendations on how to approach the implementation of each of those strategies.

The research team also identified the following strategies to support the implementation of the strategies described previously in this chapter but which need development work:

- **Develop a robust reference 3D utility data model**. An increasing number of utility data models are available in the literature. However, they handle data (both spatial and nonspatial) differently, making it difficult for State transportation departments to determine which, if any, of the existing models is appropriate for their needs. 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 final design, construction, and the production of as-built documentation. Issues to address in this area include, but are not limited to, spatial data quality (including horizontal and vertical positional data accuracy and uncertainty) and attribute data.

- **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. The level of attribution for underground facilities in LandXML is very limited, which limits the capability 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. 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. Issues to address in this area include short-term and long-term usability of the data, as well as compatibility with existing data processes at State transportation departments, utility owners, engineering consultants, contractors, one-call services, and other stakeholders. This also includes conducting extensive testing to measure the degree to which it is possible to exchange data across 3D CAD platforms using data exchange standard import and export operations, including utility features.

- **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. However, a common problem is that 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.(1) 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. The manual should also document a comparison of the relative increases in cost and benefits associated with different types of utility investigation techniques to determine the range of application and thresholds for each technique.

- **Improve coordination between State transportation departments and the one-call process**. As the membership of State transportation departments in one-call notification centers increases, an opportunity exists to help introduce changes to the process in ways that could benefit the project delivery process at State transportation departments throughout the country. Over the years, 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 seems to be working well for damage prevention is proving to be inadequate to address 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 needed 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. Current clash detection techniques use highly simplistic buffering models that do not properly account for factors such as uncertainty, construction sequence considerations, or, in some cases, utility accommodation restrictions and rules.

APPENDIX. IMPLEMENTATION GUIDANCE

FHWA conducted research to document issues associated with State transportation departments asserting their responsibility for managing utility installations within the highway right-of-way, with a focus on the use of 3D techniques. More specifically, the research addressed the following topics:

- Feasibility of having State transportation departments as the central repository of utility data within the State highway right-of-way.
- Potential benefits of having accurate utility data available during the project delivery of highway projects.
- Barriers that State transportation departments may encounter in collecting, storing, and maintaining utility location data, as well as recommendations on how to overcome these barriers.
- Potential cost to State transportation departments to collect and maintain 3D utility location data, as well as to mark utilities with RFID technology.

The research included a literature review on the use of 3D technologies; documentation of business practices and case studies; analysis of strategies, barriers for implementation, and ROI; and evaluation of the use, benefits, and costs of using RFID technology to mark underground utility installations. The research outlined 16 implementation strategies, including 10 strategies that are readily implementable and 6 strategies that need additional development or research work. These strategies are grouped according to five main implementation goals, as shown in figure 1 through figure 3. Readers should note that some strategies could apply to multiple implementation goals.

This implementation guidance provides how-to steps and other information of interest to State transportation departments, FHWA, and other stakeholders for the implementation of the 16 strategies that resulted from the research. For each strategy, content includes an objective, description, identification of potential implementation leaders or champions, activities that are necessary for successful implementation, and criteria for judging the progress and success of the implementation.

The criteria for implementation progress and success refer to a basic set of high-level measures to assess the progress of completion of the implementation activities. More detailed, disaggregated measures are possible in most cases, but these would probably change from agency to agency depending on factors such as local business protocols and procedures and specific implementation path selected. Likewise, because decisions related to implementation approach, path, and funding are likely to vary by agency, this implementation guidance does not cover logistical issues such as implementation schedule, management tools and software, or reporting requirements.

The main audience for this implementation guidance is State transportation departments, based on the assumption that implementation of the strategies will occur primarily at the State level. In many cases, State transportation departments are assumed to play a leading role in the implementation. When appropriate, the guidance outlines a potential role (either lead or support) for other stakeholders, including, but not limited to, AASHTO, FHWA, NCHRP of the Transportation Research Board (TRB), consultants and contractors, and relevant trade organizations, such as ASCE, AGC, and ARTBA. Table 26 lists anticipated or potential roles for different stakeholder groups.

Table 26. Anticipated role of key stakeholders for the implementation of strategies.

