UTILITY DATA MANAGEMENT AT TRANSPORTATION AGENCIES

INTRODUCTION

A challenge at transportation agencies nationwide is how to manage information about utility facilities that occupy the right of way in ways that facilitate data extraction and data analysis and contribute to an effective management of the right of way. The challenge is both during the process to deliver transportation projects and over the lifetime of transportation corridors and the utility facilities that occupy those corridors.

Depending on the circumstances and the timing for the interaction between a transportation agency and a utility owner, data management needs and associated procedures may vary. In most cases, the interaction should involve several critical steps or phases, including utility investigation, utility conflict management (UCM), utility design, and utility construction management (Figure 1). Each of these phases involves exchanging and using spatial and non-spatial utility data.

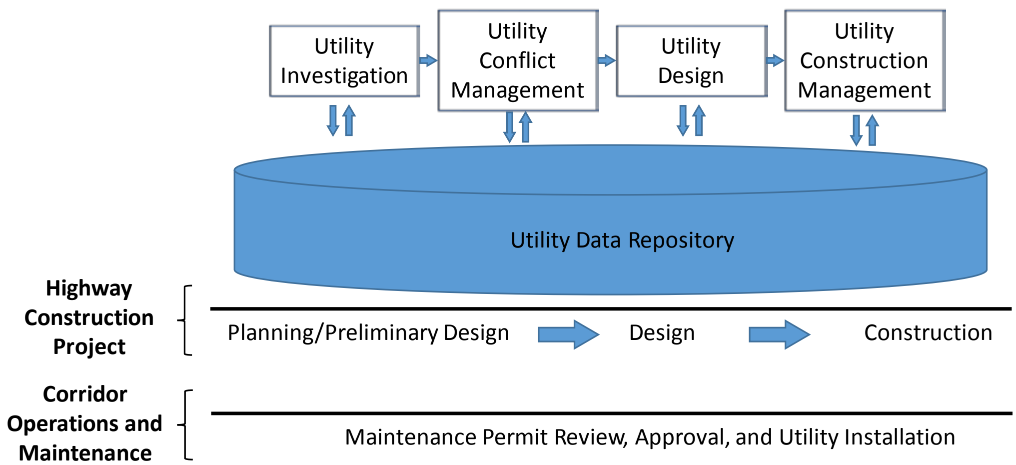


Figure 1. Lifecycle of Utility Data Management at Transportation Agencies.

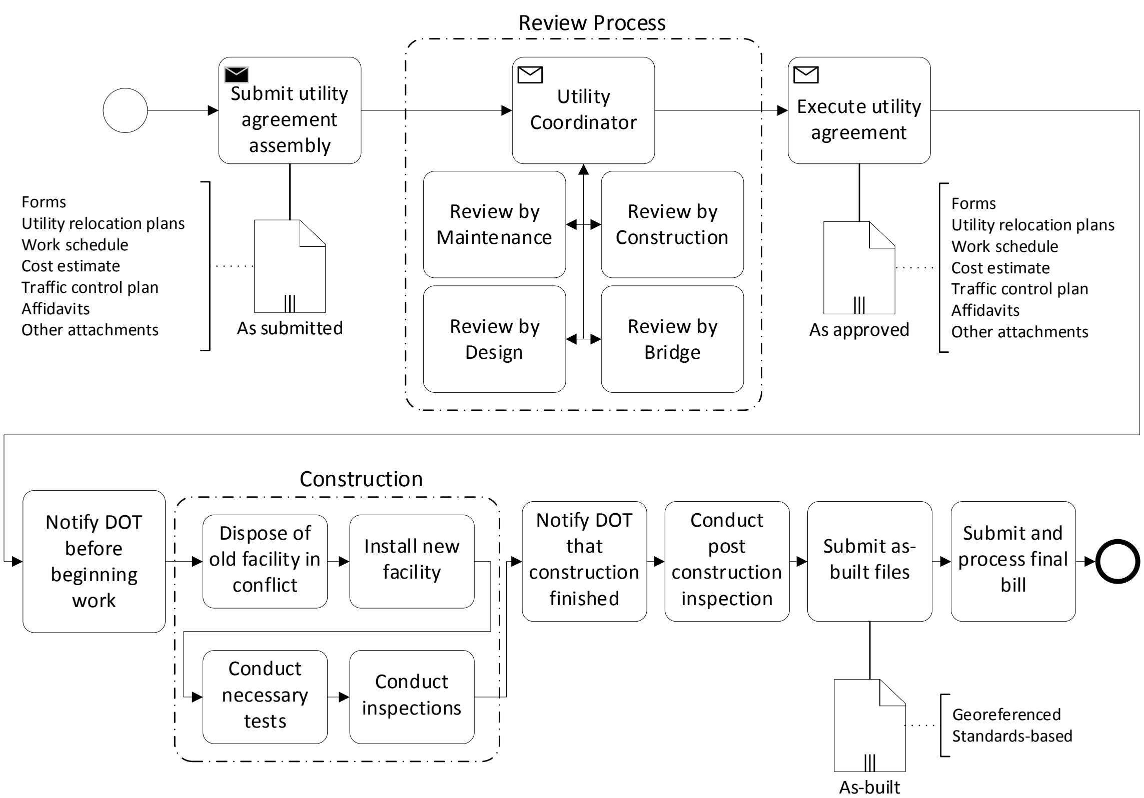
A utility data repository is the framework and information technology (IT) components for managing spatial and non-spatial utility data. In practice, transportation agencies might have very different ideas on what to include in a utility data repository (and how to manage it). The range of potential scenarios on what kind of data to include is quite wide. Examples include:

