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Best Practices on Collecting Asset Information from the Construction Stage

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16. Abstract

Accurate and comprehensive as-built information is crucial for the effective maintenance and rehabilitation of transportation infrastructure systems. This information encompasses details such as installation dates, locations, materials, dimensions, and asset conditions. However, a significant gap exists between project delivery and asset operation and maintenance at the South Carolina Department of Transportation (SCDOT), resulting in data loss and limited access to current information. This gap leads to costly and time-consuming efforts to re-collect data, especially during asset operation. This study aims to identify best practices from other states and develop a systematic guide, along with automated tools, to integrate data generated in construction projects into existing asset repositories at SCDOT. The research addresses specific questions about required asset data, recording practices in construction documents, mapping construction data to asset inventories, and innovative approaches for automated data reuse. This approach allows the agency to eliminate the duplication of data collection while improving the precision and completeness of asset data by correctly extracting asset information from construction records made by construction inspectors and contractors

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Furthermore, we extend our sincere gratitude to Terry Swygert and Jade Watford, personnel of the SCDOT's research program. Their steadfast support was instrumental in ensuring the successful completion of this project.

Executive Summary

Accurate and complete as-built information, including installation date, location, material, dimension, and asset condition, is crucial for the effective maintenance and rehabilitation of transportation infrastructure systems. However, a significant gap exists between project delivery and asset operation and maintenance at SCDOT, resulting in data loss and limited access to the most current information. This leads to costly and time-consuming efforts to re-collect data, especially during asset operation. This study aims to identify best practices from other states and develop a systematic guide, along with automated tools, to integrate data generated during the construction phase into existing asset repositories at the South Carolina Department of Transportation (SCDOT). The research addressed specific questions about required asset data, recording practices in construction documents, mapping construction data to asset inventories, and innovative tools for automated data reuse.

A critical literature review was undertaken to synthesize the current state-of-the-art in asset data collection during the construction stage. This helped extend our current understanding of the existing technologies and their implementation challenges. The findings of this objective informed the team in developing a new framework suitable for SCDOT. A web-based nationwide survey was conducted aiming to identify the current practices of leveraging construction data for asset data inventory across State DOTs in the United States. The focus was on approaches, specific tools, and uses to determine their best practices regarding the use of advanced technologies for obtaining asset information from as-built construction records captured during construction.

Several interviews with various SCDOT offices were also conducted, focusing on the current practices at SCDOT regarding asset data attribute needs and their importance to SCDOT, as well as the details of as-built data collected during the construction phase. Furthermore, the research team undertook an extensive review of the agency’s manuals, sample tabulations, construction inspection forms, specifications, and software applications to cross-validate the input provided by the experts regarding data attributes. This was done to determine the current construction and asset data format and establish a connection between asset data needs and the data available in construction management systems by identifying common data interests between the two phases. Using the results of these tasks, a matrix mapping data between construction and asset data was developed.

Informed by the information obtained from the previous tasks, the research team crafted a data mapping matrix linking data attributes sourced from various origins. Subsequently, data translator models were created to extract asset data from construction documents. Our vision was that these translators would facilitate the sharing and reutilization of data gathered during construction in subsequent phases. The innovative technology was engineered to minimize workflow disruptions and maintain the roles of construction inspectors while optimizing the reuse of data found in construction verification documents, rather than transferring the burden of asset data collection to construction engineers.

The main outcomes of the research include a comprehensive research report outlining a systematic strategy for the SCDOT to enhance its existing asset data inventory practices in order to effectively manage transportation system assets. Additionally, a supplementary Excel spreadsheet has been developed to aid the agency in identifying the necessary data attributes for various types of assets, along with their sources and methods for leveraging data to facilitate a smooth transition to the new EAMS system.

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List of Acronyms and Abbreviations

BIM	Building Information Modeling
CAAD	Computer-aided Architectural Design
DOT	Department of Transportation
DWR	Daily Work Report
FHWA	Federal Highway Administration
GPS	Global Positioning System
GIS	Geographic Information Systems
HPMS	Highway Performance Monitoring System
INDOT	Indiana Department of Transportation
MnDOT	Minnesota Department of Transportation
O&M	Operation and Maintenance
SCDOT	South Carolina Department of Transportation
TAM	Transportation Asset Management
UDOT	Utah Department of Transportation
UVM	University of Vermont
USDOT	United States Department of Transportation
VTrans	Vermont Agency of Transportation
WMS	Work Management System

Chapter 1: Introduction

Accurate and comprehensive information regarding assets' as-built details, including installation dates, locations, materials, dimensions, and conditions, are vital for the effective implementation of maintenance and rehabilitation strategies for transportation infrastructure systems. Such data constitute a fundamental element of the MAP-21 Act, which seeks to revolutionize transportation asset management by transitioning it into a data-centric and performance-oriented program (Gordon et al., 2011). Due to periodic construction projects that alter assets, regular updates to asset data repositories are essential. New construction endeavors require the creation of entirely new data entries, whereas reconstruction, rehabilitation, or major maintenance activities necessitate revisions to specific sections of the asset database. Considering that approximately 50% of the total annual budget allocated by the SCDOT is spent on maintenance and preservation for the transportation system, the importance of updating transportation asset data upon the completion of construction projects cannot be overstated.

Construction records such as construction inspection results (i.e., material testing and DWRs) or as-built plans are a great source of in-place asset data, for example, assets' location, materials, dimensions, and key dates (project start date, final inspection date, and date facility opens to traffic). However, there is currently a disconnection between project delivery and asset operation and maintenance (O&M) at SCDOT. Very little, if any, of the as-built data collected by construction inspectors are passed and reused in the operation and management of the asset. This disconnection can lead to significant data loss and poor access to up-to-date data. At SCDOT, maintenance staff spends significant time and resources re-collecting those as-built data which may have been already captured in DWRs. The cost of this duplicated data collection issue can be substantial. According to a study conducted by the National Institute of Standard and Technology (NIST), the inability to reuse as-built construction data was estimated to cost the US capital facilities industry around $10 billion per year for recollecting data during the O&M stages (Gallaher et al. 2004). Moreover, the post-construction stage is not the best time for as-built data collection, especially for some underground assets such as culvers which become invisible and difficult to access when roads are open to traffic (Cai et al. 2015). As a result, asset inventory during the operation of assets is often expensive, time-consuming, and involves many safety concerns. In addition, some asset data can be inaccurate if they are not being correctly referenced to the final construction documents. Form our previous projects with SCDOT, we noticed that there are tremendous limitations with the SCDOT's as-built asset information, specifically the construction date data on pavement assets, as the letting dates are tracked and used rather than the actual dates of work completion. Such problem can be avoided if as-built construction data is timely and properly handed in the right format over to O&M. Given the current circumstance that SCDOT undertakes a large number of construction projects each year, reducing expensive asset inventory needs by re-using construction data can, in turn, translates into substantial savings while keeping the database current and accurate. Therefore, the team proposes to investigate innovative approaches that recycle the data already captured during the project delivery by contractors and construction engineers to make automated revisions on associated asset databases.

The overarching goal of this project is to provide SCDOT with systematic guidance on state-of-practice technologies and procedures for reusing asset data that could have been already captured during the construction phase. This allows the agency to eliminate the duplication of data collection while improving the preciseness and completeness of asset data by correctly extracting asset information from construction records made by construction inspectors and contractors. We understand that implementing any new technology requires changes in workflows and the agency may encounter many potential organizational and financial challenges. The understanding of effective strategies to tackle these challenges may not be practically achievable without a real adoption of the technology on various types of assets, which may take years to complete. For this reason, we suggest that the scope of the current project should be focused primarily on addressing technical challenges regarding the utilization of construction records for as-built asset information acquisition, specifically identifying data needs and examining technologies for converting those construction management data to a format suitable to asset management. We suggest potential future projects to examine effective strategies to address any associated organizational challenges regarding the adoption of the new data collection approach. Future projects should also leverage the results of the current project to develop a comprehensive framework that can enable a complete cycle of data from creation to final decision-making in asset management system.

The research team performed the following four objectives to identify best practices and test the feasibility of the new approach in collecting asset data.

- Objective 1: Synthesized the current state-of-the-art and state-of-practice in asset data collection during the construction stage. This helped extend our current understanding of the existing technologies and their implementation challenges. The findings of this objective informed the team in developing a new framework suitable for SCDOT. We accomplished this objective through a critical literature review followed by a nationwide survey of other state DOTs to determine their best practices regarding the use of advanced technologies for obtaining asset information from as-built construction records captured during construction.
- Objective 2: Identified critical asset data needs for highly prioritized types of assets that can be captured from construction records at SCDOT. This objective aims to better understand the current state-of-practice at SCDOT to identify asset data needed for highly prioritized types of assets and how as-built construction data are captured and structured. We established a connection between asset data needs and those data available in construction management systems by determining common data interests between the two phases.
- Objective 3: Developed, demonstrated, and validated a new technology that allowed SCDOT personnel to quickly obtain asset data from construction records. Informed by the knowledge obtained from Objective 1, we selected and assessed the top promising practices in terms of effectiveness and suitability to SCDOT. We envisioned that the new data extraction technology would enable the data collected during construction to be sharable and reusable in the downstream phase. The new data collection technology has been designed so that it could minimize the disruption it might have on the workflow and responsibilities of construction inspectors and maximize the effectiveness in reusing the data available in construction verification documents rather than transferring the asset data collection burden to construction engineers.
- Objective 4: Provided a systematic report that provides specific guidance for SCDOT personnel to successfully implement the new asset data collection method.

To address the research objectives above, the research team accomplished the following seven tasks:

- Task 1: Systematic Literature Review. This task involved the synthesis of existing knowledge related to the proposed research objectives.
- Task 2: Survey Other State DOTs for Best Practices. This task was to identify the current practices of asset data collection during construction across the State DOTs in the United States with a focus on approaches, specific tools, and uses. We also interviewed personnel at other state DOTs to identify the-state-of-practice on how construction records are reused for updating transportation asset inventories.
- Task 3: Conduct Interviews to Understand the Essential Asset Data Needs. In this task, we undertook meetings with various SCDOT offices. We centered the questionnaire on asset data attribute needs and their importance to SCDOT. In-depth interviews further identified the details of as-built data collected and verified during the construction phase.
- Task 4: Review of Technical Documents and Software Applications. This task included an extensive review of agency's manuals, sample tabulations, construction inspection forms, specifications, and software applications to cross-validate the input provided by the experts regarding data attributes. The objective of this task was to avoid bias in interview methods and determine the current construction and asset data format.
- Task 5: Identify Data Attributes and Develop Matrices Mapping Data Interest Between Phases. This task focused on prioritizing transportation assets, identifying their critical attributes and formats, and mapping them into as-built data records captured during the construction phase. This new understanding helped us develop a data handover matrix suitable to SCDOT defining the mapping between construction and asset data.
- Task 6: Develop a Data Translator to Extract Asset Data from Construction Pay Items. In this task, we developed a data translator to support extracting asset data items from those pay items recorded in construction documents and converting them into the right format compatible with asset data repositories.
- Task 7: Reporting, Training, And Technology Transfer. In this task, the research team synthesized the research into a final report, which included comprehensive recommendations for effective utility relocation.

Upon completion of the research, the deliverables included:

- An Excel spreadsheet including a hierarchical list of important asset data attributes, data sources, and their equivalent attributes in construction documents.
- A reliable FME model for extracting asset data from construction records.
- A comprehensive report of the project findings. The report included recommendations on best practices and a user manual with visual examples to demonstrate how to properly use the new technology for obtaining real-time asset data from construction inspection activities.

Chapter 2: Literature Review

2.1. Method

As part of this task, we utilized our existing database of relevant literature primarily obtained from our previous projects. Additionally, we conducted an extensive review of international, national, state, and local agency technical reports, manuals, and specifications to determine the state-of-the-art methods. Our knowledge sources for the literature search included Web of Science, TRIS, and Google Scholar. We paid particular attention to relevant NCHRP reports, as well as international and national data standards. Examples of keywords used for publication searches included 'transportation assets data,' 'data sharing,' and 'data handover from construction to operation.' Furthermore, we reviewed proceedings from relevant conferences, which were also included in our knowledge database. The review focused on how asset data can be collected, updated, and integrated from construction to operation and maintenance phases.

2.2. Key Findings

2.2.1. Regular Statewide Field Asset Inventory Data Collection

With an increasing demand for quality asset inventories, DOTs have explored opportunities to implement innovative and effective technologies for statewide field asset inventory data collection. Many technologies are available for collecting asset data, from paper-based to geospatially enabled electronic forms and cutting-edge technologies. In 2018, USDOT released a Strategic Plan of Transportation (USDOT, 2018). The plan includes the Federal Highway Administration efforts with the four strategic goals of safety, infrastructure, innovation, and accountability. At the same time, FHWA has promoted the use of GIS among State DOTs to efficiently administer the transportation system and achieve strategic goals. With a wide range of applications, GIS can assist all four strategic goals. Besides, asset management collection tools for field data specifically target three goals: infrastructure, innovation, and accountability (Lee & Gilman, 2020).

a. Mobile Device

In supporting State DOTs in utilizing GIS, FHWA released report focusing on using mobile applications to collect and manage geospatial asset data (Lee & Gilman, 2020). At INDOT, the Office of Technical Services built a data model for monitoring drainage assets of the right of way and distributed it to the personnel using Collector for ArcGIS on mobile devices (e.g., smartphones, tablets). After several successful utilizations, INDOT decided to use Esri's Collector and Survey123 mobile applications to gather inventory and condition data and report issues to its work management system. Esri's Collector is a mobile data collection application that simply captures accurate data and delivers it to the office. Collector's intuitive interface allows field personnel of every experience level with GIS to record accurate field data integrated effortlessly into ArcGIS. Survey123 is a form-centric solution for creating, sharing, and analyzing field surveys. This application can collect data via web or mobile devices, even when disconnected from the Internet. INDOT indicated that the most challenging aspects of adopting the tools were managing the content, building data models, and establishing and assessing process performance. Although the agency encountered some implementation issues, the new tools have proved successful, with largely positive feedback from users. Figure 1 shows the INDOT's Drainage Assets Viewer application, containing a mix of assets that move water through INDOT's right of way or structures that span them. In this figure, a culvert is selected.