Strategy	State Transportation Departments	Utility Owners	Utility Coordination Councils	AASHTO	FHWA	TRB's NCHRP	Consultants/Contractors	Trade Organizations
Use utility data model	L	S	S	—	—	—	S	—
Strengthen utility permitting requirements	L	S	S	—	—	—	—	—
Update State transportation department policies and procedures	L	S	S	S	S	—	—	—
Conduct webinars to highlight benefits of reliable utility inventories	S	—	—	—	L	—	S	S
Use standards-based utility data collection and reporting protocols	L	—	—	—	S	—	S	S
Include mechanisms to update database in response to changes	L	—	—	—	—	—	S	—
Integrate 3D utility conflict management process	L	—	—	L	L	—	S	—
Develop catalog of projects that manage utilities in 3D	S	—	—	L	S	L	—	—
Promote the use of RFID technology to mark utilities	S	—	—	L	L	L	—	S
Assess total cost of damage to underground utilities	—	—	—	—	L	—	—	S
Develop robust reference 3D utility data model	S	—	—	L	L	L	—	—
Develop robust data exchange standard for utilities	S	—	—	S	—	—	—	L
Develop library of 3D components for utility installations	S	—	—	S	—	—	—	L
Develop manual for effective utility investigations	S	—	—	L	S	L	—	S
Improve coordination between State transportation departments and the one-call process	S	—	—	L	L	—	—	S
Develop tool to quantify utility location risk levels	S	—	—	L	—	L	—	—

—Not applicable.
L = leading role; S = support role.

GOAL 1: FACILITATE THE DEVELOPMENT OF RELIABLE REPOSITORIES OF UTILITY FACILITY DATA

Use Utility Data Model

Objective: Use a utility data model that meets most current State transportation department needs for design, construction, operation, and maintenance applications throughout the lifecycle of both highway and utility facilities.

Description: This strategy is different from, although related to, the strategy to develop a robust reference utility data model for utilities (which is described later in this appendix in more detail and will likely need leadership at the national level to develop or help implement). The basic premise of this strategy is to use data sources that are already available (if they meet minimum data quality standards) to begin developing an inventory of utility installations within the right-of-way. Most State transportation departments already collect a wealth of information about existing utilities. Therefore, the goal would be to start developing the inventory of utilities even if the data are not ideal or perfect. As the quality and completeness of the data improve, it would be possible to update or complement the existing inventory.

In most cases, this strategy will result in 2D inventories of utility facilities. With some limited exceptions, the current state of the practice at State transportation departments produces 2D utility deliverables, typically in the form of plan views, profiles, and cross sections. Although the ultimate goal would be to develop 3D utility inventories, starting with 2D inventories would enable State transportation departments to start using data that they are already collecting now.

Implementation leaders or champions: State transportation departments could lead the implementation of this strategy. Some State transportation departments have already started the process to develop business cases or have begun the formal data modeling process. Leaders or champions at the State transportation department level include high-level officials representing groups such as utilities, IT, surveying, design, construction, operations, and maintenance. Other champions include utility owners, utility coordination councils, consultants, and contractors.

Activities necessary for successful implementation: Activities include, but are not limited to, the following (listed in the approximate order that they would need to be completed):

- Prepare the business case for the utility data model.
- Communicate with all stakeholders early and often.
- Develop a catalog of existing utility data sources.
- Develop utility data model following the agency’s IT data standards.
- Develop protocol for collecting, processing, and maintaining the data.
- Update utility data model as more data become available.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- The business case document is in place.
- The catalog of existing utility data sources is in place.
- The utility data model is in place, including business process model, logical data model, physical data model, and data dictionary.
- The protocol for collecting, processing, and maintaining the data is in place.
- The enterprise database and user interfaces based on the physical data model and the protocol are in place.
- Number of database records documenting utility facilities within the right-of-way.
- Number of centerline miles of highway with comprehensive utility facility records.
- Number of miles of utilities included in the database.

Strengthen Utility Permitting Requirements

Objective: 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.

Description: This strategy involves strengthening permitting requirements at a State transportation department to increase the quality of the data that utility applicants submit to the agency. Relevant requirements include measuring and submitting accurate horizontal and vertical locations 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.

Some State transportation departments have begun to implement electronic utility permitting systems (e.g., in Georgia, Michigan, Missouri, Pennsylvania, Texas, and Utah). Most States include a requirement for utility owners to comply with the State's utility accommodation policy. However, this requirement is rarely enforced. Strengthening utility permitting requirements could increase the amount and quality of utility location information that utility owners provide the agency. It would also reduce the impact of practices that prevent State transportation departments from knowing what utility facilities are installed within the right-of-way (e.g., in the case of blanket permits).