- Spatial data (and attribute data) representing historical as-built conditions. This scenario is consistent with the traditional practice of conducting a utility records research at the beginning of a project.
- Spatial data (and attribute data) representing as-built conditions resulting from new construction or repair of existing utility facilities, as well as adjustment or relocation of existing utility facilities. Ideally, accurate as-built data would result from a comprehensive field inspection and verification process.
- Spatial data (and attribute data) representing any situation where existing utility facilities are exposed, e.g., as part of new construction or maintenance activities.
- Spatial data (and attribute data) resulting from any survey or utility investigation effort.

- Engineering documents, such as computer aided design (CAD) files, technical specifications, cost estimates, and schedules.
- Contractual documents, such as utility agreements, permits, and lease agreements.
- Communications and transactions, such as emails, notification letters, responses, and utility permit reviews.
- Versioning for any of the data categories listed above.

To manage all these data categories, agencies use a variety of IT tools, including, but not limited to, entity-relational (ER) databases, spatial databases, CAD file management systems, electronic document management systems (EDMS), geographic information systems (GIS), file servers, and email servers. Data storage practices also vary widely, ranging from standalone files to enterprise systems, both in-house and in the cloud.

Utility data management involves a great deal of interaction between a transportation agency and a utility owner. Visualization of the interaction depends on what specific aspect is being described. For example, Figure 1 shows a high-level view of data flows between business process phases and the utility data repository, but without highlighting specific areas of responsibility. In contrast, Figure 2 shows a partial view of the typical process to review and execute utility agreements, as well the overall management of the utility relocation process in the field, but without looking at specific utility data flows. A complete view of the utility data management process involves generating a wide range of diagrams to illustrate data flows, business process steps, and how these elements are interconnected.



(Note: With some modifications, this diagram could also apply to utility permits that occur throughout the lifetime of a transportation corridor)

Figure 2. Utility Agreement Process, Including Inspection and Production of As-Builts.

UTILITY DATA REPOSITORY COMPONENTS

It is common for transportation agencies not to consider all the utility data categories mentioned previously as necessary components of a utility data repository. A typical reason for excluding a data category is the existence of a system that already handles that data category. For example, agencies might use a file server or an EDMS to manage documents, such as technical specifications, cost estimates, schedules, and utility agreements. Likewise, it is common to use email servers to manage communications, notifications, and responses. Increasingly, agencies are using web-based systems and protocols to handle processes such as certifications and electronic signatures.

Most transportation agencies lack the tools to know what utility facilities occupy the right of way. Not surprisingly, agencies typically consider spatial and corresponding non-spatial attribute data as the minimum required data category to include in a utility data repository. Other data categories may be important, even critical, but are usually at a lower priority level if they do not reflect actual utility locations on the ground. For example, CAD files representing partial stages in the process to identify where to relocate an existing utility facility might be critical to resolve a utility conflict, but they do not reflect the final location where the utility facility will be relocated. Under this scenario, CAD files would be handled outside the utility data repository environment.

Utility investigation deliverables would normally be considered a utility data repository component because they represent existing utility locations. However, in a typical transportation construction project, it is common to adjust or relocate existing utility facilities. Therefore, a distinction must be made at the system implementation level between utility facilities that remain in place (including facilities whose status changes from active to out of service) and utility facilities that are adjusted or relocated. In practice, this means using utility investigation deliverables as input to the utility data repository and changing the status of utility records as final decisions are made whether to keep utility facilities in place or to relocate them.

The distinction between utility facility data (including both spatial and non-spatial data) and business processes would normally result in system requirements that focus primarily on utility facility locations and attribute data, as well as integration points where business processes provide data to feed the utility data repository or use data from the utility data repository (Figure 1). An example of an input integration point is the process to collect and upload survey data to the utility data repository. An example of an output integration point is the process to make utility data accessible to a CAD file in real time.

In practice, a utility data repository includes hardware and software components. The requirements and specifications for these components depend on the level of implementation the agency has identified for the utility data repository, which, in turn, depends on factors such as business needs, available funding, and access to IT resources. The relationship between these variables is dynamic and involves tradeoffs that agencies should recognize early on. For example, a business need might dictate a requirement for a horizontal positional accuracy of 0.1 feet. However, the agency has not been able to secure funding for a surveying grade global navigation satellite system (GNSS) receiver or commitment by IT personnel to develop the necessary utility data dictionary to facilitate the implementation of a data collection system compatible with the positional accuracy requirement. Under these circumstances, the agency would need to reconsider its business requirements.

GENERAL RECOMMENDATIONS TO DEVELOP UTILITY DATA REPOSITORIES

The ability to develop a successful utility data repository depends on a number of factors. This section outlines a few common challenges and general recommendations for addressing them.