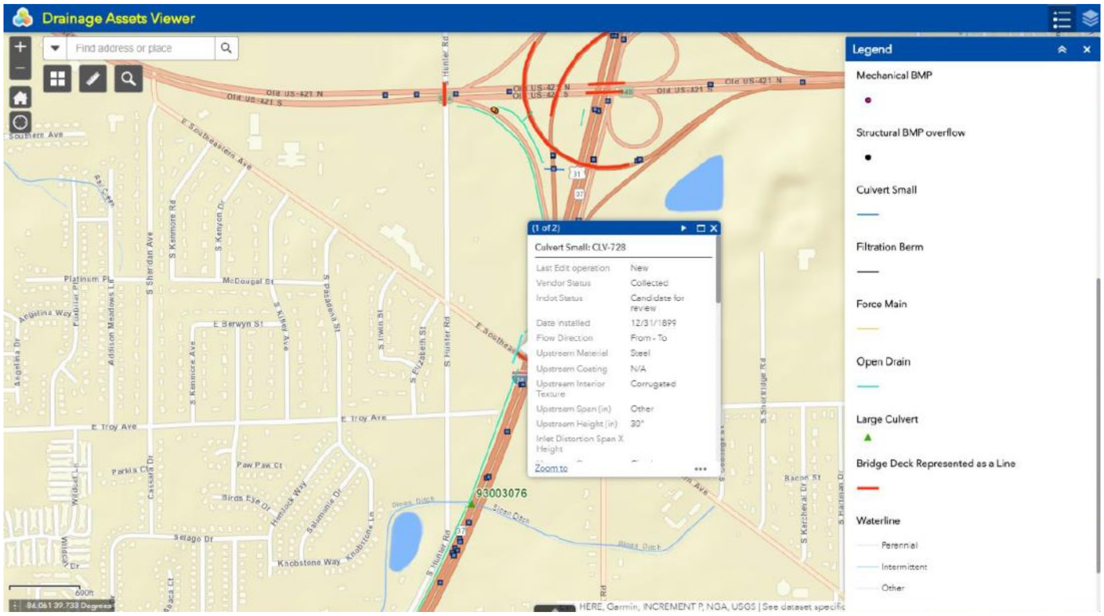


Figure 1. Project delivery process chart showing earliest efforts on utility conflict management (UCM) at INDOT (Source: Lee & Gilman, 2020)

Several other states, such as New Hampshire and Virginia, have been using mobile devices to collect asset data (CTC & Associates, 2020). These devices are cellphones or tablets, which are equipped with collector apps such as ArcGIS Collector and the Infotech Mobile Inspector. Some states developed their app for asset data collection. While many DOTs have used tablets for field data collection and review, it is much easier to use smartphones for these purposes due to their availability (National Academies of Sciences Engineering and Medicine, 2021). The Utah Department of Transportation (UDOT) is currently utilizing mobile applications for asset data collection. The new approach allows UDOT to reduce asset maintenance cost by relying less on the regular statewide collection (National Academies of Sciences Engineering and Medicine, 2021).

b. LiDAR technology

The airborne LIDAR system is a widely utilized tool for asset data collection. Typically, it consists of a LiDAR scanner, an inertial measurement unit (IMU), and a flight navigation unit (as depicted in Figure 2). Another commonly employed data collection tool in numerous highway agencies, such as Kansas, Minnesota, and Mississippi DOTs, is terrestrial LiDAR (also known as ground-based LiDAR). This method is suitable for relatively small areas where precision is paramount or where field crew safety is a priority.

The data gathered by a LiDAR system is in the form of point clouds, wherein an object's identification relies on its corresponding points. Extracting asset data, such as geographical information and structural features, from point cloud data captured by LiDAR can be done manually. However, manually identifying all road elements would consume considerable time and effort and may result in data discrepancies or inaccuracies due to human errors. To mitigate this issue, researchers have devised ArcGIS-based algorithms for extracting specific types of road features from LiDAR data, as illustrated in Figure 3. These automated feature extraction results underscore the efficacy of advanced algorithms for highway inventory data collection. Some DOTs integrate LiDAR data and BIM models to facilitate as-built data acquisition, as exemplified by Utah's Mobile LiDAR and BIM/CADD Integration in Figure 4.

(a) (b)

Figure 2. (a) Cessna TP206 research aircraft; (b) Onboard integrated remote sensing system (Source: He et al., 2017)

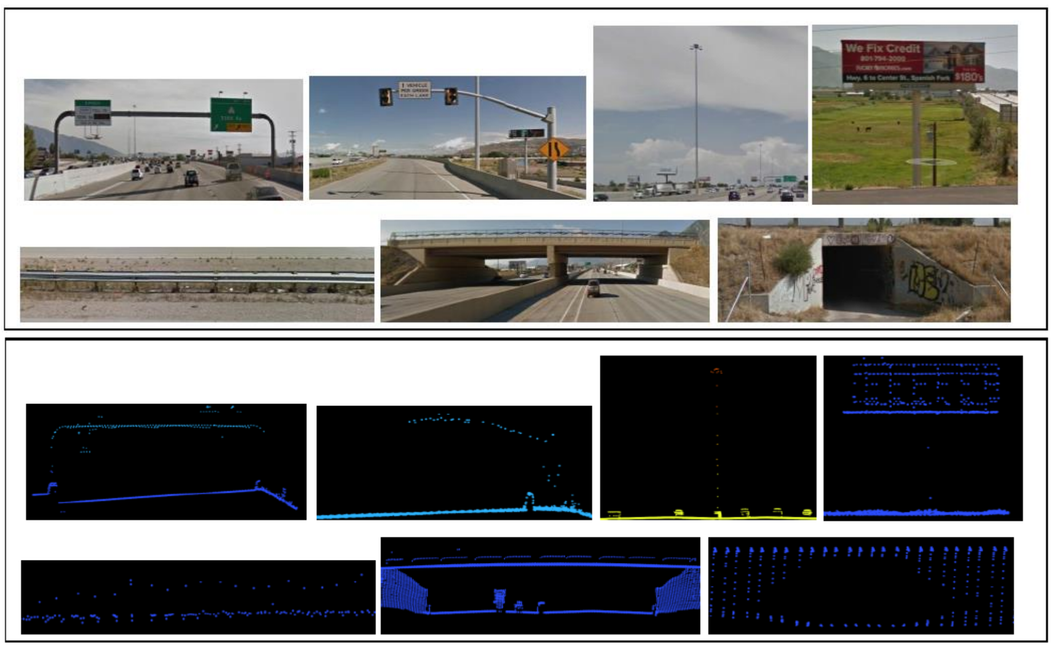
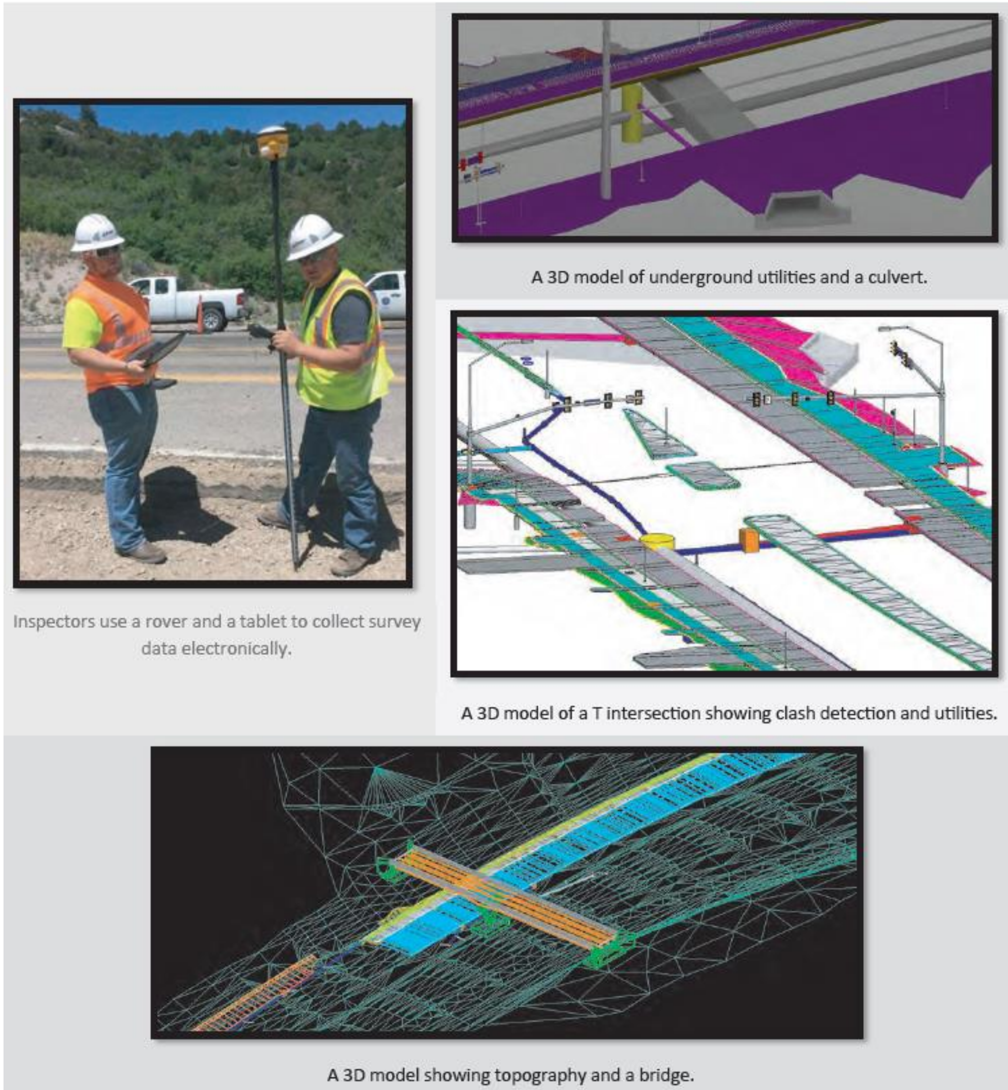


Figure 3. 3D view of large traffic sign, traffic signal, light pole, billboard, barrier, bridge, and culvert in airborne LiDAR (Source: He et al., 2017)



Inspectors use a rover and a tablet to collect survey data electronically.

A 3D model of underground utilities and a culvert.

A 3D model of a T intersection showing clash detection and utilities.

A 3D model showing topography and a bridge.

Figure 4. Mobile LiDAR and BIM/CADD Integration at UDOT (Source: National Academies of Sciences Engineering and Medicine, 2021)

c. Data Collection Van

Data Collection Vans are also widely employed tools by State DOTs for asset inventory data. Current practices primarily focus on gathering the identity and location of the Manual of Uniform Traffic Control Devices (MUTCD). The data collected through this technology consist of images and their corresponding geographical coordinates. To extract assets, some states utilize advanced image processing algorithms. For instance, the Vermont Agency of Transportation collaborated with UVM's Vermont Artificial Intelligence Lab to develop a sophisticated method for automatically identifying, categorizing, and geolocating traffic signs from right-of-way imagery obtained annually across the state's roadway network using a data collection van (Lee & Gilman, 2020). Figure 5 illustrates the automated sign detection process.

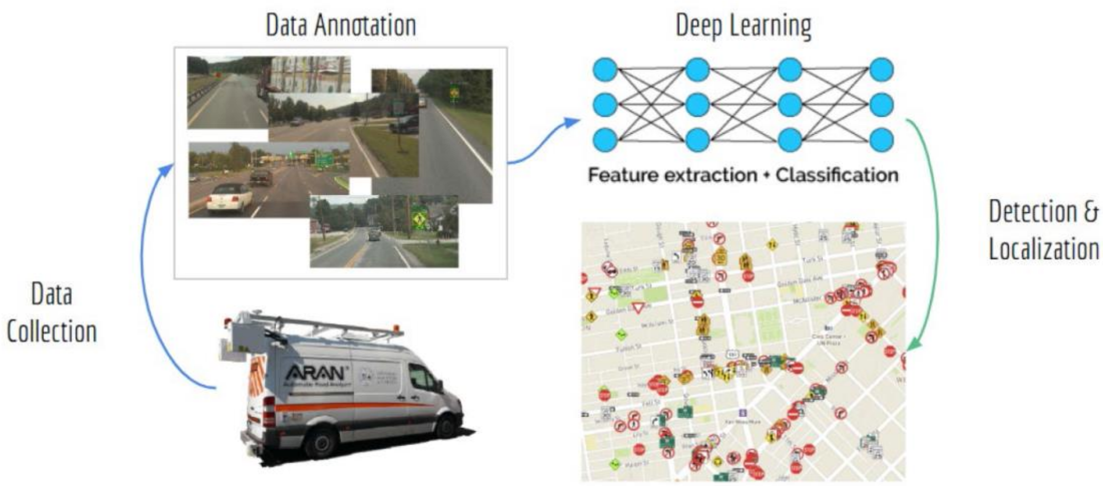


Figure 5. VTrans's automated sign detection process, from data collection to sign detection (Source: Lee & Gilman, 2020)

Data collection vans equipped with multisensory mobile mapping systems are commonly utilized to meet the demand for comprehensive and current inventory and geometric data along transportation routes, including roads, railways, rivers, and pipelines. Early pilot demonstrations of such technology trace back to the inception of a mobile highway inventory system (MHIS) proposed by certain Canadian provincial governments and U.S. state governments in the early 1980s (Chiang et al., 2021) (refer to Figure 6). During that period, the system relied on GPS and odometers to furnish navigation parameters, while the primary image sensing involved two cameras capable of continuously capturing stereo pairs. Nowadays, geometric data can be acquired using a variety of sensors such as INS/GPS, CCD cameras, extensometers, and tiltmeters. Multi-sensor systems typically necessitate highly efficient software tools for data adjustment and storage.

Figure 6. The first land-based mobile mapping technology (Source: Chiang et al., 2021)

d. Other State-of-the-art Technologies

State DOTs have also implemented many other state-of-the-art technologies for collecting asset data (depicted in Table 1) (CTC & Associates, 2020).

Table 1. State-of-the-art technologies used to collect asset data

No	State	GPS Devices	LiDAR (Airborne)	LiDAR (Terrestrial)	Mobile Device App	Multisensory Mobile Mapping Platforms	Photogrammetric Processes	Surface Geophysics	UAS
1	Alabama	✓		✓	✓				✓
2	Hawaii	✓		✓		✓			
3	Iowa	✓		✓	✓		✓		✓
4	Indiana								
5	Kansas	✓		✓					
6	Minnesota	✓		✓	✓				
7	Mississippi	✓	✓	✓	✓		✓		
8	New Hampshire	✓			✓			✓	✓
9	New York					✓	✓		
10	North Carolina	✓	✓	✓		✓			✓
11	Utah	✓	✓	✓	✓	✓			✓
12	Virginia	✓			✓				
13	Vermont					✓			
14	Wisconsin				✓				
Total		10	3	8	8	5	3	1	5

2.2.2. Highly Prioritized Assets

Highway agencies are responsible for managing numerous assets, which necessitates asset prioritization. Criteria utilized for prioritizing assets include the criticality of data items (such as the risk associated with lacking certain items), the disparity in cost and quality between collecting them during construction and post-construction, and the significance of project cost, duration, and quality impacts (Cai et al., 2015). According to a report by CTC & Associates (2020), there are seven prevalent categories of assets that DOTs are particularly interested in collecting inventory data for (outlined in Table 2). Bridges and pavement rank among the two crucial assets collected by all DOTs. Additionally, other assets commonly monitored include guardrails, drainage features, and signs.