Although State transportation department-owned facilities do not require a permit to occupy the state right-of-way, applying the strategy described here to situations where the State transportation department installs or exposes a facility within the right-of-way would also result in improvements in the amount and quality of information the State transportation department has about its own facilities.

Implementation leaders or champions: State transportation departments could lead the implementation of this strategy. Leaders or champions at the State transportation department level include high-level officials representing groups that oversee the utility permitting process, such as utilities, right-of-way, and maintenance. Other champions include utility owners and utility coordination councils. With respect to the feasibility of enacting permit fees, only a few State transportation departments around the country have the authority to assess utility permit fees. For the rest of State transportation departments, an act of legislation at the State level would be necessary so that the agencies can assess utility permitting fees.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Reach out to the utility industry to get buy-in on the stronger data collection requirements.

- Update 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.

- Develop a Web-based utility permitting system that enables applicants to upload locations of proposed utility installations and display those locations on an interactive map.

- Change State law to enable State transportation departments to assess utility permit fees. Buy-in from the industry would be critical to get the State legislature's support. To obtain buy-in from the industry, it would be necessary to tie the use of permit fees to substantial improvements in the way the agency manages utility information, making sure that utility owners also know of, and benefit from, the results.

These activities are not listed in a particular order of implementation. For the most part, these activities could occur in parallel.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- The protocol for collecting, processing, and maintaining the data is in place.

- A Web-based utility permitting system is in place with a user interface that enables authorized users to upload and view accurate utility locations, including depth, and attribute information.

- Increase in the number of centerline miles of highway with utility facility records.

- Number of miles of utilities included in the database.

Update State Transportation Department Policies and Procedures

Objective: Update State transportation department policies and procedures to achieve the goal of managing the right-of-way effectively based on the requirement to obtain accurate location of all the assets within that right-of-way. Updating AASHTO utility accommodation guidelines accordingly would also assist in promoting a uniform implementation of this strategy around the country.

Description: This strategy involves updating State transportation department policies and procedures to achieve the goal of managing the right-of-way effectively based on 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 within the highway right-of-way. It also includes establishing reliable protocols to identify, map, and document recorded and nonrecorded utility facilities within project boundaries throughout the highway project delivery process. Updating AASHTO utility accommodation guidelines and FHWA utility regulations accordingly would also assist in promoting a uniform implementation of this strategy around the country. This strategy complements the previous strategy by focusing on an update of all relevant utility accommodation policies and procedures, not just those that pertain to the permitting process. These two strategies should be implemented simultaneously. Updated FHWA utility regulations in 23 CFR 645 would also assist in promoting a uniform implementation, even if the strategy is only recommended.

Implementation leaders or champions: State transportation departments could lead the implementation of this strategy. Leaders or champions at the State transportation department level include high-level officials representing groups that oversee the utility accommodation process, such as utilities, right-of-way, design, construction, and maintenance. Other champions include utility owners and utility coordination councils.

Updating AASHTO utility accommodation guidelines would involve coordination among all State transportation department utility directors and other representatives to relevant AASHTO subcommittees, including the Subcommittee on Right-of-Way, Utilities, and Outdoor Advertising Control, and the Subcommittee on Design. FHWA would also be involved given its historical role providing assistance to the States in preparing draft updates to AASHTO guidelines and updating FHWA utility regulations accordingly.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Update State transportation department utility accommodation policies and procedures.
- Update AASHTO utility accommodation guidelines and FHWA utility regulations in accordance with established procedures.
- Coordinate with utility owners to request comments related to the updated State transportation department utility accommodation policies and procedures.

These activities are not listed in a particular order of implementation. For the most part, these activities could occur in parallel.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Updated utility accommodation policy, manuals, and other relevant documents are in place.
- Buy-in from utility owners on the requirement that they provide accurate locations of all their assets located within the highway right-of-way.
- Updated AASHTO utility accommodation guidelines and FHWA utility regulations are in place.

GOAL 2: HIGHLIGHT THE BENEFITS OF RELIABLE, ACCURATE UTILITY DATA DURING PROJECT DELIVERY

Conduct Webinars to Highlight Benefits of Reliable Utility Inventories

Objective: Conduct webinars, create and maintain blogs, and develop training materials that highlight the benefits of having reliable, accurate utility data during project delivery.