Obtain and Maintain Buy-In from the Administration

Utility data repositories are a new concept at transportation agencies. Leadership is probably unaware of the importance of managing utility data effectively. Identifying champions within the administration who understand this concept is key to secure support for developing sustainable utility data repository implementations. Because the concept of utility data repositories is new, it is not necessarily clear what offices or units should be responsible for developing and maintaining the data repositories. There is a consensus that IT personnel should be involved throughout the process, but the requirements for their involvement or the funding to sustain that effort are usually not clear. Making the administration aware of these challenges is critical so that appropriate strategies can be identified and implemented.

Identify "Low-Hanging Fruits" to Begin a Utility Data Repository

Implementing a relatively simple utility data repository at first is likely to result in fewer challenges than pursuing a comprehensive IT solution. At the same time, simple utility data repository implementations might lack certain elements such as scalability and sustainability, which are important requirements for statewide implementation efforts.

It is critical to engage IT personnel even for relatively simple data repository implementations. It is also critical to engage other groups within the agency, e.g., surveying, design, and maintenance because these groups can provide important input that can substantially improve the quality of the implementation at very low costs. For example, the surveying group can assist with the development of data dictionaries that build on already existing survey code libraries that include elements such as poles, pedestals, junction boxes, manholes, and valves. The surveying group can also provide critical information related to positional accuracy requirements, data collection equipment, and compatibility with CAD and GIS software.

Follow Standard IT Phases for Developing an Enterprise Utility Data Repository

Most state DOTs have highly structured processes to develop, deploy, and operate IT systems. IT regulations and practices vary from state to state. For example, some states encourage the use of distributed in-the-cloud storage solutions, while other states do not allow these solutions. Policies and regulations are also evolving quickly, so it is critical to involve IT personnel early in the planning phase.

Improve Related Business Processes

Business practices might need to change to support utility data repositories. Examples of areas where relevant business practices could be strengthened to support utility data repositories include:

- Utility investigation timing, scope, quality, and completeness. Utility investigation deliverables are often insufficient or inadequate to help officials determine whether a potential utility conflict is indeed a conflict. In many cases, utility investigation deliverables include utility locations, but no information about the size, capacity, or operational characteristics of the utility facilities involved.
- Mapping and documentation of utility data on project files. It is common to find design files showing utility locations where critical information from the utility investigation phase has been

removed to limit the amount of clutter. Unfortunately, the information is also lost to subsequent project file users, including contractors.

- Quality control on CAD files. Extracting utility feature data from CAD files offers significant benefits, but substantial challenges remain. The feasibility of using software to automate the extraction of features depends directly on how clean CAD files are. For example, CAD files that do not have a clear layer or level structure (i.e., one level for water line features, a separate level for water point features, and so on) dramatically increase the level of difficulty and amount of work to process the files. A similar consideration applies to CAD files that have quality problems such as duplicate objects, short objects, undershoots, overshoots, node clusters, dangles, or unnecessary vertices.
- Documentation of as-built conditions. Frequently, state DOTs assume that utility owners will conduct the inspection and verification of utility work within the right of way (because utility owners are responsible for their own installations), but utility owners assume that state DOTs will conduct the inspections (because the installations are located within the state right of way or the utility work is a relocation needed for a transportation project). Because of the lack of clarity, inspections are frequently not carried out, and if they are, they are inadequate to produce quality as-builts.

CHALLENGES FOR DEVELOPING ROBUST 3D MODELS

Utility data quality is an important requirement for most state DOT applications but is particularly critical in a 3D design and construction workflow (Figure 3). It is critical to recognize the dilemma between having incomplete utility datasets (with varying levels of horizontal and vertical positional accuracy) and the goal to reduce the level of risk when developing 3D models of utility facilities. This dilemma makes it critical to document the positional accuracy of utility datasets and make sure to include that documentation as part of the datasets, either as utility record attributes or in the metadata.