Table 2. Highly prioritized assets requiring intensive data

No	State	Guardrails	Bridges	Underdrains	Pavements	Signs	Culverts	Pavement Markings
1	Alabama	✓	✓		✓	✓		
2	Hawaii	✓	✓	✓	✓	✓		✓
3	Iowa	✓	✓	✓	✓	✓	✓	
4	Indiana	✓	✓	✓	✓		✓	
5	Kansas		✓	✓	✓	✓		
6	Minnesota	✓	✓	✓	✓	✓		✓
7	Mississippi		✓		✓			
8	New Hampshire	✓	✓	✓	✓	✓		
9	New York	✓	✓	✓	✓	✓		✓
10	North Carolina		✓		✓			
11	Utah	✓	✓	✓	✓	✓		✓
12	Virginia	✓	✓	✓	✓			
Total		9	12	9	12	8	2	4

2.2.3. Data Needs

A thorough examination of previous studies was undertaken concerning the data requirements for asset management within State DOTs. Data needs encompass crucial attributes utilized for monitoring, integrating, and reporting asset inventory information. For instance, in the research conducted for INDOT, the investigative team held numerous working sessions and meetings with various departments within the agency to ascertain asset inventory data requirements for seven types of assets, comprising road pavement sections, underdrains, guardrails and attenuators, utilities crossing and relocations, culverts, ditches and outfalls, and signs (Cai et al., 2015). Figures 7-11 illustrate the data needs for some highly prioritized assets. The asset breakdown structure was segmented into three levels: asset level, asset subtype level, and component level. The data needs were categorized into six groups: location, geometry, physical attributes, condition/performance, administrative, and construction and maintenance.

Similarly, the research work conducted for Iowa DOT identified numerous asset data attributes (Jeong, 2018). Group discussions and interviews with highway experts were conducted to capture their insights into asset data workflows. Tables 3 and 4 outline typical asset data attributes. Actors contributing to the life cycle of data are classified as (1) creator, (2) updater, (3) verifier, and (4) consumer. The designer predominantly creates asset information in construction projects, while the contractor and asset manager serve as vital data consumers. From a maintenance perspective, asset location, geometry, material, and condition are of interest. These types of data are initially generated by various actors, including designers and contractors (Le et al., 2018).

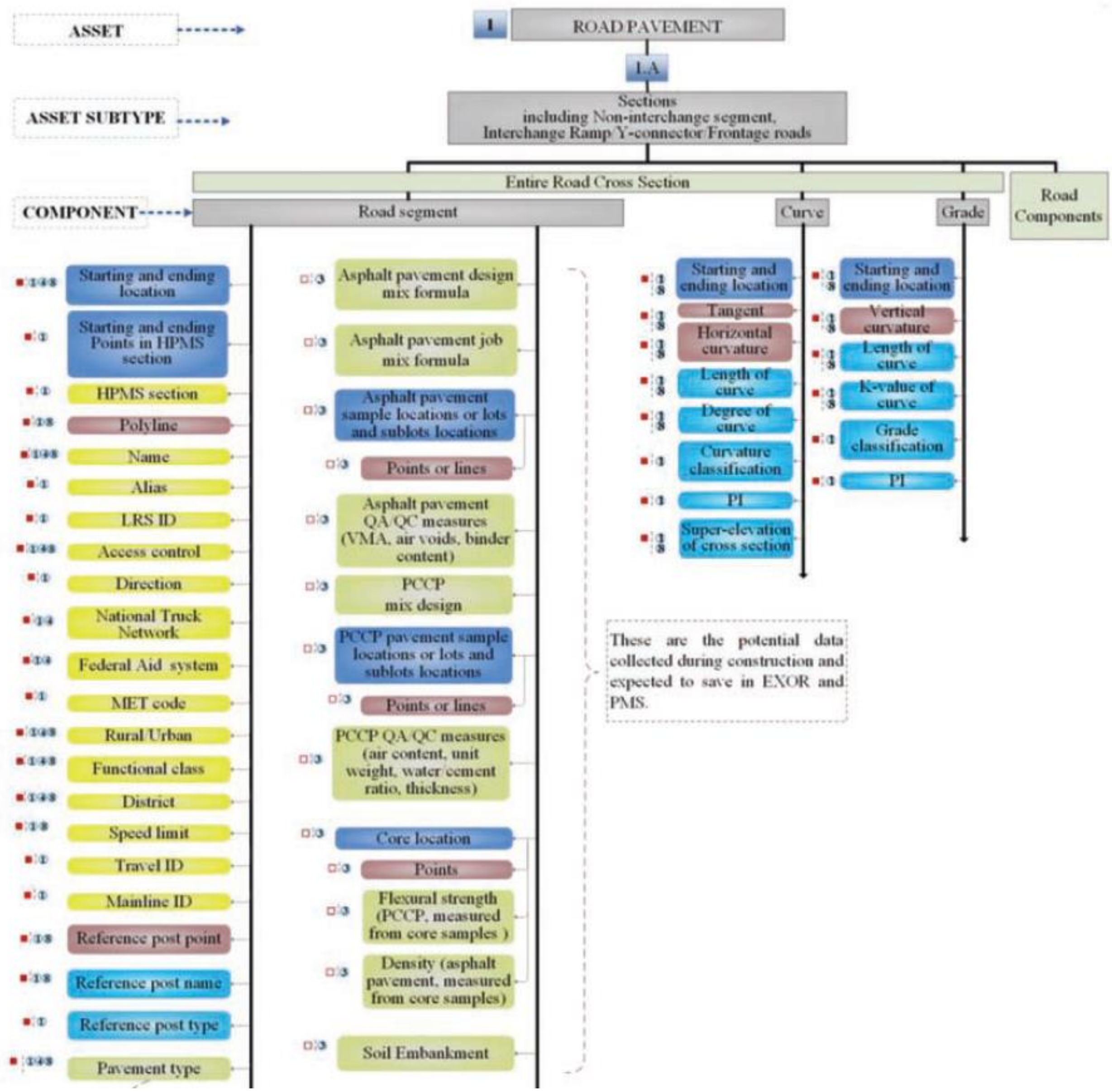


Figure 7. Data needs of the entire road cross section at INDOT (Source: Cai et al., 2015)

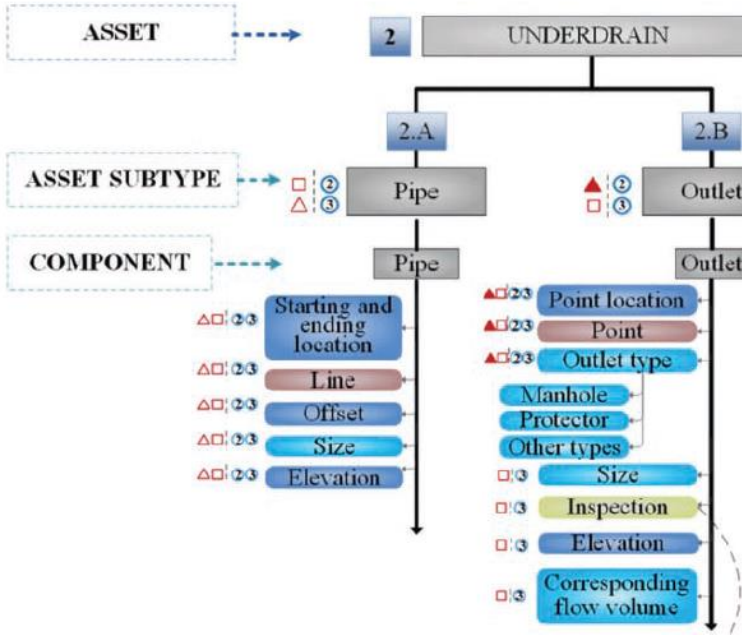


Figure 8. Data needs of underdrains at INDOT (Source: Cai et al., 2015)

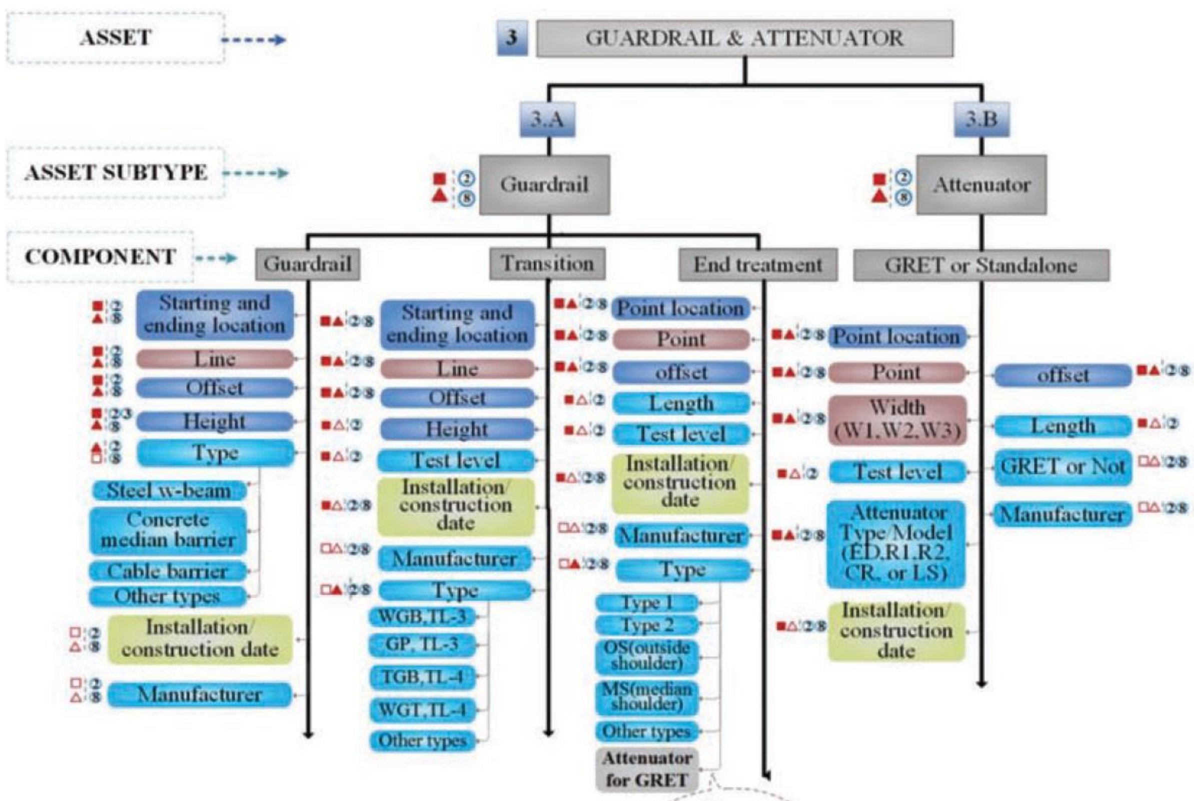


Figure 9. Data needs of guardrails and attenuators at INDOT (Source: Cai et al., 2015)

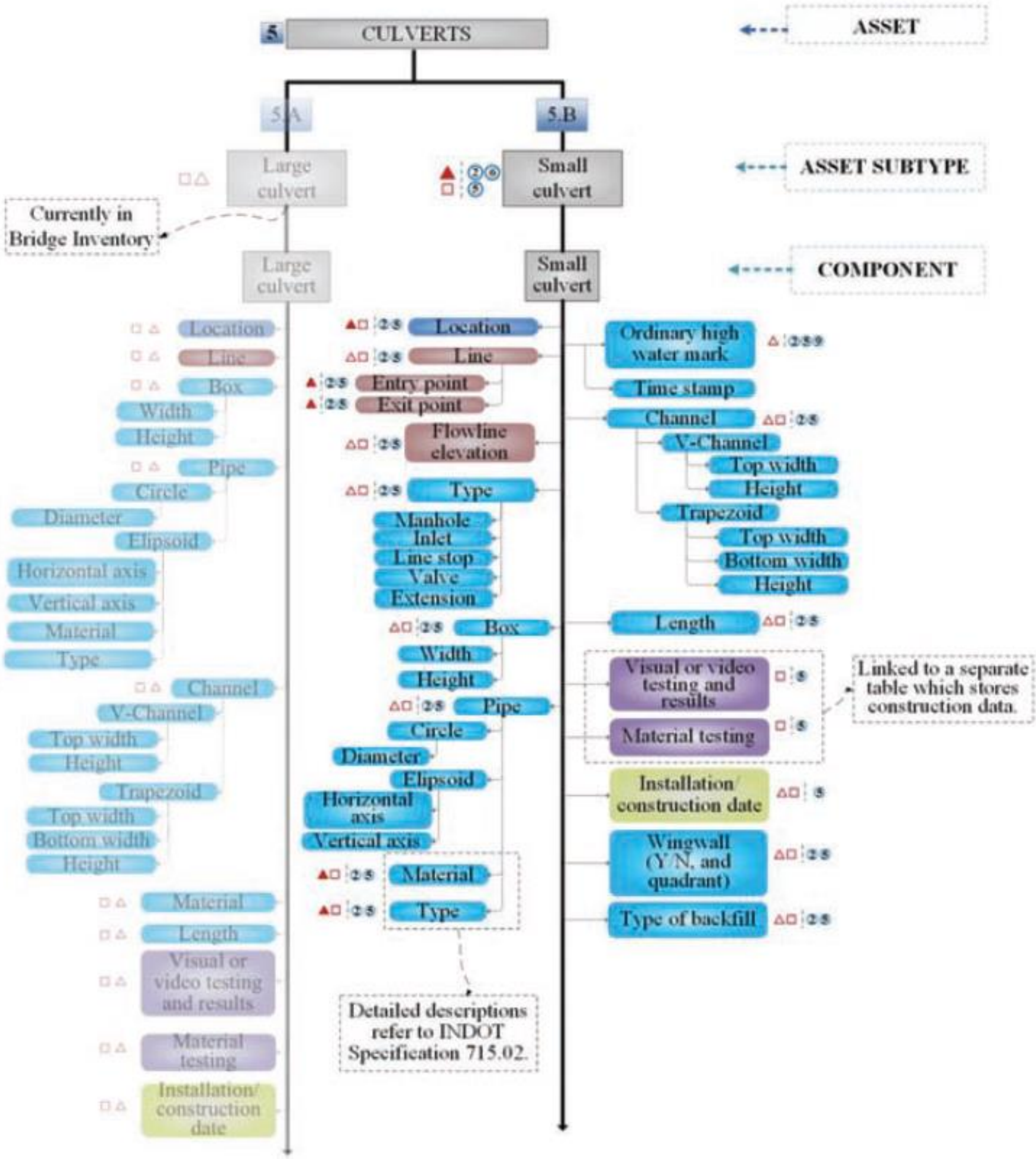


Figure 10. Data needs of culverts at INDOT (Source: Cai et al., 2015)