Description: This strategy involves conducting webinars, creating and maintaining blogs, and developing training materials that highlight the benefits of having reliable, accurate utility data during project delivery. The audience for these outreach and training programs would be primarily State transportation departments, more specifically executive level, project managers, designers, and other professionals who collect, use, or manage utility data. Because of the differences between 2D and 3D design environments, the outreach programs should consider the following:

- Focus on how a 3D design environment actually works because this environment requires designers and coordinators to approach things differently compared with a traditional 2D design environment.
- Conduct webinars to introduce the subject at any time but only conduct detailed training when the agency is committed to start designing in 3D. The reason is that staff interest and effectiveness decreases substantially as the lag between training and implementation increases. Another reason is that transition to a 3D design environment is not plug-and-play. Depending on the process followed to transition to a 3D environment, it may be necessary to make adjustments in the business process.
- Start small. It is easier to achieve buy-in within the agency if success is demonstrated on small projects.

Implementation leaders or champions: FHWA could lead the implementation of this strategy by conducting webinars that describe examples from around the country highlighting the benefits of having reliable, accurate utility data during project delivery. Through the National Highway

Institute (NHI), it might also be possible to develop training courses for State transportation departments on relevant topics (e.g., how to develop and implement utility data models and databases or how to integrate utility inventories into critical business processes). The courses could include both Web-based training materials and courses or modules that require in-person participation. At the State level, State transportation departments could work with consultants and software vendors to develop training packages that are tailored to the specific needs of the State transportation department. Trade organizations could also play an important role developing, promoting, or conducting training modules.

Activities necessary for successful implementation: Activities include, but are not limited to, the following (listed in the approximate order that they would likely be completed):

- Develop a catalog of projects or examples where State transportation departments have successfully used reliable, accurate utility data during project delivery.
- Schedule webinars to highlight those examples.
- Prepare business case for relevant NHI courses.
- Develop NHI courses.
- Promote and schedule training opportunities.
- At the State level, develop training packages that are tailored to the specific needs of the State transportation department.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Number of webinars held.
- Number of users who subscribe to relevant blogs.
- Number of training courses conducted by NHI.
- Number of training courses conducted by State transportation departments around the country.

GOAL 3: ADDRESS BARRIERS FOR COLLECTING AND MANAGING UTILITY LOCATION DATA

Use Standards-Based Utility Data Collection and Reporting Protocols

Objective: Use standards-based, agencywide utility data collection and reporting protocols, including appropriate surveying CAD, and GIS standards and specifications.

Description: Using standards-based data collection protocols includes 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 began an initiative to develop a standard for recording and exchanging utility infrastructure data.

Implementation leaders or champions: State transportation departments could lead the implementation of this strategy. Leaders or champions at the State transportation departments level include high-level officials representing groups such as utilities, IT, surveying, design, construction, operations, and maintenance. Other champions include State transportation department consultants and contractors, utility consultants and contractors, and relevant trade organizations, such as ASCE, AGC, and ARTBA. ASCE could contribute to the implementation of this strategy through its initiative to develop a standard for recording and exchanging utility infrastructure data. FHWA could also play an important role by documenting and disseminating case studies among State transportation departments.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Develop utility data collection and reporting protocols that use appropriate surveying, CAD, and GIS standards and specifications, as well as CI/ASCE 38-02 and LandXML.[1]

- Reach out to State transportation department consultants and contractors, utility consultants and contractors, and trade organizations to contribute content to the development of the data collection and reporting protocols.

- Establish or promote communication channels between State transportation departments and ASCE.

These activities are not listed in a particular order of implementation. For the most part, these activities could occur in parallel.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Standards-based utility data collection and reporting protocols are in place.

- State transportation department data collection and reporting protocols are compatible with CI/ASCE 38-02, LandXML, and ASCE's upcoming utility data standard.

- Number of presentations given on the implementation of the standards-based utility data collection and reporting protocols.

Include Mechanisms to Update Database in Response to Changes

Objective: 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).

Description: This strategy involves implementing appropriate mechanisms and protocols to update utility inventory databases whenever there are changes on the ground. To achieve this goal, it is important to establish effective communication channels within the agency, including, but not limited to, assigning the overall responsibility for tracking all utility locations and data to just one department or unit within the State transportation department.