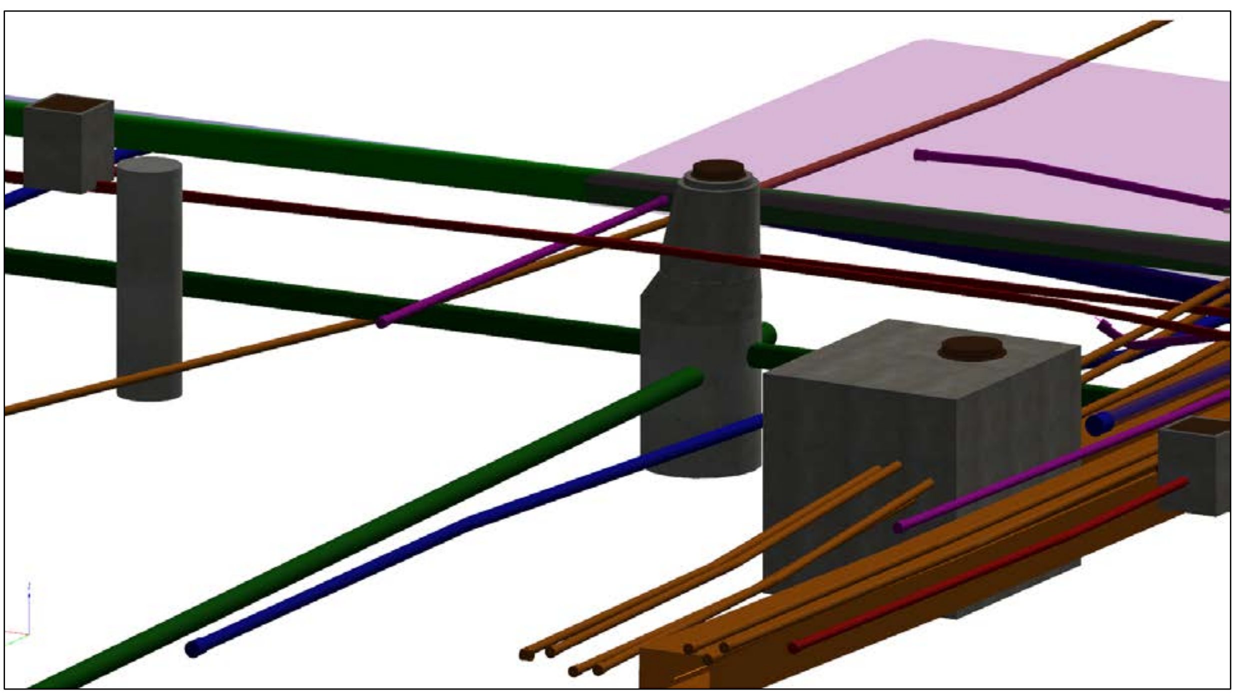


Figure 3. Sample 3D Utility Model.

The challenge of handling and managing 3D utility data is particularly acute in situations where there is no clarity about where the infrastructure is actually located. For example, Figure 4a shows four locations where data collection enabled a positive determination of the X-Y-Z coordinates of an underground pipe. Based on these four locations, Figure 4b, Figure 4c, and Figure 4d show three potential interpretations of the pipe alignment. Determining which alignment is correct is a critical requirement for building a reliable 3D model of the underground pipe.

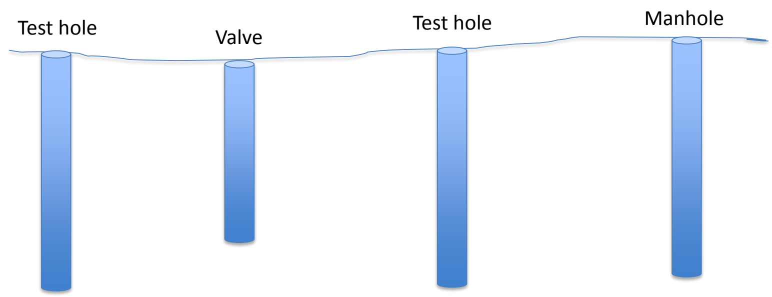
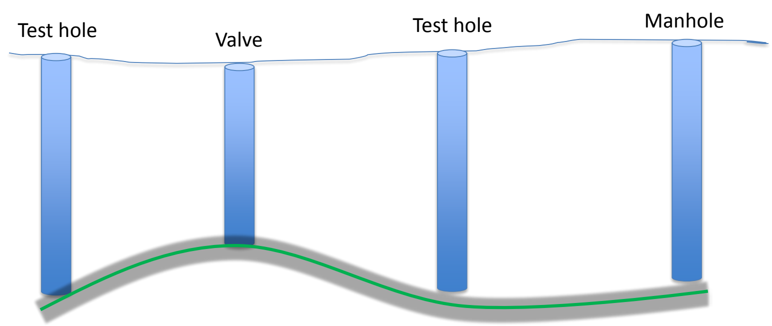
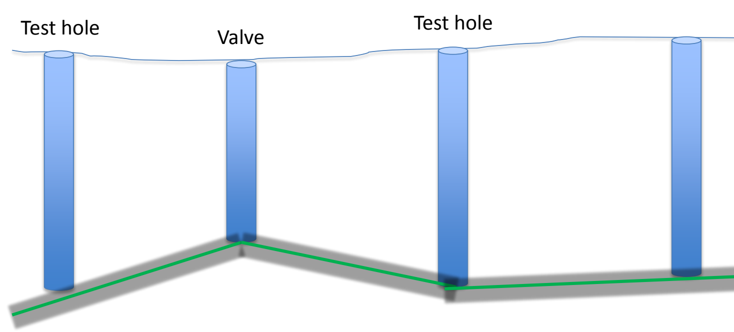
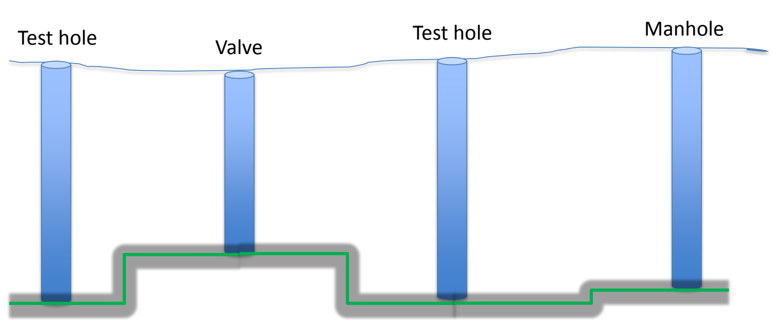
(a) Locations where X-Y-Z data were collected	
(b) Assumed curved vertical pipe alignment between points where X-Y-Z data were collected	
(c) Assumed straight vertical pipe alignment between points where X-Y-Z data were collected	
(d) Assumed horizontal alignment between mid-points	

Figure 4. Potential Pipeline Alignments Based on Four Points where X-Y-Z Data were Collected.