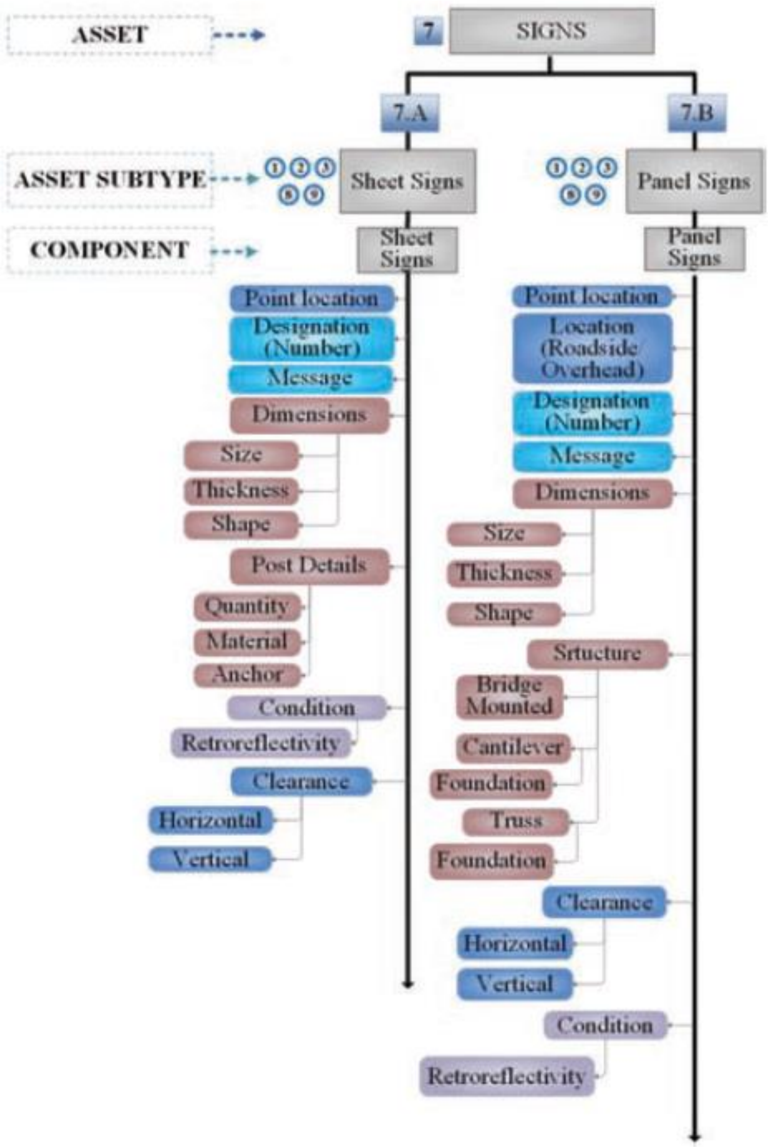


Figure 11. Data needs of signs at INDOT (Source: Cai et al., 2015)

Table 3. Typical asset data attributes at IowaDOT (Source: Le et al., 2018)

Asset	Constituent components
Sign	sign panel, post, footing, support structure, mounting bracket, anchor, message
Guardrail	beam, cable, delineator, object marker, end anchor, post, post foundation, turnbuckle, adapter, sand barrel, transition, end terminal, obstacle
Culvert	pipe, elbow, diaphragm, tee section, C connection, joint, dike, apron, reducer, manhole
Pavement	lane, cross section, shoulder, surface, median, barrier, curb, ditch, lane
Bridge	deck, pavement, girder, barrier, light, sidewalk, abutment, guardrail, pier, gutter

Table 4. Examples of required asset data attributes at IowaDOT (Source: Le et al., 2018)

Contract administration	Asset geometry and material	Asset location	Asset identifier	Asset condition
Start date, end date, proposed price, bid price, contract price, bid item quantity	Sign width, sign height, sign color, sign message, sign sheeting material, post length	District, county, route, ID, milepost, GPS latitude, GPS longitude	Sign ID, DOT, stock number, Iowa MUTCD Federal MUTCD	Day time rating, day retroreflectivity, night condition date, nighttime rating, night retroreflectivity, flag beacon

2.2.4. Mapping the Construction Data to Asset Data Needs and Updating Asset Repository

With respect to the practices of transferring data from construction to operation and maintenance (O&M), the capital facility sector is the pioneer. Some state highway agencies recently attempted to adopt this approach to reduce their data collection effort.

a. Construction Operations Building Information Exchange (COBie)

The U.S. Army Corps of Engineers was among the first agencies that conducted research on leveraging construction data for use in O&M. In 2007, a framework, namely Construction Operations Building Information Exchange (COBie), was introduced by the U.S. Army Corps of Engineers that is a modern data format used to streamline the handover process to the operators or owners of a building, focusing on vertical projects (East, 2007). COBie helps the project team organize electronic submittals approved during design and construction and deliver a consolidated electronic O&M manual with little or no additional effort. Although COBie has been effectively utilized in vertical construction, it was not designed for use in road construction.

The United Kingdom drove the adoption of digital information exchange for all new government projects, resulting in an effort to create a hybrid COBie-for-All specification that would contain both vertical and horizontal infrastructure. Based on studies undertaken between 2011 and 2013, the first version of CoBie-for-All was released (Scarponcini et al., 2013). To apply the lessons learned from COBie, road authorities in Australia and New Zealand are currently developing a specification named CONie (Construction to Operation for Network information exchange) that is expected to apply in road asset management systems (Perumpilly et al., 2019).

b. Information Delivery Manuals (IDMs)

An IDM is a technical documentation of workflows and information exchange requirements between different stakeholders throughout the project life cycle (Wix & Karlshøj, 2010). IDM identifies which and when information is to be transferred from one stakeholder to another. Specifically, an IDM document is to (1) identify and describe the processes in which data sharing is required; (2) identify the data producer and receiver for each data-sharing scenario; and (3) document data requirements in detail for a data-sharing scenario. The core components of an IDM include a Process Map (PM) and an Exchange Requirement (ER) matrix. A process map explains the sequence of activities to be completed and the actors (stakeholders) involved in the process. The ER matrix specifies what data attributes are to be transferred to whom and by whom. The IDM development guidance that was initially developed by buildingSMART has become part of the United States National BIM standard (National Institue of Building Sciences (NIBS), 2015).

Iowa DOT initiated a research effort to adopt IDM for developing new tools and workflows for streamlining their digital data from project delivery to post-construction staff (Le et al., 2018). The research team conducted interviews with software vendors, highway engineers, and contractors for five different types of assets, including pavements, guardrails, signs, culverts, and bridges. The main discussion topics are which data is required to be shared by whom and to whom and when, data formats, and supporting software applications. Furthermore, a kick-off meeting and a series of domain meetings were used to generate further detailed data on the data they need, where to obtain input data, what data they create, and the format of the final deliverables. The obtained valuable information was eventually used for developing ER matrices and PM. Figure 12 demonstrates an example PM of new sign construction. An in-depth analysis of the PMs and ER matrices can offer guidance to practitioners on how to better collect, manage, and exchange asset data (as shown in Figure 13). In this research, this conceptual data model was modeled in the OWL format in Protégé and showed that the model successfully enables a direct query of handover project data to prepare a data set ready for updating existing asset databases.

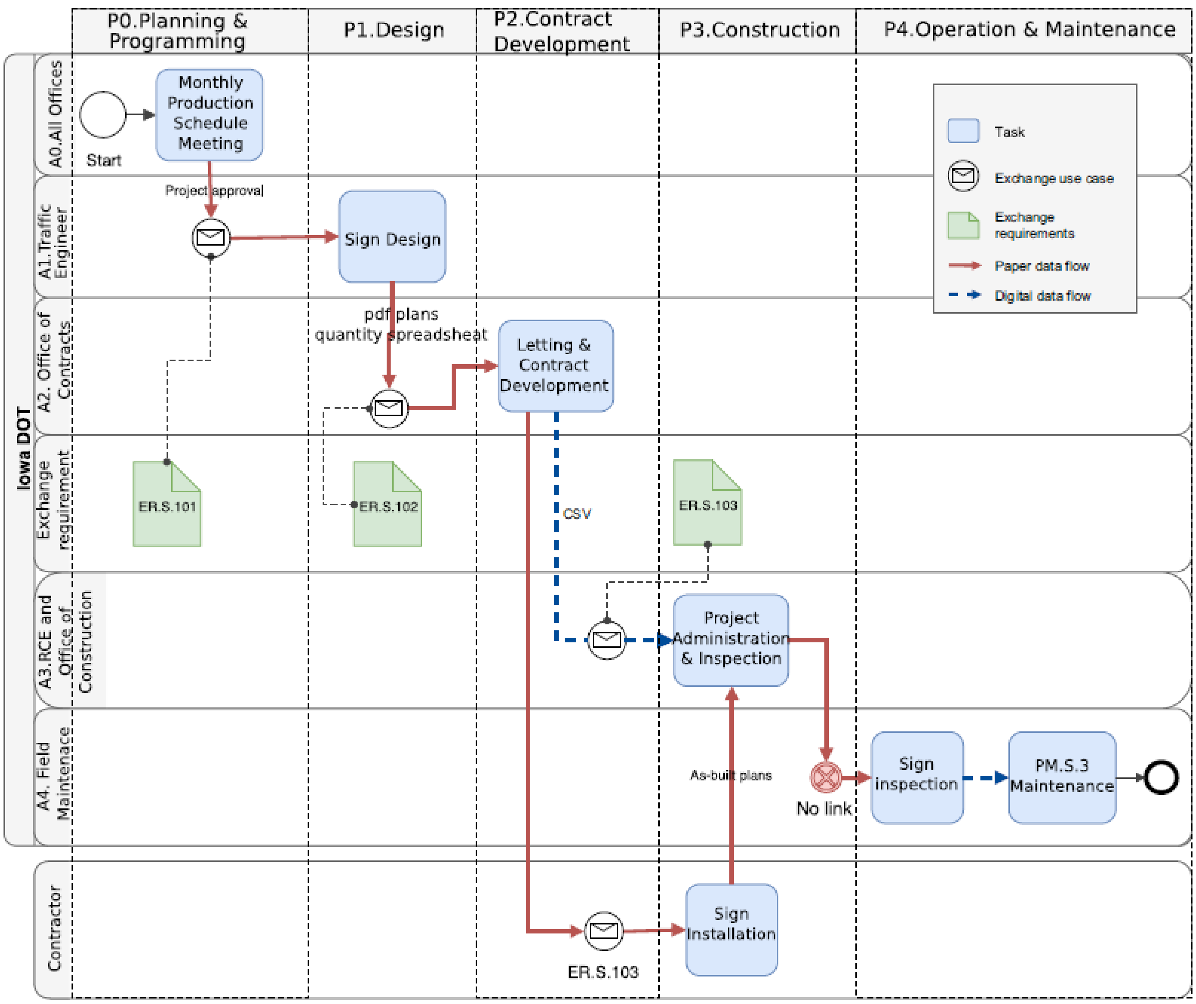


Figure 12. Process map of asset during life cycle (Source: Le et al., 2018)

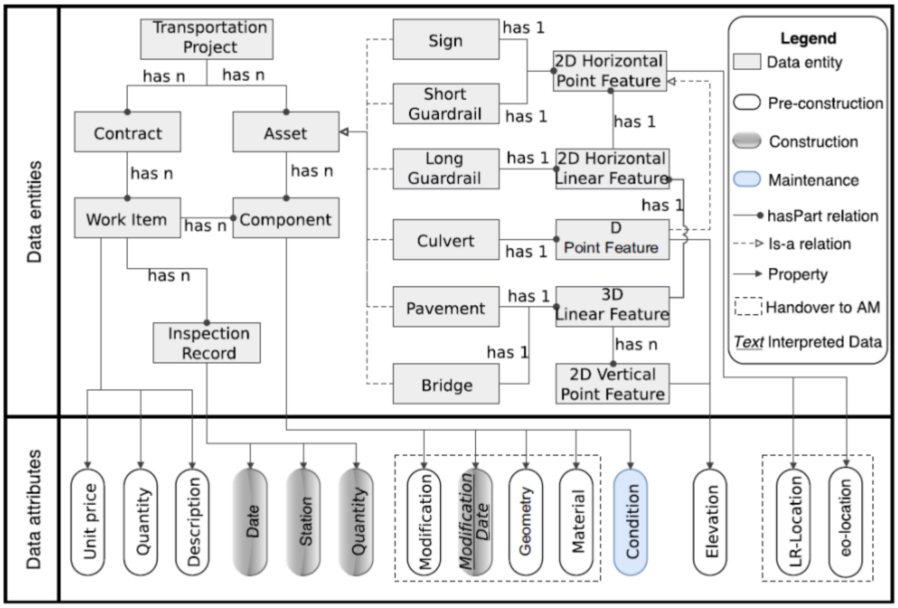


Figure 13. Conceptual transportation lifecycle asset data handover model (Source: Le et al., 2018)

c. Data Integration Model Specifications Across Life-Cycle Stages

State DOTs track project information from planning through construction stages. If properly organized, this information can be utilized within transportation asset management to update asset inventories and condition projections and to monitor asset-specific work histories (National Academies of Sciences Engineering and Medicine, 2021). The mapping of project operations against specific project line-items allows asset managers to have a better understanding of what assets were modified or added through construction activities. This is beneficial for TAM decision-making.

Asset information is often manually retrieved from project development documents (e.g., proposal and contract), project delivery systems (e.g., AASHTOWare Project SiteManager), and field data inspection. In an effort to develop a guidebook for data and information systems for TAM, a research team who conducted focus group discussions with participants from various DOTs (National Academies of Sciences Engineering and Medicine, 2021) found that they were at varying stages of incorporating detailed asset information within their project files. The respondents acknowledged that, generally, DOTs have not managed and tracked their projects by specific assets but by activities or bid items. The study reported that current DOT practices typically involve disconnected processes since the design model is discarded, and the contractor builds a new model optimized for their delivery purpose. Alternative delivery methods are creating new efficiencies, but the owners can take responsibility for defining model requirements throughout the phases of design-bid-build projects. When model specifications are developed contractually, the as-built plans can be distributed digitally as as-built models. With model specifications directly synchronized with the asset information model, asset information defined in the as-built model can be immigrated to supplement the asset inventory. Crucial as-built information (e.g., location and dimension) can be leveraged in maintenance work orders, asset management, and operation. This study also demonstrated a conceptual example of data integration across life-cycle stages by developing model specifications.

d. Asset Data Collection by Leveraging the Construction Inspection and Documentation

In the recent work on streamlining asset data for Indiana DOT, the authors developed a framework to employ construction inspection and documentation to retrieve asset data (Cai et al., 2015). The framework comprises 1) a data needs component for identifying the information needed from O&M, 2) a construction documentation module, and 3) a mapping technique that links data to be captured during construction documents to asset management systems. The technique that matches plan assets to assets in asset management systems such as Work management system is the key to collecting and leveraging construction data for capturing and updating asset data during construction. Figure 14 illustrates the framework for linking plan assets and assets in WMS via pay items.