Implementation leaders or champions: State transportation departments could lead the implementation of this strategy. Leaders or champions at the State transportation department level include high-level officials representing groups such as utilities, IT, surveying, design, construction, operations, and maintenance. Other champions include State transportation department consultants and contractors, as well as utility consultants and contractors.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Develop utility data collection and reporting protocols that use appropriate surveying, CAD, and GIS standards and specifications, as well as CI/ASCE 38-02 and LandXML.[(1)]

- 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).

- Update 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.

- Assign the overall responsibility for tracking all utility locations and data to just one department or unit within the State transportation department.

These activities are not listed in a particular order of implementation. For the most part, these activities could occur in parallel.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Standards-based utility data collection and reporting protocols are in place.

- Utility inventory system that includes appropriate mechanisms and protocols to update the database whenever there are changes is in place.

- Updated permitting process is in place.

- Overall responsibility for tracking all utility locations and data is assigned to one department or unit within the State transportation department.

- Number of edits or changes tracked in the database in response to changes in utility facilities in the field.

Integrate 3D Utility Conflict Management Process

Objective: 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.

Description: This strategy involves using the generalized UCM process developed as part of the SHRP2 R15B and R15C projects, augmenting it with protocols and procedures to handle 3D utility data workflows, and providing interactive hands-on training on the use of the UCM approach to link utility activities throughout the project delivery process. Although FHWA is providing some introductory training to State transportation departments on the UCM approach as part of the current SHRP2 R15B implementation assistance program, emphasis on interactive hands-on training will be critical to ensure the successful implementation of the UCM approach. This training should include the three groups of recommended activities to support utility 3D design and construction activities: 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 keeping the 3D utility information current throughout project design and construction. Part of the process will involve developing and disseminating model design and construction specifications for utility 3D modeling techniques. It will also require significant training to judge buffer zones around utilities (i.e., soft versus hard utility conflicts).

Implementation leaders or champions: AASHTO and State transportation departments could lead the implementation of this strategy by scheduling and providing interactive hands-on training on the use of the UCM approach to link utility activities throughout the project delivery process, augmented with protocols and procedures to handle 3D utility data workflows. FHWA could play a leading role by working through NHI on the implementation of aspects of the 1-d UCM training course that do not require interactive hands-on training activities. AASHTO and trade organizations such as AGC and ASCE could also play a role by promoting the use of systematic approaches for managing utility conflicts during project delivery, including strategies on how to manage utility data in a 3D environment.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Schedule and provide interactive hands-on training on the use of the UCM approach to link utility activities throughout the project delivery process, augmented with protocols and procedures to handle 3D utility data workflows. To ensure the successful implementation of the UCM approach, it will be critical to involve a wide range of State transportation department officials who are involved in the utility process, including, but not limited to, project managers, design engineers, utility coordinators, construction managers and engineers, consultants, and contractors.

- Implement NHI course on the implementation of aspects of the 1-d UCM training course that do not require interactive hands-on training activities. The course could include both Web-based training materials and in-person participation modules.

- Schedule webinars.
- Promote and schedule training opportunities.

These activities are not listed in a particular order of implementation. For the most part, these activities could occur in parallel.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Number of interactive hands-on training courses on the use of the UCM approach.
- Number of participants in each interactive hands-on training course, grouped by title or job function (e.g., project managers, design engineers, utility coordinators, construction managers and engineers, consultants, and contractors).
- NHI course on utility conflict management is in place.
- Number of training opportunities held, including webinars.

GOAL 4: DOCUMENT THE COST AND ROI OF COLLECTING, USING, AND MAINTAINING 3D UTILITY DATA

Develop Catalog of Projects That Manage Utilities in 3D

Objective: Develop a catalog of projects that use 3D modeling techniques for utility facilities during project delivery.

Description: This strategy involves assembling a catalog of projects that use 3D modeling techniques for utility facilities 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.

Implementation leaders or champions: AASHTO and TRB could lead the implementation of this strategy by funding a research project to develop the catalog of projects that use 3D modeling techniques for utility facilities during project delivery. FHWA could play a leading role by using incentives (e.g., through the STIC Incentive Program) for State transportation departments to incorporate 3D modeling techniques for utility facilities during project delivery. State transportation departments could also play a leading role by participating in the FHWA incentive program and by providing documentation needed to determine the effectiveness of using 3D modeling techniques for utilities during project delivery.