Migrating to a 3D platform involves the development of a library of 3D objects to represent typical utility features. Developing 3D cell libraries of utility features can take a significant amount of time and effort. It is also important to recognize that the shapes and outside dimensions of the 3D cells should meet certain minimum standards to ensure the usability of the 3D models beyond basic visualization applications, e.g., for clash detection.

UTILITY DATA MODELS AND DATABASES

Implementing a utility data repository requires developing a utility data model and implementing this model in a database structure. Selecting a utility data modeling approach depends on factors such as practices for modeling spatial data already in place at the agency, preference for a specific type or brand of software, and specific business process requirements.

Utility data models fall into one of two general categories:

- Disaggregated data models where feature differentiation is at the feature class level. These data models tend to have many tables (usually one table for each individual type of feature). A disadvantage of disaggregated data models is that the number of tables needed for a complete inventory of all the different types of utility features that occupy the right of way can be quite large.
- Compact data models where feature differentiation is by attribute. These data models tend to have a low number of tables (usually one table for point features and one table for linear features for each type of utility). Each table typically has an attribute to distinguish between different kinds of features. For example, for water utility features, there would be one table for point features and a second table for linear features. The point water table has an attribute to distinguish between different types of point features. Similarly, the line water table has an attribute to distinguish between different types of linear features. Agencies tend to prefer compact data models because of the low number of tables needed to develop utility data inventories.

UTILITY DATA STANDARDS

Industry data standards are beginning to emerge to facilitate the development of 3D data repositories and the exchange of data among stakeholders. In addition, agencies typically have developed their own IT specifications (including data), which will likely have an impact on how utility data repositories are planned and executed. A summary of a small sample of relevant standards, either existing or under development, follows.

Industry Foundation Classes Extensible Markup Language (ifcXML)

IFC is an open, standardized specification for building information modeling (BIM), which is developed and maintained by buildingSMART and is registered as International Organization for Standardization (ISO) 16739:2013. 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 design and construction. The domain layer contains entity definitions for common elements (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, including, but not limited to, services such as water, electrical, and communications.

PipelineML

In 2014, the Open Geospatial Consortium (OGC) announced the 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.

Standard Guideline for Recording and Exchanging Utility Infrastructure Data

The American Society of Civil Engineers (ASCE) is currently developing a standard guideline to establish minimum and optional elements of spatial and non-spatial attribute data associated with utility infrastructure. The standard guideline provides recommendations for effective practices to facilitate data exchange among project stakeholders. It specifies essential elements for recording and exchanging data about the location and other attributes of underground and aboveground utility infrastructure, with a focus on newly installed, repaired, or exposed infrastructure. It is anticipated that the guideline will be used to capture, document, and exchange utility data for project scoping, planning, design, construction, operation, and long-term management of utility systems.

Important features of the ASCE standard guideline include:

- Requirement to reference horizontal and vertical locations to the U.S. National Spatial Reference System (NSRS) horizontal and vertical datums. This requirement emphasizes the need to reference all location to the project datum. If it is necessary to match a localized reference system, the data should include all the necessary parameters for transforming the data from the local system to the NSRS horizontal and vertical datums.
- Requirement to report the horizontal and vertical positional accuracies of utility infrastructure at the 95% confidence level, in accordance with FGDC-STD-007.4-2002. The standard emphasizes the need to report actual positional accuracies obtained during the data collection and processing campaign (i.e., not nominal positional accuracies).
- Explicit representation of utility features according to their function. The standard guideline includes the following feature types:
    - Segment: A linear utility feature represented by a series of connected points.
    - Device: A discrete utility feature that is directly involved with the conveyance, control, or distribution of a utility service.
    - Access point: An opening that provides access to utility devices, segments, and containing structures.
    - Support structure: A structure used to support utility lines and devices.
    - Containing structure: A structure or chamber that houses or provides access to utility devices and typically provides a junction area for multiple utility lines.
    - Secured utility area: An area typically fenced off to restrict access to utility facilities.
    - Encasement: A structure that encloses and protects utility facilities and surrounding infrastructure, environment, and the public.
    - Marker: A visible or detectable (e.g., geophysically) sign or device used to reference the location of a utility feature.
    - Tracer: Typically, a wire or tape used to reference the location of a linear utility feature.

- Differentiation of attributes depending on whether they should be a minimum requirement, optional, or conditional (i.e., an optional attribute that becomes a minimum requirement if the geometry type used is a 3D object or if observed data are available).

GENERAL PROCESS TO POPULATE AND UPDATE THE UTILITY DATA REPOSITORY

Once the utility data repository structure is in place, there should be a systematic, predictable process to populate and update the utility data repository. In general, the process involves the following high-level activities:

- Conduct utility investigation. In practice, utility investigations have four phases (which might run sequentially or concurrently depending on the project type and needs):
  - Utility records research.
  - Documentation of visible utility facilities.
  - Use of geophysical techniques.
  - Exposure of utility facilities.
- Identify existing utility infrastructure that will be unaffected by the project and update utility data repository.
- Identify, analyze, and resolve utility conflicts.
- Prepare utility relocation plans and utility relocation schedules.
- Dispose of old facility in conflict and install new facility.
- Monitor utility relocations to ensure that (a) relocated utilities are built and surveyed in accordance with project survey accuracy requirements and (b) changes in the field with respect to the design plans are surveyed and depicted on as-built plans.
- Assemble composite utility plans showing all existing and relocated utility installations.
- Extract and validate utility facility data.
- Update utility data repository.