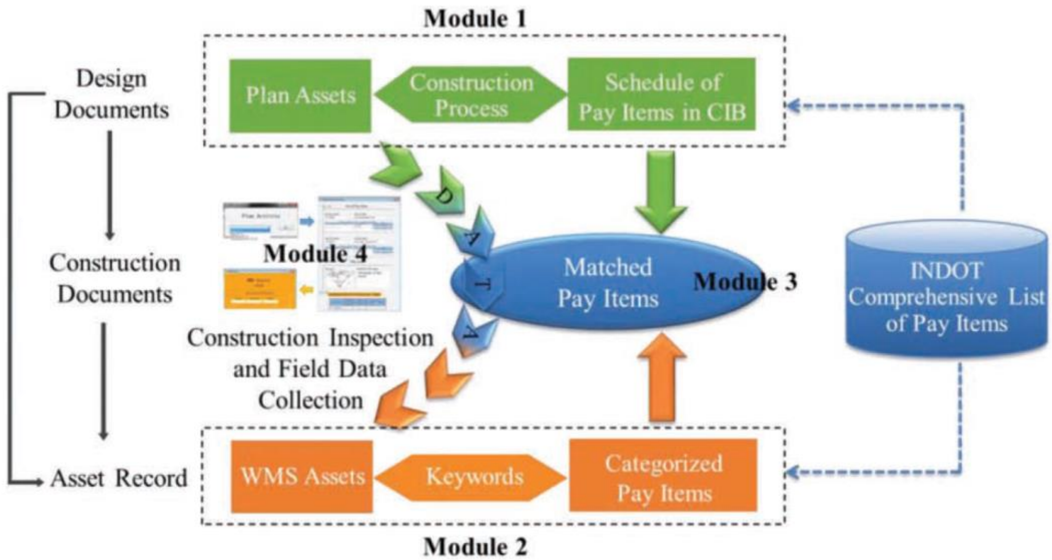


Figure 14. The framework for linking plan assets and assets in WMS via pay items (Source: Cai et al., 2015)

The framework is composed of four modules and uses pay items to link plan assets and assets in WMS:

- **Module 1 Associating Pay Items in the Contract Information Book (CIB) to Plan Assets:** The objective of module 1 is to link the pay item(s) in the CIB to each physical plan asset structure specified in the design documentation (drawings). In order to achieve this objective, the research team interviewed construction engineers and examined four INDOT standards, including INDOT 2014 CAD Standards Manual, INDOT 2013 Design Manual, INDOT 2014 Standard Specifications, and INDOT 2014 Standard Drawings. INDOT standards offer information about how and where physical structures (plan assets) are specified in the plans. For example, the data for underdrain assets, including different kinds of pipes, outlets, and outlet protectors, is contained in the table of underdrains. The expertise and experience of construction engineers assist in determining the association between plan assets and pay items. Together, they enable the retrieval of pay item information for every plan asset. The result of module 1 is the association between plan assets and pay items in CIB.
- **Module 2 Pre-compiling Pay Items for WMS Assets:** A list of keywords was developed by utilizing INDOT standard specifications and knowledge on construction. These keywords were then employed to retrieve pertinent pay items by searching through the comprehensive set of pay items. The resulting list was then scrutinized to eliminate irrelevant pay items to obtain a final list. The result of Module 2 is the list of pre-compiled pay items for each WMS asset.
- **Module 3 Matching Pre-compiled List of Pay Items (from Module 2) to Pay Items in CIB:** The matching itself is pretty straightforward since every pay item in CIB and in the pre-compiled lists has a unique identifier. The result of Module 3 is a set of CIB pay items that match pay items in the pre-compiled lists and the specific WMS assets to which these pay items belong.
- **Module 4 Construction Inspection and Field Data Collection:** Module 4 is the field data

collection and allocating of construction documentation data items to WMS. Construction engineers utilize the field app to capture pertinent data for certain pay items and collect additional information as needed. Relevant data items automatically flow into WMS. Certain data items can be obtained directly from the design documents; they do not require field involvement. While those can come from design documents, certain data items must be verified by construction engineers in the field. For those asset data not covered in the construction documentation, construction engineers must collect them. In this Module, every data item is annotated as either "Field collected," "Field verified," or "Field not involved/Information passing through." As a result of completing module 4, asset data items collected throughout the construction documentation are obtained. Figure 15 indicates the unintuitive interface in collecting asset data by leveraging construction documentation.

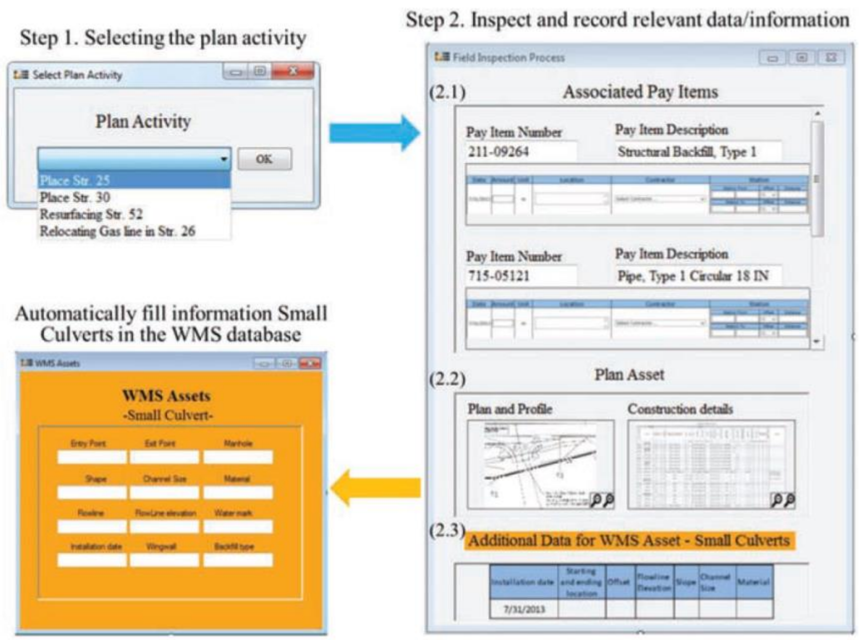


Figure 15. The conceptual mobile app user interface of Construction Inspection and Field Data Collection (Source: Cai et al., 2015)

The mapping technique was tested and validated using four priority asset classes, including underdrains, guardrails, attenuators, and small culverts from an INDOT construction project. The results revealed that the developed framework is workable and reliable for capturing asset data during the construction phase for O&M use later on without adding additional workload to construction personnel.

Chapter 3: State DOTs' Best Practices

3.1. Method

Initially, a questionnaire draft was developed that aims to identify current practices of asset data collection during construction across the State DOTs in the United States, focusing on approaches, specific tools, and uses. The survey instrument was finalized according to the feedback of the steering committee on the draft. Later, an online survey for the final questionnaire was developed on Qualtrics consisting of 45 questions that were divided into two sections.

- The first section, "Asset Inventory Data Collection and Management," asks questions related to various aspects of asset inventory, such as data collection methods, the types of projects and assets collected, technologies, tools, software, and mobile applications used by State DOTs, personnel responsible for inventory, guidelines adopted for data collection, data collection procedures, limitations and difficulties associated with various data collection techniques, the effectiveness of alternative data collection methods, and challenges related to using construction documents and maintenance work orders to extract inventory data.

- The second section, "Construction Project Data Collection and Management," requires more specialized and detailed input on current agency practices for collecting and managing construction data. It includes questions about the types of data collected during the construction stage, as-built drawings, technology, and tools for collecting construction project data, mobile applications used for field collection, software applications used for managing data, and construction documents that can be used to extract asset inventory data.

The survey was distributed electronically to AASHTO members. Individuals working in certain state DOT offices, such as Construction and Materials, Data/Information Administration and Services, Maintenance, and Asset Management, were eligible to participate. To supplement the survey, virtual interviews were conducted with selected DOTs' representatives, particularly those that use effective methods for collecting asset data from construction records. According to the survey results, the Nevada and Minnesota DOTs were identified as pioneers in using innovative asset inventory data management systems. In-depth interviews were conducted with both agencies to learn from their experiences. The interviews were to identify the state of practice on how construction records are reused for updating transportation asset inventories, including EAMS. We specifically sought their feedback and lessons learned regarding technologies, technical challenges, methods for mapping construction data and asset data, asset data needs, data being collected during the construction phase, and strategies for overcoming the resistance to workflow changes.

Figure 16 displays the states participating in the survey. As shown, 29 completed responses from 22 states were received (nearly 44 percent of the US states). The obtained responses were saved in a Microsoft Excel spreadsheet for further data analysis. Four state DOTs provided multiple responses from more than one professional. The responses from the same agency were analyzed to determine any discrepancies regarding their current practices. To achieve this, only one answer was selected based on the following criteria:

- The most complete responses were given a higher priority. For instance, if one staff reported that their state agency used two mobile applications for statewide field asset inventory data, while another one reported using the same two applications and an additional one, the final response would include all three software applications from the latter response.

- The response of an individual, whose areas of expertise are closely matched the survey questions and input fields, was given a higher priority.

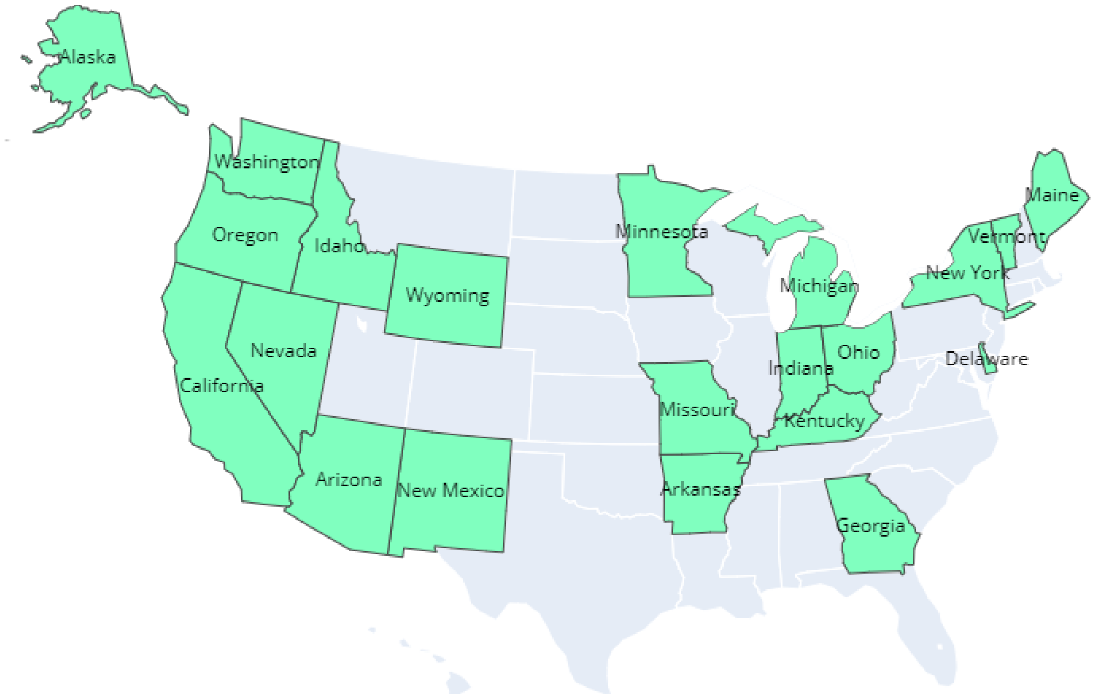


Figure 16. States participating in the survey

The responses to the question concerning the knowledge and experiences of respondents are summarized in Figure 17. According to the figure, 81 percent of the respondents (18/22 states) indicated they possess knowledge or experience with an Asset Inventory Collection and Management system. Only 7 in total 22 participating individuals have expertise related to Construction Project Data Collection and Management.

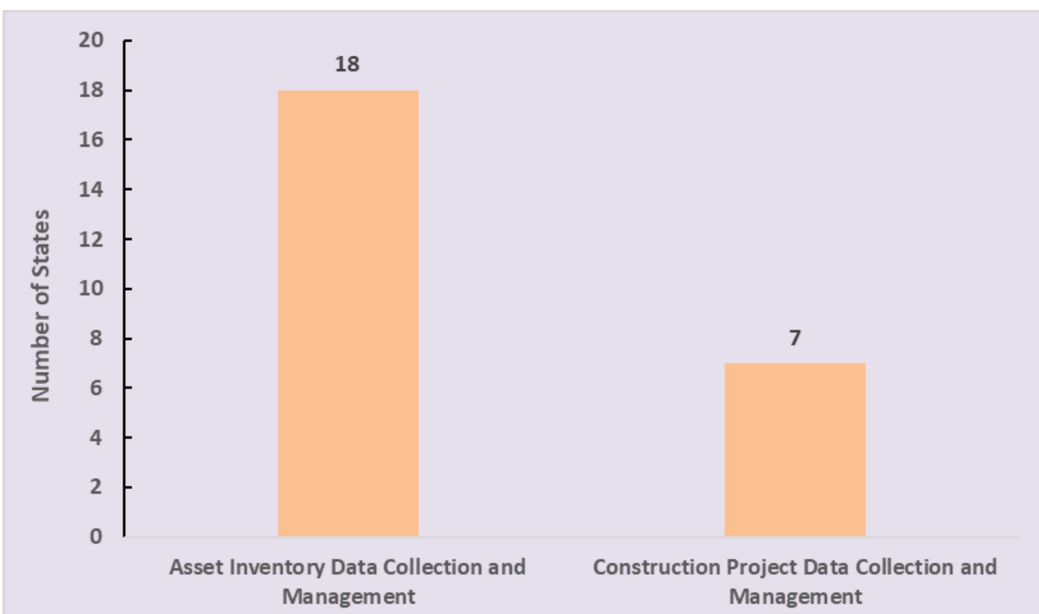


Figure 17. Distribution of knowledge and experience of respondents

3.2. Key Findings

3.2.1. Asset Inventory Data Management Systems

Table 5 displays the types of asset inventory data collected by state highway agencies, which include bridges, pavements, traffic signals, guardrails, signs, culverts, drainage, and others. Each row represents a state, and the columns show different types of assets being collected and managed. The table shows that bridges and pavements are the most common asset types that are collected by almost all the surveyed states. Traffic signals, guardrails, and signs are also commonly collected by state agencies, with 14, 13, and 13 in total 17 participating states, respectively. Culverts and drainage are less frequently collected, with only 11 and 8 states. It is worth noting that the surveyed states showed dissimilarity in the types of assets of which inventory are captured. This indicated that state agencies have different priorities on asset types that are most relevant to their businesses.

Table 5. Types of assets inventory data collected by state agencies

No	States	Asset types							
		Bridges	**Pavements**	**Traffic signals**	**Guardrails**	**Signs**	**Culverts**	**Drainage**	**Others**
1	AK	✓	✓						
2	AR	✓	✓	✓	✓	✓	✓	✓	✓
3	CA	✓	✓	✓			✓		✓
4	DE	✓	✓	✓	✓	✓	✓	✓	
5	DC	✓	✓		✓	✓			
6	IN	✓	✓	✓	✓	✓	✓	✓	
7	KY	✓	✓	✓	✓				
8	MI	✓	✓	✓	✓	✓	✓		
9	MN	✓	✓	✓	✓	✓	✓	✓	✓
10	MO	✓	✓	✓	✓	✓	✓	✓	✓
11	NV	✓	✓	✓	✓	✓			✓
12	NM	✓	✓	✓	✓	✓	✓	✓	
13	NY	✓	✓	✓	✓	✓	✓	✓	✓
14	OH	✓	✓	✓	✓	✓	✓		
15	VT	✓	✓	✓	✓	✓	✓	✓	✓
16	WA	✓	✓	✓		✓			
17	WY	✓	✓						
Total		**17**	**17**	**14**	**13**	**13**	**11**	**8**	**7**

Regarding software applications for asset inventory data management, it was found that the majority of the states that participated in the survey have already implemented asset management systems. Table 6 shows that 15 states use Esri ArcGIS (Roads and Highways), and nine use AgileAssets Enterprise Asset Management System (EAM) to manage their asset inventory data. Additionally, Microsoft Excel was also a popular choice, used by six states. Other software applications such as ProjectWise, Roadway Information Management System (RIMS), SQL databases, SharePoint, Microsoft Access, and others were used by fewer states.