Activities necessary for successful implementation: Activities include, but are not limited to, the following (listed in the approximate order that they would likely be completed):

- Develop a research need statement for consideration by AASHTO and NCHRP.
- Identify State transportation departments that would be interested in participating in the research based on their work using 3D techniques for utilities during project delivery.
- For each active project, quantify the cost to acquire and map utilities in 3D, measure the impact on practices and the effectiveness in the management of utility conflicts, and document lessons learned and economic benefits.
- Participate in the STIC incentive program to encourage the use of 3D modeling techniques for utility facilities during project delivery.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Research project funded by NCHRP in place, executed, and completed.
- Number of State transportation departments that participate in the NCHRP research.
- Number of State transportation departments that participate in the STIC Incentive Program to encourage the use of 3D modeling techniques for utility facilities.

Promote the Use of RFID Technology to Mark Utilities

Objective: 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.

Description: 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.

Implementation leaders or champions: FHWA could lead the implementation of this strategy by conducting webinars that provide examples of how to use RFID technology to mark underground utilities; build reliable, comprehensive utility inventories; and assist in damage prevention programs. FHWA or NCHRP could play a leading role by preparing a compilation of standards and specifications for RFID markers to assist State transportation departments during the implementation phase. VDOT could support this effort given the unique aspects of the RFID implementation at that agency. Speakers from other agencies where RFID markers have been installed to mark underground utilities could also give presentations on topics such as standards and specifications, installations costs, and damage prevention results.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Schedule webinars describing examples of how to use RFID technology to mark underground utilities; build reliable, comprehensive utility inventories; and assist in damage prevention programs.

- Prepare a compilation of standards and specifications for RFID markers.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Number of webinars conducted and number of participants.
- Compilation of standards and specifications for RFID markers prepared.

Assess Total Cost of Damage to Underground Utilities

Objective: Develop a systematic assessment of the total cost associated with the damage to underground utilities during project construction to complement the statistics that CGA compiles, which currently include the number of events that result in utility service interruptions and contractor downtime hours but no information about total costs to all affected stakeholders.

Description: This activity involves assessing the total cost associated with the damage to underground utilities during project construction. This assessment would complement the statistics that CGA compiles, which currently include the number of events that result in utility service interruptions and contractor downtime hours but no information about total costs to all affected stakeholders.

Implementation leaders or champions: FHWA could lead the implementation of this strategy by conducting a study to assess the total cost associated with the damage to underground utilities during project construction. CGA and the PHMSA could play a leading role, providing funding, data, and or case studies to conduct the assessment. Developing a working relationship with CGA for this effort could result in a product that serves the needs of the utility and contractor industries as well as the needs of other stakeholders such as State transportation departments, emergency services, hospitals, and insurance providers.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Reach out to CGA, PHMSA, and other stakeholders to participate in the preparation of the study and follow-up efforts.

- Conduct a study to develop a systematic assessment of the total cost associated with the damage to underground utilities during project construction.

- Establish a program or method to report the total cost of damage to underground utilities on an annual basis.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Total cost associated with the damage to underground utilities during project construction measured.
- Yearly statistics on the total cost are prepared.
- Reduction in the number of damage events and total cost associated with these events.

GOAL 5: PROVIDE STRATEGIC SUPPORT TO IMPLEMENTABLE STRATEGIES

Develop a Robust Reference 3D Utility Data Model

Objective: Promote 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 final design, construction, and the production of as-built documentation.

Description: An increasing number of utility data models are available in the literature. However, they handle data (both spatial and nonspatial) differently, making it difficult for State transportation departments to determine which, if any, of the existing models is appropriate for their needs. 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 final design, construction, and the production of as-built documentation. Issues to address in this area include, but are not limited to, spatial data quality (including horizontal and vertical positional data accuracy and uncertainty) and attribute data.

This strategy complements the strategy to develop utility data models for utilities at the State level (which was described earlier in this appendix) by providing a more generalized framework that State transportation departments could use to improve the way they manage utility installations within the highway right-of-way. The generalized framework could also benefit from the lessons learned with the implementations that are beginning to take place at several State transportation departments.

Implementation leaders or champions: AASHTO could lead the implementation of this strategy in conjunction with other organizations and programs, such as TRB’s NCHRP and PHMSA. Once the robust reference data model is in place, FHWA could play a leading role by using incentive programs to encourage State transportation departments to implement the 3D utility model at their agencies. State transportation departments could also play a leading role by participating in the incentive program.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Develop a catalog of existing utility data models.
- Develop a robust generalized 3D utility data model (including spatial and nonspatial data that supports all phases of project delivery, from preliminary design to design to construction to the production of as-built documentation.