Figure 5 depicts the data flow for a generic case where the utility data repository provides input data to the utility investigation, and then the agency updates the utility data repository based on how utility conflicts are resolved and utility relocations proceed in the field (including inspections and the collection of as-built data). In practice, it may be necessary to prepare a wide range of use cases to document data flows. For example, a variation of Figure 5 is one in which the utility data repository is updated after the utility design phase to reflect design-level conditions.

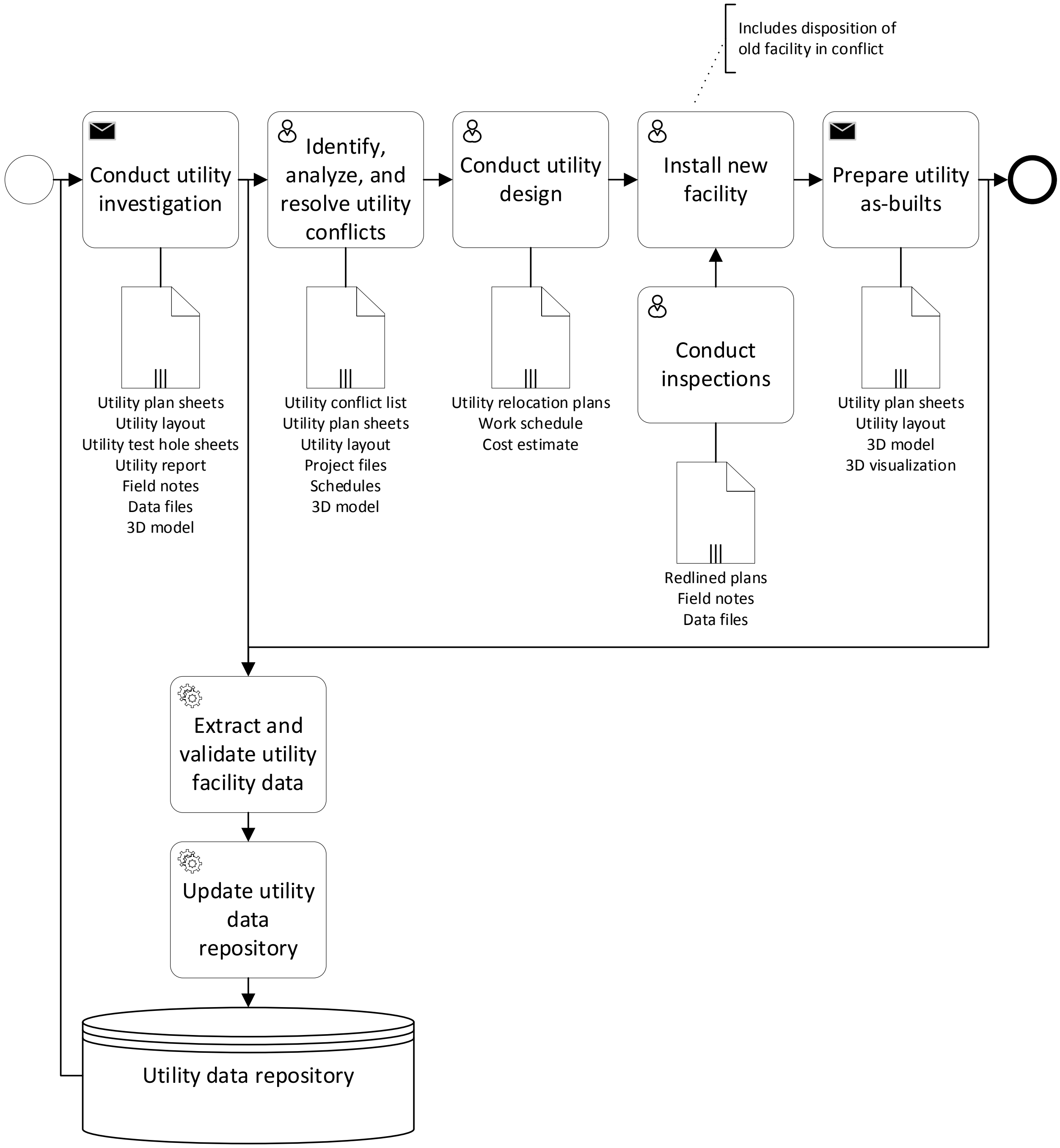


Figure 5. Generic Process to Populate and Update the Utility Data Repository.

Realistically, the process to populate the utility data repository depends on the specific activities that are involved, which, in turn, depends on the project delivery phase where those activities happen. To illustrate this point, Figure 5 provides a representation of the design-bid-build project delivery process. The diagram depicts both phases (planning, preliminary design, and so on) as well as major functional areas (environmental, real property acquisition, utilities, and so on). Depending on the type of project, some phases or activities might not apply. Utility process activities span most phases of the project delivery process (area highlighted in red).