Table 6. Software Applications used to manage asset inventory data

No	States	Software applications								
		Esri ArcGIS (Roads and Highways)	AgileAssets Enterprise Asset Management System (EAM)	Microsoft Excel	ProjectWise	Roadway Information Management System (RIMS)	SQL databases	SharePoint	Microsoft Access	Others
1	AK	✓	✓	✓						
2	AZ									✓
3	AR			✓			✓	✓	✓	✓
4	CA	✓			✓					✓
5	DE	✓								✓
6	DC	✓								
7	ID	✓	✓		✓					
8	IN	✓	✓							✓
9	KY	✓		✓						✓
10	MI	✓								✓
11	MN	✓	✓							✓
12	MO									✓
13	NV	✓	✓							
14	NM	✓	✓			✓				
15	NY	✓	✓	✓	✓	✓		✓	✓	
16	OH	✓	✓							
17	OR									✓
18	VT	✓		✓			✓			✓
19	WA	✓		✓		✓	✓			
20	WY		✓							
Total		**15**	**9**	**6**	**3**	**3**	**3**	**2**	**2**	**11**

3.2.2. Asset Inventory Data Collection Methods

The participants were asked to specify their data collection methods, which are categorized into four types:

- Method a: regular statewide field asset inventory collection at a predefined frequency.
- Method b: field asset inventory collection data during the construction stage of project delivery.
- Method c: asset inventory data extraction from construction documents, such as as-built plans/models and daily reports of work items.
- Method d: asset inventory data extraction from asset maintenance work orders.

Table 7 presents the methods used among the states for collecting asset inventory data. The table shows that Method a is the most common method employed, with 18 States using this method. Besides, extracting asset data from construction documents is the second most common approach, with ten States.

Methods b and d are less common as only nine and five agencies utilizing them, respectively. The use of different methods may be due to the unique needs and available resources in each state. Overall, the data presented in this table can provide insights into the methods used by various states to collect asset inventory data, which can help benchmark and identify best practices.

Table 7. Methods used for collecting asset inventory data

No	States	Method a: Regular statewide field asset inventory collection at a predefined frequency	Method b: Field asset inventory data collection during the construction stage of project delivery	Method c: Asset inventory data extraction from construction documents (e.g., as-built plans/models and daily reports of work items)	Method d: Asset inventory data extraction from asset maintenance work orders
1	AK	✓			
2	AZ	✓			
3	AR	✓	✓	✓	✓
4	CA	✓	✓	✓	✓
5	DE	✓	✓		✓
6	DC	✓			
7	ID	✓		✓	
8	IN	✓		✓	
9	KY	✓			
10	MI		✓		
11	MN	✓	✓		
12	MO	✓		✓	
13	NV	✓			
14	NM	✓	✓	✓	✓
15	NY	✓	✓		
16	OH	✓	✓	✓	
17	OR			✓	
18	VT	✓	✓	✓	✓
19	WA	✓			
20	WY	✓		✓	
Total		**18**	**9**	**10**	**5**

The findings also revealed that Method a is used for all types of assets, as shown in Figure 18. Method b collects data on only six asset types and is used in fewer states, while Method c is implemented in only four asset types. The inventory data of bridges, pavements, culverts, and drainage are often collected using all four methods. All four methods gather data on signs, drainage, and roadway assets, but these assets are collected less frequently compared to bridges and pavements. Overall, the figure indicates that the states prioritize collecting asset data on bridges and pavements using Method a. Other assets may be less prioritized and collected less frequently using alternative methods.

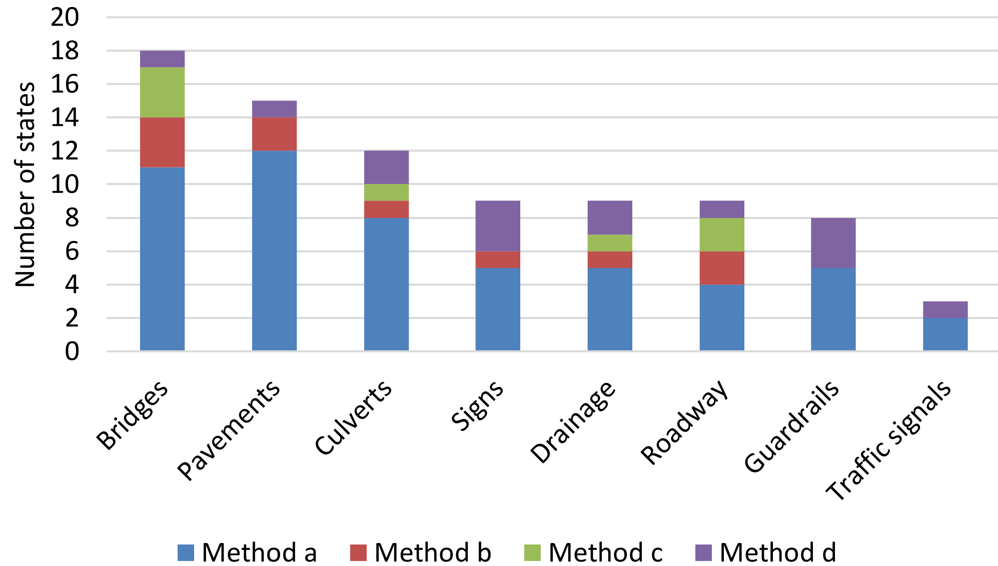


Figure 18. Methods used to collect each type of asset data

a. Regular Statewide Field Asset Inventory Collection at a Predefined Frequency

The survey includes six questions regarding regular statewide field asset inventory collection at a predefined frequency. The questions asked about what assets and asset data types the agency collects, what technologies, tools, and mobile applications are utilized, who performs the inventory, and the agency's specific guidelines for data collection.

Table 8 provides information about the technologies and tools used for statewide field asset inventory data collection in different states. The table shows eight different data collection methods, including data collection vans, GPS devices, manual data collection using field books, mobile devices such as smartphones and tablets, terrestrial LiDAR, airborne LiDAR, drone LiDAR, and others. According to the table, data collection vans are the most common method that is used in 13 states (65%), followed by GPS devices and terrestrial LiDAR, each used in 9 states. Manual data collection using field books and mobile devices are used in 7 and 6 states, respectively. The use of LiDAR from airborne and drone platforms is limited, with only three states using each method. Two states reported using other methods not specified in the table.

Table 8. Technologies and tools used for statewide field asset inventory data collection

No	States	Data collection vans	GPS devices	Manual data collection (e.g., field books)	Mobile devices (e.g., smartphones, tablets)	LiDAR (terrestrial)	LiDAR (airborne)	LiDAR (drone)	Others
1	AK	✓		✓					
2	AZ		✓						
3	AR	✓	✓		✓			✓	
4	CA	✓	✓						
5	DE	✓		✓		✓			
6	DC	✓	✓	✓					
7	ID	✓				✓			
8	IN	✓	✓	✓	✓				

No	States	Data collection vans	GPS devices	Manual data collection (e.g., field books)	Mobile devices (e.g., smartphones, tablets)	LiDAR (terrestrial)	LiDAR (airborne)	LiDAR (drone)	Others
9	KY	✓	✓				✓	✓	
10	MN								✓
11	NV			✓	✓	✓			
12	NM	✓	✓	✓	✓	✓	✓		
13	NY	✓							✓
14	OH	✓			✓				
15	VT	✓	✓		✓		✓	✓	
16	WY	✓	✓	✓					
Total		**13**	**9**	**7**	**6**	**4**	**3**	**3**	**2**

Regarding mobile applications, Table 9 shows that out of the 15 states included, six states are using Esri ArcGIS Collector, four states are using Esri ArcGIS Survey123, two states are using Esri ArcGIS Quick Capture, and one state is using Agile Structures Inspector. Clearly, the Esri applications are the most popular mobile app in collecting asset data. Additionally, the surveyed states use other mobile applications to collect field assets inventory data, such as Inspect X, Fugro-Roadware iVision Asset Extraction, PAVER, HPMS, and ARAN Van. The personnel responsible for collecting statewide field asset inventory data are mainly in-house field maintenance staff and external consultants, with 11 and 10 selections from 16 States (as shown in Table 10).

Table 9. Mobile applications used for collecting statewide field asset inventory data

No	States	Esri ArcGIS Collector	Esri ArcGIS Survey123	Esri ArcGIS Quick Capture	Agile Structures Inspector	Others
1	AK					✓
2	AZ					✓
3	AR		✓	✓		
4	CA					✓
5	DE					✓
6	DC					✓
7	ID	✓				
8	IN	✓	✓			
9	KY	✓				
10	NV		✓			
11	NM					✓
12	NY	✓			✓	✓
13	OH	✓				
14	VT	✓	✓	✓		✓
15	WY					✓
Total		**6**	**4**	**2**	**1**	**9**

Table 10. Personnel responsible for collecting statewide field asset inventory data

No	States	In-house field maintenance staff	External consultants	Others
1	AK		✓	✓
2	AZ			✓
3	AR	✓		✓
4	CA	✓	✓	
5	DE	✓	✓	
6	DC		✓	
7	ID	✓		
8	IN	✓	✓	
9	KY	✓	✓	
10	MN	✓		
11	NV	✓		✓
12	NM	✓	✓	
13	NY		✓	
14	OH	✓		
15	VT	✓	✓	✓
16	WY		✓	
Total		**11**	**10**	**5**

b. Field Asset Inventory Data Collection during the Construction Stage of Project Delivery

The state agencies were also asked questions regarding field asset inventory data collection during the construction/maintenance stage (at the point of installation). The survey aimed to gather information on project types, data types, mobile applications, personnel involved, workflow, effectiveness, drawbacks, and agencies' guidelines using this method. Table 11 presents the findings regarding tools used for field asset inventory data collection during the construction stage of project delivery. It is found that only a small number of states collect inventory data during this stage. According to the table, out of the seven states surveyed, Michigan and Vermont use the Esri ArcGIS Collector mobile application to collect field asset inventory data during construction. Michigan also utilizes Esri ArcGIS Survey123. The remaining five states (New Mexico, Ohio, Delaware, and California) use different mobile applications.

Table 11. Mobile applications used for collecting field asset inventory data during the construction stage

No	States	Esri ArcGIS Collector	Esri ArcGIS Survey123	AASHTOWare Project Mobile Tester	Others
1	AR			✓	
2	CA				✓
3	DE				✓
4	MI	✓	✓		
5	NM				✓

6	OH				✓
7	VT	✓			
Total		2	1	1	4

Table 12 provides information on personnel responsible for collecting field asset inventory data during the construction stage in various states. The table lists five categories of personnel, including contracted consultants, in-house field maintenance staff, in-house construction engineers, highway construction contractors, and others. The findings show that in some states, more than one personnel category is responsible for this task. Specifically, contracted consultants are responsible in five states, in-house field maintenance staff in five states, in-house construction engineers in four states, highway construction contractors in three states, and others in one state. Vermont and California are the states where the responsibility is not assigned to a contracted consultant. New Mexico has the highest number of personnel categories responsible for collecting data during the construction stage, including contracted consultants, in-house field maintenance staff, in-house construction engineers, and highway construction contractors.

Table 12. Personnel responsible for collecting field asset inventory data during the construction stage

No	States	Contracted consultant	In-house field maintenance staff	In-house construction engineers	Highway construction contractor	Others
1	AR	✓				
2	CA		✓			
3	DE	✓		✓	✓	
4	MI	✓	✓			✓
5	NM	✓	✓	✓	✓	
6	OH	✓	✓	✓		
7	VT		✓	✓	✓	
Total		5	5	4	3	1

c. Asset Inventory Data Extraction from Construction Documents

The agencies were also asked to provide information about the process of asset inventory data extraction from construction documents, including the types of projects and assets that they collect inventory data, the software applications and construction project documents used for data extraction, the workflow for data collection, and the challenges associated with using construction documents for updating transportation asset inventories. Table 13 displays findings on the approaches employed for extracting asset inventory information from construction project documents across several states. The table outlines three extraction methods, manual, semi-automatic, and automatic reported by eight states. The results indicate that manual extraction is the most popular method that is employed by six states, while New Mexico and Ohio use semi-automatic methods. As shown in the table, none of the participating states utilize automatic extraction methods.

Table 13. Methods of extracting asset inventory from construction project documents

No	States	Manually	Semi-automatically	Automatically
1	CA	✓		
2	ID	✓		
3	IN	✓		
4	NM		✓	
5	OH		✓	
6	OR	✓		
7	VT	✓		
8	WY	✓		
Total		**6**	**2**	**0**

Regarding construction documents used for extracting asset inventory data, Table 14 presents the following three types of documents: as-built plans, design plans, and daily work reports. This data was reported by eight participating states. As shown, most states utilize both as-built and design plans for extracting asset inventory data. These two document types are used as asset inventory data sources in seven states. On the other hand, daily work reports are leveraged only by New Mexico DOT.

Table 14. Construction document types used for extracting asset inventory

No	States	As-built plans	Design plans	Daily work reports
1	CA	✓	✓	
2	ID	✓		
3	IN	✓	✓	
4	NM	✓	✓	✓
5	OH		✓	
6	OR	✓	✓	
7	VT	✓	✓	
8	WY	✓	✓	
Total		**7**	**7**	**1**

d. Asset Inventory Data Extraction from Maintenance Work Orders

The survey comprises a section containing questions concerning the extraction of asset inventory data from asset maintenance work orders. These questions encompass the categories of projects, the assets gathered, the types of asset data, and the format of maintenance work orders utilized for data extraction. Additionally, agencies were queried about the process of data extraction, the workflow of data collection, the responsibilities of personnel and supporting tools, and the challenges encountered in utilizing maintenance work orders to update transportation asset inventories.

Table 15 and Table 16 provide summaries of the findings concerning the methods and types of maintenance work orders utilized to extract asset inventory data across various states. Four states have reported employing different methods for this purpose (refer to Table 15). Specifically, California and Vermont employ manual methods, while New Mexico adopts a semi-automatic approach. Delving into the semi-automatic method, New Mexico has affirmed the importance of extracting asset data from maintenance work orders. Table 16 illustrates the diverse forms of maintenance work orders used for extracting asset inventory data among five states. New Mexico, Ohio, and Vermont utilize both digital forms available in software applications and hard-copy paper forms. In contrast, California and Delaware rely solely on one source, either digital or hard-copy paper forms. Notably, New Mexico stands out as the only state employing all three types of work orders for extracting asset inventory data.

Table 15. Methods of extracting asset inventory from maintenance work orders

No	States	Manually	Semi-automatically	Others
1	CA	✓		
2	DE			✓
3	NM		✓	
4	VT	✓		
Total		2	1	1

Table 16. Maitenance work order types used for extracting asset inventory

No	States	Digital forms available in a software application	Hard-copy paper forms	PDF forms
1	CA		✓	
2	DE	✓		
3	NM	✓	✓	✓
4	OH	✓	✓	
5	VT	✓	✓	
Total		4	4	1

3.2.3. Construction Project Data Collection and Management

The survey also inquired about current practices concerning the collection and management of construction data from participants. In this regard, the survey encompassed various aspects, including the types of project data collected during the construction stage, the types of as-built drawings utilized, the technology, tools, and methods employed for data collection, mobile applications utilized for field collection, software applications used for data management, and construction documents applicable for extracting asset inventory data. Table 17 shows the usage of four types of as-built drawings by agencies for managing and collecting construction project data, which include redline PDF plans, redline paper plans, direct updates on digital design plans such as CAD or Microstation files, and other types. As per the presented data, all states utilize redline PDF plans, while redline paper plans are used by five states. Three states reported direct updates on digital design plans, with one state employing other forms of as-built drawings. Notably, New York stands out as the only state employing all four types of as-built drawings for managing and collecting construction project data.