- Schedule webinars to disseminate the 3D utility data model to stakeholders across the country.
- Use incentive programs to encourage State transportation departments to implement the 3D utility model at their agencies.
- Update the 3D utility data model as lessons learned from various implementations become available.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- The catalog of existing utility data models is in place.
- The robust, generalized 3D utility data model is in place, including business process model, logical data model, physical data model, and data dictionary.
- Number of State transportation departments that participate in the incentive program.
- Number of State transportation departments that use the 3D utility data model to document utility facilities within the right-of-way.

Develop a Robust Data Exchange Standard for Utilities

Objective: Promote updating data exchange standards such as LandXML and other data exchange standards such as ifcXML to provide the support needed to manage utility installations at State transportation departments effectively. Issues to address in this area include short-term and long-term usability of the data, as well as compatibility with existing data processes at State transportation departments, utility owners, engineering consultants, contractors, one-call services, and other stakeholders. This also includes conducting extensive testing to measure the degree to which it is possible to exchange data across 3D CAD platforms using data exchange standard import and export operations, including utility features.

Description: Data exchange standards such as LandXML facilitate the AMG process but do not provide adequate support for utility facilities. The level of attribution for underground facilities in LandXML is very limited, which limits the capability 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. 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. Issues to address in this area include short-term and long-term usability of the data, as well as compatibility with existing data processes used by State transportation departments, utility owners, engineering consultants, contractors, one-call services, and other stakeholders. This also includes conducting extensive testing to measure the degree to which it is possible to exchange data across 3D CAD platforms using data exchange standard import and export operations, including utility features.

Implementation leaders or champions: Trade organizations, such as LandXML, buildingSMART (which maintains ifcXML), and OGC could lead the implementation of this strategy. OGC recently established a PipelineML Standards Working Group in conjunction with the Pipeline Open Data Standard Association to develop an XML standard to enable the exchange of pipeline data among parties, systems, and software applications. State transportation departments could also play a significant role through relevant AASHTO subcommittees, including the subcommittees on design; construction; information systems; and right-of-way, utilities, and outdoor advertising control.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Contact organizations that are in charge of developing and maintaining relevant data exchange standards.
- Participate in the process to develop or update relevant data exchange standards such as LandXML, ifcXML, and PipelineML.
- Disseminate the findings through webinars and conference presentations.
- Provide incentives to State transportation departments to begin using or increase the use of relevant data exchange standards to exchange utility data in all appropriate phases of project delivery.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Communications with standards developing organizations are documented.
- Updated versions of data exchange standards such as LandXML and ifcXML are available to provide the support needed to manage utility installations at State transportation departments effectively.

Develop a Library of 3D Components for Utility Installations

Objective: Coordinate with the engineering community and trade organizations to promote the establishment of information warehouses to exchange libraries of commonly used 3D primitives, objects, and templates.

Description: 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. However, a common problem is that 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.

Implementation leaders or champions: Trade organizations representing consultants and contractors, as well as software vendors, could lead the implementation of this strategy in conjunction with relevant AASHTO subcommittees, including the subcommittees on design; construction; information systems; and right-of-way, utilities, and outdoor advertising control. State transportation departments could play a critical role by identifying user and system requirements, market initiatives, and opportunities for standardization.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Coordinate with relevant AASHTO subcommittees and trade organizations early and often.
- Develop a catalog of commonly used 3D primitives, objects, and templates that could form the basis for the library of 3D components.
- Develop and test a prototype information warehouse. This also entails drawing lessons from that effort to develop recommendations for best practices that could be implemented nationwide.
- Conduct webinars and training programs.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- The catalog of commonly used 3D primitives, objects, and templates is in place.
- The prototype information warehouse is in place. Alternatively, a sample of information warehouse concepts is in place.
- Lessons learned from the prototype information warehouse effort are in place.
- Number of webinars and/or training programs.

Develop a Manual for Effective Utility Investigations

Objective: Promote the development of a utility investigation 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.

Description: This strategy involves developing a utility investigation 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 should document a comparison of the relative increases in cost and benefits associated with different types of utility investigation techniques to determine the range of application and thresholds for each technique.

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.(1) 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. The manual should also include documentation providing a comparison of the relative increases in cost and benefits associated with different types of utility investigation techniques to determine the range of application and thresholds for each technique.