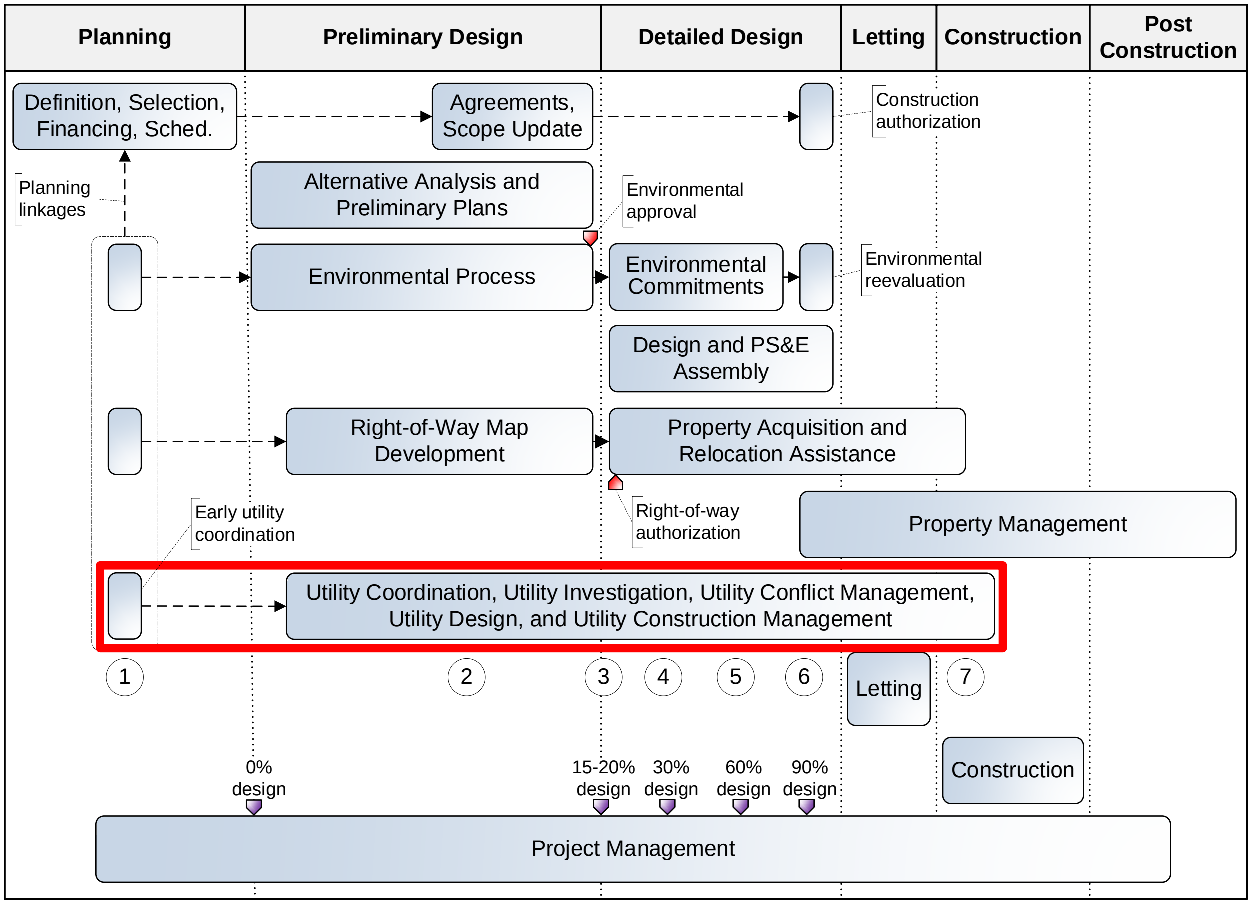


Figure 6. Utility Process within the Project Delivery Process (Traditional Design-Bid-Build Project Delivery Method).

Figure 5 also shows the approximate location of seven stages where utility data would likely have an input or output impact on project delivery. In practice, the number of stages can vary widely depending on the specific characteristics and delivery method of the project under consideration. Table 1 shows a generalized description of the seven major stages. The table also lists typical utility process activities, included related utility data activities (which are highlighted in bold).

Table 1. Utility Process Stages (Traditional Design-Bid-Build Project Delivery Method).

UCM Stage	Description	Activities
1	Stage 1 corresponds to the beginning of the process when planning-level utility coordination takes occurs.	• Conduct utility coordination meetings to inform project owners of future transportation plans. This meeting also provides utility owners with the opportunity to share information about future expansion plans with the transportation agency. • Participate in other planning-level events to exchange relevant information with stakeholders. • Identify critical utility-related issues to include in project scopes. • **Identify and use existing databases to display locations and attributes of existing utilities.**