Table 17. Types of As-built drawings used by agencies

No	States	Redline PDF plans	Redline paper plans	Direct updates on digital design plans (e.g., CAD or Microstation files)	Others
1	AR				✓
2	CA	✓		✓	
3	DE	✓	✓		
4	GA	✓	✓		
5	KY				✓
6	ME	✓	✓		
7	NY	✓	✓	✓	✓
8	OH	✓	✓	✓	
9	OR	✓			
10	WY	✓			
Total		**8**	**5**	**3**	**3**

The data in Table 18 outlines the methods and tools used for collecting construction project data in twelve states. The table categorizes the methods into five groups: mobile devices, laptops with AASHTOWare Project SiteManager/AASHTOWare Project FieldManager, contractors' submittals, paper fieldbooks, and others. The data reveals that seven states use mobile devices and seven use laptops with AASHTOWare Project SiteManager/AASHTOWare Project FieldManager to collect construction project data. Six states use contractor submittals and paper field books for the same purpose. Some states employ multiple methods for collecting construction project data. Two states Arkansas and New York use all four methods listed in the table.

Table 18. Technologies, tools, and methods used for collecting construction project data

No	States	Mobile devices (e.g., smartphones or tablets)	Laptops with AASHTOWare Project SiteManager/AASHTOWare Project FieldManager	Contractor's submittals	Paper field books	Others
1	AR	✓	✓	✓	✓	✓
2	CA		✓	✓	✓	
3	DE	✓		✓		
4	GA	✓	✓	✓	✓	
5	KY					✓
6	ME	✓	✓		✓	
7	NY	✓	✓	✓	✓	✓
8	NY	✓	✓	✓	✓	
9	OH		✓			
10	OR					✓

11	WY	✓				✓
Total		**7**	**7**	**6**	**6**	**5**

Table 19 illustrates the current practice in using mobile applications for collecting construction project data in six states. The table lists three applications: Infotech Mobile Inspector, AASHTOWare Project Mobile Tester, and Others. The data indicates that four states use other mobile applications to collect construction project data. Arkansas and Delaware do not use any of the listed mobile applications. Georgia uses AASHTOWare Project Mobile Tester, while Maine and New York use Infotech Mobile Inspector. New York has also piloted Reconstruct software, Agile Assets, and 3D/4D/5D BIM on large Design/Build projects. Wyoming uses the iPDWeb Fieldbook application. Two states use Infotech Mobile Inspector, one uses AASHTOWare Project Mobile Tester, and four use other mobile applications for collecting construction project data.

Table 19. Mobile applications used for collecting construction project data

No	States	Infotech Mobile Inspector	AASHTOWare Project Mobile Tester	Others
1	Arkansas			Doc Express
2	Delaware			Oracle Primavera Unifier
3	Georgia		✓	
4	Maine	✓		
5	New York	✓		Agile Assets, piloting Reconstruct software,3D/4D/5D BIM on large Design/Build projects
6	Wyoming			iPDWeb Fieldbook application
Total		**2**	**1**	**4**

Table 20 provides data on the software applications used to collect construction project data across twelve states. The table indicates that AASHTOWare Project SiteManager is the most commonly used application and is employed by seven states. Six states use ProjectWise, while five states use Microsoft Excel. AASHTOWare Project Construction & Materials is used by four states, and Microsoft Access and AASHTOWare Project FieldManager are used by three and two states, respectively. The table also shows that some states use additional software applications, including Oracle Primavera Unifier and iPDWeb. Some states use multiple software applications for collecting construction project data, such as New York, which uses AASHTOWare Project SiteManager, ProjectWise, Microsoft Excel, AASHTOWare Project Construction & Materials, and is piloting Reconstruct software.

Table 20. Software applications used for collecting construction data

No	States	AASHTOWare Project SiteManager	ProjectWise	Microsoft Excel	AASHTOWare Project Construction & Materials	Microsoft Access	AASHTOWare Project FieldManager	Others
1	AR	✓		✓	✓	✓		
2	CA	✓	✓					
3	DE		✓					Oracle Primavera Unifier
4	GA	✓			✓		✓	
5	KY	✓	✓	✓	✓			
6	ME			✓		✓	✓	
7	NY	✓	✓	✓	✓	✓		Piloting Reconstruct
8	NY	✓	✓	✓				
9	OH	✓						
10	OR		✓					
11	WY							iPDWeb
Total		**7**	**6**	**5**	**4**	**3**	**2**	

3.2.4. Current Practices in Pioneering States

Table 21 summarizes the current practices of certain leading DOTs. Further elaboration on their practices is provided in the subsequent sections below.

Table 21. Best practices at pioneering states

No	State	Respond	Using Agile	Asset inventory data collection method			Construction Data Collection Method Using Mobile Apps	Some construction/maintenance data is leveraged for asset inventory?	Some data is collected at the point of installation?
				Field Data Collection Using Mobile Apps	Extraction from Construction Data	Data Extraction from Maintenance Work Orders			
1	California	CP	No	Trimble with GoPro Dash Cam by consultants or field maintenance staff at the end of the project or after it is open to traffic, periodic overnight collection, focusing on location, road characteristics, some HPMS items	Manual extraction from CADD files and As-builts (needs ability to read plans)	Manual extraction as much as possible from hard-copy forms, for signs and guardrails	Unsure	Yes (From construction, maintenance data)	Yes (Not until the project is completed)
2	Delaware	CB	No	Unsure	Import GPS Survey collected by construction staff into Esri, for storm water/sewer structures and new bridges	Extract data from digital work orders in IBM Maximo, focusing on installed devices not easily identified by Lidar	Unsure	Yes (From construction, maintenance data)	Unsure
3	Michigan	RG	No	-Esri ArcGIS Collector and Esri ArcGIS Survey123 by consultants or in-house maintenance staff, mostly location information	Unsure	Unsure	Unsure	Unsure	Unsure
4	New Mexico	HY	Yes	- Smartphones, tablets by consultants and in-house maintenance staff; and AASHTOWare Project Mobile Tester by construction engineers, mostly for bridges and highways	Semi-automatic extraction from As-builts plans, design plans and DWRs, mostly for bridges and highways	Semi-automatic extraction from digital and electronic paper forms, mostly for drainage structure	N/A	Yes (From construction, maintenance data)	Unsure
5	New York	MR & BD	Yes	-Agile Structures Inspector, Esri ArcGIS Collector, RoadwareiVision Asset Extraction (manual Extraction from photologs), during post-construction by consultants (Mike Rossi)	Unsure	Unsure	Infotech Mobile Inspector, Agile Assets (Brett Dean)	Maybe (Using Agile in construction)	Maybe (Using Agile in construction)
6	Wyoming	WB	Yes	Unsure	Manual from as-built plans and design plans in iPDWeb system, mostly for culverts, roadway thickness, and rehabilitation	Unsure	iPDWeb and Fieldbook	Yes (From construction data)	Unsure
7	Alaska	JN	Yes	None	Unsure	Unsure	Unsure	Yes (Using Fugro-Roadware in construction as-built data, mostly for installation dates and	Unsure

No	State	Respond	Using Agile	Asset inventory data collection method			Construction Data Collection Method Using Mobile Apps	Some construction/maintenance data is leveraged for asset inventory?	Some data is collected at the point of installation?
				Field Data Collection Using Mobile Apps	Extraction from Construction Data	Data Extraction from Maintenance Work Orders			
								locations of signs, lights, and guardrails)	
8	Indiana	DF	Yes	-Esri ArcGIS Collector and Esri ArcGIS Survey123 by consultants or in-house maintenance staff, mostly for bridges, culverts, drainage, signs and pavement condition.	Manual extraction from Oracle Database and PDF files, mostly for drainage and smaller assets.	Unsure	Unsure	Yes (From construction data)	Unsure
9	Minnesota	TS	Yes	Unsure	Unsure	Unsure	Unsure	Yes (using remote sensing technologies on above ground assets and as-built post-construction to collect asset inventory data; Maintenance crews are also updating asset inventory)	Unsure
10	Idaho	DA	Yes	Esri ArcGIS Collector by In-house field maintenance staff for Bridges	Manual extraction from As-built plans, mostly for Pavement, including new construction, reconstruction, rehabilitation, and preservation.	Unsure	Unsure	Yes (From construction data stored as pdf's in Share point)	Unsure
11	Arizona	SM	No	In House Program by In House Features Inventory Service Team for Bridges, Culverts, Drainage, Guardrails, Signs, Traffic signals	Unsure	Unsure	In House Program	Unsure	Unsure
12	Oregon	PK	No	Unsure	Manual extraction from As-built plans and Design plans using Filenet for Bridges, Culverts, Drainage, Guardrails, Pavements, Signs, and Traffic signals (Location, Identification and classification, Geometry, Material, Quantity, Condition (e.g., damages), Cost, Key dates (e.g., installation date, inspected date)) including new construction, reconstruction, rehabilitation, and preservation.	Unsure	Unsure	Yes (From construction data)	Unsure

No	State	Respond	Using Agile	Asset inventory data collection method			Construction Data Collection Method Using Mobile Apps	Some construction/maintenance data is leveraged for asset inventory?	Some data is collected at the point of installation?
				Field Data Collection Using Mobile Apps	Extraction from Construction Data	Data Extraction from Maintenance Work Orders			
13	Ohio	IK	Yes	Esri ArcGIS Collector by consultant or In-house construction engineer/In-house field maintenance staff for Pavement annually, mostly IRI, Rutting, Cracking, Faulting, Pavement Condition Rating, and other assets on a defined lifecycle or other frequency	Semi-automatic extraction from design plans using FME to convert asset data into GIS (SQL server)	Extract data from Digital forms available in a software application and Hard-copy paper forms using Agile Assets, and ODOT does not create inventory from work orders.	Agile Assets	Yes (From construction data using FME to convert asset data into GIS (SQL Server), and using Agile Assets on Digital form and Hard-copy forms Maintenance data.	Yes (Using ArcGIS Collector and Agile in construction)
14	Minnesota		Yes	Trimble by Consultant to collect location, Lidar for capturing traffic barriers and signs. AI is used to determine the size of the sign panels.	Extract data from the Oracle database. As-Built Specifications have been developed to capture data for assets by contractors, which are then imported to TAMS, including signals, lighting, IPS devices, signs, and traffic barriers. ASSHTOWare and CHIMES have been used to manage the construction data.	The asset inventory resides inside the application (AgileAssets). Assets are added to work orders for recording work and the costs of repairs.	Esri's Collector app, Portal, Surveys 123, and Work Manager have been used to capture data in the field and bring it into their system.	Yes (From As-built data in Excel tables obtained by surveyors and contractors, which are then imported into the Agile system)	Unsure
15	Nevada		Yes	Esri ArcGIS Survey123 by maintenance staff for pavement sections, shoulders, fencing, and lighting. Lidar is used to populate the asset inventory database. Contractors use special equipment and software to capture infrastructure assets.	Unsure	There is an option in EAMS to collect work orders on a mobile device. However, the data is then entered by supervisors rather than through mobile devices while in the field.	Esri ArcGIS Survey123, Lidar	Yes (From construction data)	Unsure

a. Ohio DOT Practices

Asset data inventory has not been managed in EAMS, but maintenance work orders have been recorded here and used for extracting data. Esri ArcGIS Collector is used to collect asset data at the point of installation during the construction stage. ODOT has not yet used "As Built" information from the construction documents. They mainly extract data from the design plans. They are currently evaluating this through their BIM initiative. ODOT has implemented an FME (Feature Manipulation Engine) process to extract asset data from plans. The current FME process runs automatically to extract asset data from Design plans but requires some manual review. They are currently evaluating this process to determine efficiency opportunities. For field data collection, the initial inventory records are created in the Collector / Field Maps systems, and then District staff perform field visits to complete the inventory and/or initial inspection.

b. NYSDOT Practices

For traditional D-B-B projects, this agency collects asset information with GPS survey equipment (GPS/total station/terrestrial LiDAR) and imports them into CADD software applications. For Design/Build projects that include the 3D/4D/5D BIM specs, the deliverables at project completion include a 3D As-built model along with a 3D GIS As-Built model. For the 3D GIS As-Built model, the spec states that ESRI Collector shall be used to collect thirty-four (34) attributes required by NYSDOT. For Maintenance projects, the ESRI collector is utilized by field staff.

NYSDOT is not using the Agile Assets mobile app for field data collection during the construction stage. It only uses EAMS as a database storing inventory asset data. 3D GIS As-Built model, ERSI collector data, or survey/CADD data are converted to a GIS format for inclusion in the Agile Assets database. The agency now has two specs, Subsurface Survey and Asset Collection, which require the contractor to collect the asset information/location (type, location, direction, etc.). Those specs have been implemented for construction projects this year. The Design-Builder shall collect major transportation asset classes that include:

- Bridges and bridge spans, including piers
- Abutments
- Pavement
- Overhead signs
- Noise barriers
- Lighting
- Retaining walls
- Guiderail and bridge rail
- Large and small culverts

Asset location and identification data will be recorded using the ESRI 'Field Maps' for ARCGIS's mobile application utilizing the NYSDOT GIS portal asset web application to collect the 34 attributes identified within the app. These new data collection methods are reported to be significantly better than re-collecting inventory data in terms of cost, time, and quality.

c. Idaho DOT Practices

The Idaho DOT extracts information from as-built plans manually, specifically regarding the location, geometry, material, and quantity of pavement assets. An employee in the office reviews the plans and inputs the relevant data into the Agile Assets system. This approach is somewhat more cost-effective and requires less effort compared to field recollection.

d. Oregon DOT Practices

Oregon DOT uses Bently Assetwise as a tool to manage asset inventory. Asset data is extracted manually from as-built plans and design plans that are stored in Filenet. However, this method results in slightly lower-quality data compared to field recollection.

e. Minnesota DOT Practices

MnDOT has adopted the Agile Assets software, called Transportation Asset Management System (TAMS), to store its asset inventory data. MnDOT's asset inventory data is stored in the AgileAssets application as tabular data. It has phased out the use of its old system and now relies entirely on the AgileAssets software to store its asset inventory data. The old system is still in use, but only for storing historical information. Keeping the old system enables them to access historical data that may not have been migrated to the new system or to perform comparative analyses between the old and new data.

Prioritizing Asset Attributes
Each asset has a different set of attributes, which are determined by the "business owners" of the asset class. Attributes include those necessary for the planning phase for future projects or replacements. When new asset classes are brought into the application, they sit with the "business" or the owner of the asset data to determine how they want to set up the data in the application: which fields, the format of the field, whether to utilize drop down values, etc. Tables 88, 89, 90 and 91 (Appendix 3) show sample data attributes of Traffic barriers, ITS devices, and Hydraulic pipes stored in the AgileAssets.