Implementation leaders or champions: AASHTO could lead the implementation of this strategy in conjunction with TRB and trade organizations such as ASCE and CGA. State transportation departments could also play a significant role through relevant AASHTO subcommittees, including design; construction; and right-of-way, utilities, and outdoor advertising control.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Coordinate with TRB, AASHTO, and relevant trade organizations early and often.
- Develop a catalog of current practices for utility investigations around the country that covers all relevant phases of project delivery, including planning, preliminary engineering, design, and construction.
- Develop manual for effective utility investigations.
- Conduct webinars to highlight the elements of the manual to the transportation community.
- Prepare and conduct a 1-d training course for State transportation departments with hands-on demonstrations and exercises on the process to conduct effective utility investigations.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Communications with TRB, AASHTO, and relevant trade organizations are in place.
- The catalog of current practices for utility investigations around the country is in place.
- The manual for effective utility investigations is in place.

- Number of webinars conducted.
- The 1-d training course for State transportation departments is in place.
- Number of courses scheduled and conducted.

Improve Coordination between State Transportation Departments and the One-Call Process

Objective: Document inaccuracies associated with one-call markings and formulate strategies to improve protocols and procedures resulting in more reliable utility data.

Description: As the membership of State transportation departments in one-call notification centers increases, an opportunity exists to help introduce changes to the process in ways that could benefit the project delivery process at State transportation departments throughout the country. Over the years, 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 seems to be working well for damage prevention is proving to be inadequate to address 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.

Implementation leaders or champions: FHWA could lead the implementation of this strategy in conjunction with TRB, AASHTO, and trade organizations such as CGA. State transportation departments could also play a significant role through relevant AASHTO subcommittees, including design; construction; and right-of-way, utilities, and outdoor advertising control. Consultants can document situations where one-call marks are not within tolerance zones after further investigations.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Coordinate with relevant stakeholders early and often.
- Develop a quantitative assessment of the accuracy and completeness of one-call markings in relation to utility data collection needs during various phases of project delivery. This assessment is a baseline analysis based on which strategies for coordination and potential changes in business processes could be established.
- Based on the baseline analysis, develop recommendations for improved protocols and procedures.
- As appropriate, develop recommendations for changes to damage prevention laws and regulations, both at the Federal and State levels.

- Conduct pilot implementations of the improved protocols and procedures and document lessons learned.
- Conduct webinars to disseminate the research findings to the transportation community.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Communications with TRB, AASHTO, and relevant trade organizations are in place.
- The quantitative assessment of the accuracy and completeness of one-call markings in relation to utility data collection needs during various phases of project delivery is in place.
- The recommendations for improved protocols and procedures are in place.
- Any potential recommendations for changes to damage prevention laws and regulations, both at the Federal and State levels, are in place.
- The pilot implementations are in place.
- Number of webinars conducted.

Develop a Tool to Quantify Utility Location Risk Levels

Objective: Develop a reliable methodology and prototype tool to quantify utility location risk levels to improve current clash detection techniques.

Description: 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 needed 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. Current clash detection techniques use highly simplistic buffering models that do not properly account for factors such as uncertainty, construction sequence considerations, or in some cases, utility accommodation restrictions and rules.

Implementation leaders or champions: AASHTO could lead the implementation of this strategy in conjunction with TRB and trade organizations representing engineering consultants and contractors, such as ASCE, AGC, and ARTBA. State transportation departments could also play a significant role through relevant AASHTO subcommittees, including design; construction; and right-of-way, utilities, and outdoor advertising control.

Activities necessary for successful implementation: Activities include, but are not limited to, the following:

- Develop a research need statement and route the statement for funding consideration.
- Conduct research to develop a reliable methodology and prototype tool to quantify utility location risk levels to improve current clash detection techniques.
- Conduct a pilot implementation at selected State transportation departments to determine the applicability of the methodology and tool to a variety of project situations.
- Conduct webinars for State transportation departments, utility owners/operators, consultants, and other stakeholders to disseminate the research findings to the transportation community.

Criteria for judging the progress and success of the implementation: Measures to assess the progress of the implementation include, but are not limited to, the following:

- Research need statement is in place.
- Methodology and prototype tool to quantify utility location risk levels to improve current clash detection techniques is in place.
- Lessons learned from the pilot implementation are in place.
- Number of webinars conducted.

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