UCM Stage	Description	Activities
2	Stage 2 corresponds to the part of the process when potential utility conflicts are identified for the first time during the preliminary engineering phase.	• **Conduct a utility records research.** • While requesting information from utility owners about existing records, ask about major physical constraints associated with existing utility facilities, with a focus on constraints that could have an impact on the project alignment or the identification of potential utility conflict resolution strategies in subsequent stages. • Conduct an initial assessment of utility conflicts and impacts. • **Identify existing utility infrastructure that will be unaffected by the project and update utility data repository.** • Schedule at least one utility coordination meeting.
3	Stage 3 corresponds to the part of the process (typically at the end of the preliminary design phase or beginning of the design phase) when the agency collects detailed survey data, including visible utility facilities.	• **Survey visible utility facilities and correlate this information with the preliminary utility investigation in Stage 2. The survey should include all aboveground utility facilities, such as poles, guy wires, pole attachments, manholes, and valves.** • Assess utility conflicts and corresponding impacts. For each potential conflict, determine whether the utility is in conflict or whether more comprehensive, accurate data are needed to decide, including locations that would warrant a more detailed utility investigation. • Request input from utility owners to confirm utility conflict locations, assess utility conflict impacts including constructability challenges, and discuss potential conflict resolution strategies. • **Identify existing utility infrastructure that will be unaffected by the project and update utility data repository.** • Schedule at least one utility coordination meeting.

UCM Stage	Description	Activities
4	Stage 4 corresponds to the part of the process, around 30-percent design, when the agency is finalizing the horizontal and vertical alignment and is undertaking other design activities including drainage design. At this point, it is common to collect detailed information about belowground utility installations and use the resulting data to identify or confirm utility conflicts, as well as analyze and review utility conflict resolution strategies.	• **Conduct a geophysical investigation to determine the horizontal locations of underground utility installations.** • Assess utility conflicts and corresponding impacts. For each potential conflict, determine whether the utility is in conflict or whether test holes are needed to determine or confirm the depth of utility facilities that may be in conflict. • Request input from utility owners to confirm utility conflict locations and assess utility conflict impacts including constructability challenges. • Analyze and review utility conflict resolution strategies. • Schedule at least one utility coordination meeting to discuss utility conflict resolution strategies. • Prepare utility relocation plans and utility relocation schedule for inclusion in utility agreements. • **Monitor utility relocations to ensure that (a) relocated utilities are built and surveyed in accordance with project survey accuracy requirements and (b) changes in the field with respect to the design plans are surveyed and depicted on as-built plans.** • Assemble composite utility plans showing all existing and relocated utility installations, and proposed utility conflict resolution strategies. • **Update utility data repository.**
5	Stage 5 corresponds to the part of the process, around 60-percent design (or earlier if possible), when critical elements of the project design are in place, including the horizontal and vertical alignments and the drainage design. At this point, it is common to expose belowground utility installations at specific locations to gather accurate depth data and other critical facility information.	• **Expose utility facilities at specific locations to gather accurate depth data and other critical facility information.** • Assess utility conflicts and corresponding impacts. For each conflict location, determine whether the utility is in conflict or not. • Request input from utility owners to confirm utility conflict locations and assess utility conflict impacts including constructability challenges. • Analyze and review utility conflict resolution strategies. • Schedule at least one utility coordination meeting to discuss utility conflict resolution strategies. • Prepare utility relocation plans and utility relocation schedule for inclusion in utility agreements. • **Monitor utility relocations to ensure that (a) relocated utilities are built and surveyed in accordance with project survey accuracy requirements and (b) changes in the field with respect to the design plans are surveyed and depicted on as-built plans.** • Assemble composite utility plans showing all existing and relocated utility installations, and proposed utility conflict resolution strategies. • **Update utility data repository.**

UCM Stage	Description	Activities
6	Stage 6 corresponds to the part of the process, around 90-percent design, when the agency begins to assemble final plan, specifications, and estimate (PS&E) documents.	• Assess any remaining utility conflicts and corresponding impacts. • Request input from utility owners to confirm utility conflict locations, assess utility conflict impacts including constructability challenges, and discuss potential conflict resolution strategies. • Analyze and review utility conflict resolution strategies. • Schedule at least one utility coordination meeting to discuss utility conflict resolution strategies. • Prepare utility relocation plans and utility relocation schedule for inclusion in utility agreements. • **Monitor utility relocations to ensure that (a) relocated utilities are built and surveyed in accordance with project survey accuracy requirements and (b) changes in the field with respect to the design plans are surveyed and depicted on as-built plans.** • Assemble composite utility plans showing all existing and relocated utility installations, and proposed utility conflict resolution strategies. • **Update utility data repository.** • Include utility plans in the PS&E documents. • Prepare utility statement for inclusion in the bid package, showing the status of utility work completed prior to construction, utilities that are not in conflict with the project, and utility work that must be completed during construction.
7	Stage 7 corresponds to the part of the process at the beginning of the construction phase. At this point, some utility relocations might still need to be completed. Depending on the situation, utility relocations might also be included in the highway contract. This phase also involves managing new utility conflicts that are identified.	• **Monitor utility relocations to ensure that (a) relocated utilities are built and surveyed in accordance with project survey accuracy requirements and (b) changes in the field with respect to the design plans are surveyed and depicted on as-built plans.** • Assemble composite utility plans showing all existing and relocated utility installations, and proposed utility conflict resolution strategies. • **Update utility data repository.** • Assess new utility conflicts and corresponding impacts that are uncovered during construction. • Analyze and review utility conflict resolution strategies. • Prepare utility relocation plans and utility relocation schedule for inclusion in utility agreements.