Asset Data Collection and Management
A consultant of MnDOT combines asset data collected using LiDAR with AgileAssets. The consultant has also developed an AI system that can extract information about pavement, such as the dimensions of pavement markings and longlines, as well as data about sign size from LiDAR technology. Additionally, MnDOT uses Agile Work Manager, an application that allows them to capture and add assets during their annual inspections and update the inventory if there are any changes in the condition of the assets. Maintenance staffs are responsible for updating the inventory after repairing or replacing assets like guardrails, signals, signs, and lighting. If assets are damaged, fail, or are replaced during maintenance operations, the records in EAMS are updated to ensure their accuracy.

MnDOT has created As-Built specifications for multiple assets, requiring contractors to collect data that MnDOT staff will later import into the Agile system. Currently, there are no construction inspectors involved in collecting data. The Asset Management Program Office is responsible for managing the application and providing support, with MNIT (Minnesota IT) employees managing the database, server, and system management. Besides, various apps, such as Esri's Collector app, Portal, and Surveys 123, are utilized to capture data in the field and integrate it into the system.

All asset inventory data in the existing systems are stored in the AgileAssets application and can be displayed in tabular and Oracle database formats. Once a "business" office or owner (e.g., maintenance office) has determined which data they want to incorporate into the Agile application, the office's staffs work with IT staff to convert and import the desired data from the existing system. However, there may be instances where only partial datasets can be imported. MnDOT manages construction data using two systems, ASSHTOWare and CHIMES. However, they are only in the initial stages of importing higher-level construction program plans for viewing into their application. Besides, they already use ASSHTOWare inside Agile for mapping purposes.

Asset Data Extraction from Maintenance Work Orders
The work orders in AgileAssets consist of two main sections, as shown in Figure 19. The first section at the top of the entry screen includes basic information about the performed work, such as the type of work, start and end dates, and other relevant details. The second section at the bottom of the window

permits the entry of more specific information, including the asset worked on, workers involved, equipment and materials utilized, and work location. The work order captures the work or repair history of the asset, and when repairs are completed, the asset inventory is updated accordingly, reflecting the improved condition of the asset.

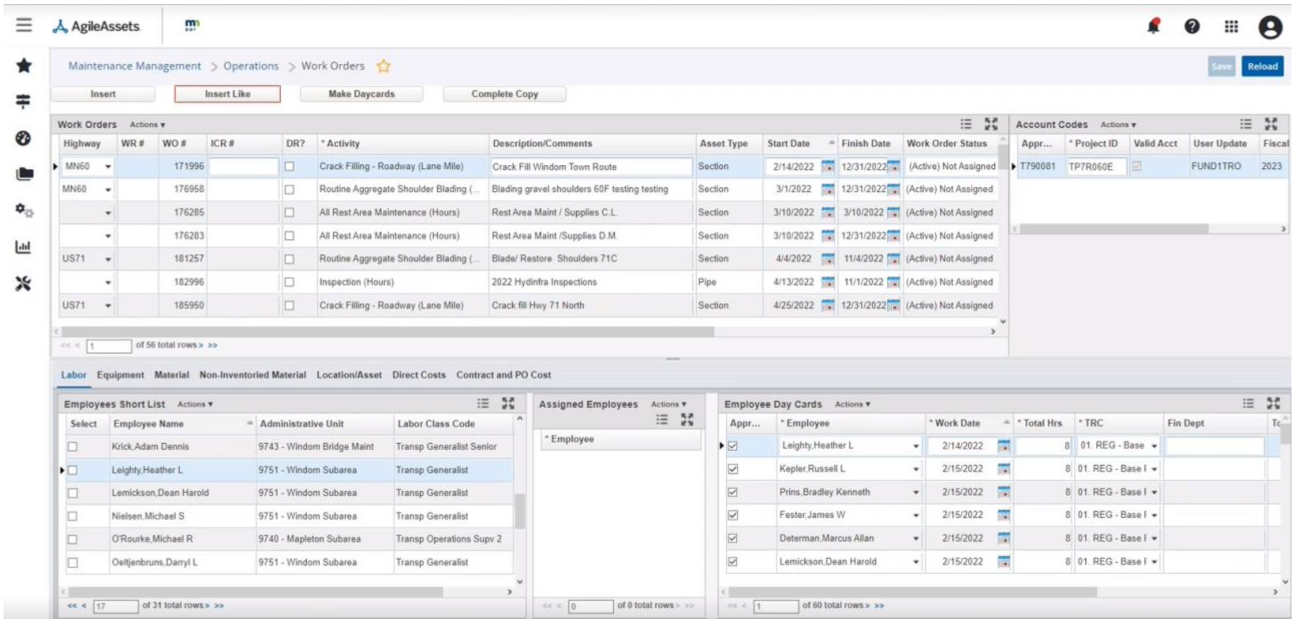


Figure 19. A sample of work orders in AgileAssets

f. Nevada DOT Practices

NDOT uses the Pavement Management System (PMS) module within the EAMS system to manage pavement, including condition assessment and forecasting. The old system, which is Oracle-based, is used for reporting to federal highways and interfacing with performance measures. Although enhancing the EAMS system is still maturing, the aim is to ensure it meets the minimum criteria for reporting to the National Highway System (NHS) and Highway Performance Monitoring System (HPMS).

Prioritizing Asset Attributes

The IT department of NDOT collaborates with other departments to prioritize asset groups and determine the approach for addressing them. The primary focus is on achieving operational efficiency for stormwater and bridge systems. The facilities module is on the agenda, but they have postponed its implementation for several years due to their higher decision-making authority.

Asset Data Collection and Management

Mobile data collection is available for maintenance staff to use with the asset management system. However, the majority of inventory data is collected through the ArcGIS Survey123 mobile application provided by Esri. The Survey123 app is primarily used by maintenance personnel who require up-to-date asset information. This data is then imported into the GIS, which will be later imported into the EAMS system, with occasional updates accomplished through manual uploads. Figure 20 shows the GIS data in the EAMS system.

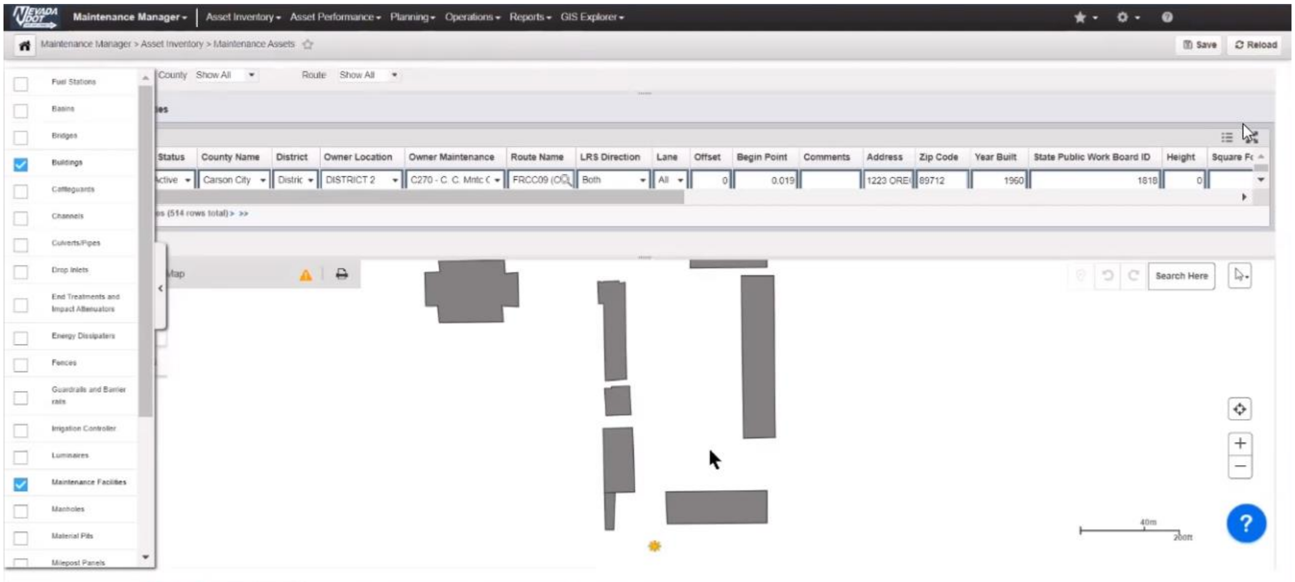


Figure 20. The user interface of EAMS

In a recent project involving collecting data using LiDAR technology to populate the asset inventory database, a contractor utilized specialized equipment and software to capture accurate and detailed information about the state's infrastructure assets. Once the LiDAR data was collected, it was processed and analyzed to create a comprehensive database of assets.

Regarding transferring asset data in the existing system, the data in the Oracle system has yet to be completely imported into the EAMS. They believe that the LRS (Linear Referencing System) is the modules' backbone. The division responsible for asset management depends on the type of asset. For example, the PMS is handled by the materials division, guardrails by the maintenance division, and bridges by the structures division. Each division works with Agile to transfer their data from existing tools to EAMS and is responsible for the asset management plan of their specific asset. EAMS can record geometry, location, and physical attributes, allowing users to see satellite imagery for the location by zooming in. However, editing this location is more complex compared to the location stored as Linear Referencing System (LRS) in GIS. Additionally, the pavement condition is recorded in PMS, but it is still within EAMS.

Asset Data Extraction from Maintenance Work Orders

The EAMS system allows capturing work orders on mobile devices, but data must be entered in the office rather than through mobile devices in the field. The work order created by the system contains information on the quantity, cost of labor, equipment, and materials, all associated with a specific date and location, as shown in Figure 21. Additionally, changes made to assets during repairs can be updated by providing feedback to maintenance personnel. For example, if a guardrail is extended during the repair, this information will be recorded in the work order. Afterward, work crews will discuss the change with maintenance staff, who will update the system manually. The process is not automated.

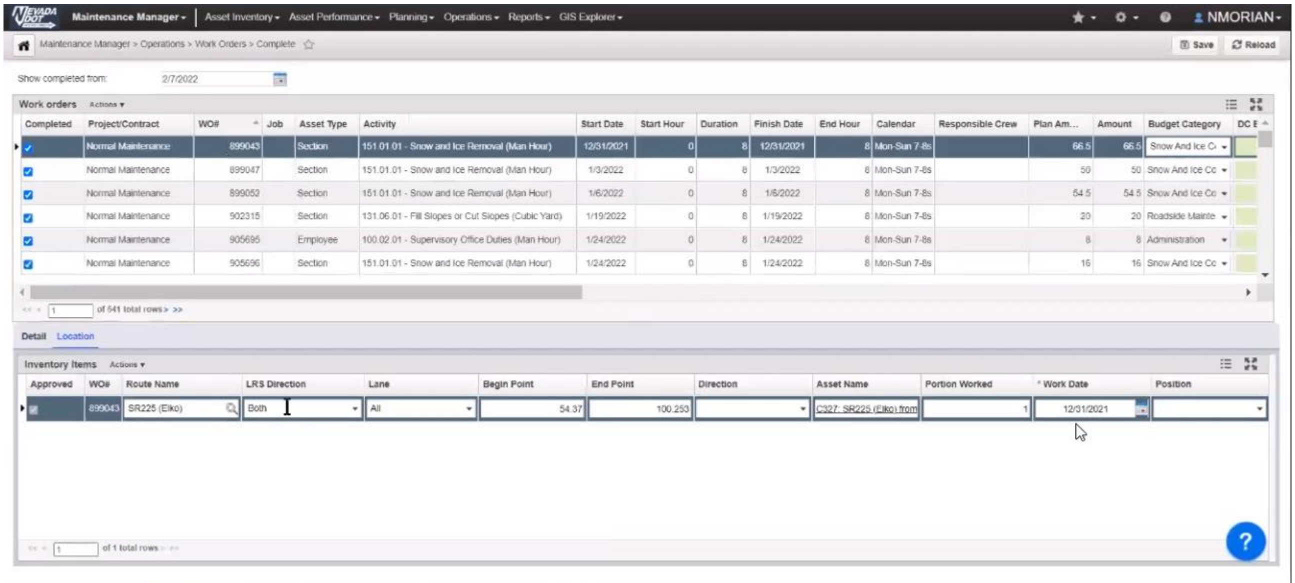


Figure 21. A sample of work orders in EAMS

3.2.5. Challenges of Leveraging Construction Data for Asset Inventory

There are several drawbacks of field asset inventory data collection during the construction stage of project delivery, noted by the participants, such as:

- Creating another additional task that field staff must perform on top of their standard inspection duties.
- Increasing the cost of traveling, periodic overnight, and vehicle maintenance.
- Changing organization.
- Non-performing in updating design plans of construction vendors.
- The cost of requiring As-built information needs to be clarified.

State highway agencies encounter various challenges when utilizing construction documents and maintenance work orders, which include:

- Uncertainty regarding the accuracy of as-built plans and the manual input of data into Agile Assets.
- A time-consuming process.
- Absence of standards to ensure consistent location and values of data.
- Conversion of CADD files to PDF, resulting in the inability to extract data directly.
- Data entry without standardization leading to questionable data quality and sometimes renders the data unusable.
- Difficulty in determining the referencing method in construction documents due to a recent change in RS means.
- Unreliable data due to the inconsistent completion of maintenance work order forms.
- The need to evaluate technology integration and data interchange issues with the current architecture and process.

3.2.6. Other On-Going Efforts and Future Directions

The collection and management of asset inventory data are exceedingly complex. Below are on-going efforts and plans for improving the practices in the surveyed agencies.

One of the strategies agencies are being piloted is to leverage digital project data. For instance, the agencies in Delaware are exploring upgrading their processes to create a more unified system that enhances asset management, digital as-built, and construction quality control. Meanwhile, Michigan DOT is developing statewide asset collection guides with a consistent data schema to ensure everyone collects the same asset data. Additionally, they aim to utilize current workflows with AASHTOWare digital measurement to collect asset information. Furthermore, they intend to capitalize on other workflows designers use to move asset information from the CAD to the GIS environment. The aim is to ensure that field staffs need only verify the location and input specific asset information rather than collect all the data in the field.

State agencies also consider utilizing innovative technologies to improve asset inventory data collection and management. For example, Delaware is looking to enhance access to the data captured by GPS Rovers for construction inspection and directly transfer the data to Esri. Meanwhile, INDOT seeks an automated method to use CAD data in construction for as-built asset data collection. NYSDOT is exploring options to extract data from contract as-built data, as some large Design Build projects require both a 3D As-Built and a 3D GIS As-Built as deliverables. MnDOT recommends using innovative remote sensing technologies such as Aerial or mobile LiDAR and imagery to generate a baseline of asset data. Maintenance crews can create work orders and update or add asset data directly on mobile hardware devices with user-friendly software. Additionally, WYDOT plans to use GPS modeling to integrate as-built data into Agile Assets. Finally, ODOT is beginning to collect mobile LiDAR and is considering utilizing it to create new inventories, such as pavement markings, and augmenting the inventories maintained by field staff with iPads (ESRI). They also explore the potential of crowd-sourced data from OEM (Original Equipment Manufacturer) vehicles as another data source.

Chapter 4: SCDOT's Current Data Collection Practices

4.1. Method

The research team obtained a list of contacts of SCDOT's personnel in the following offices: Data Services, Construction, Maintenance, and Bridge. Two focus group interviews with Data Services and Construction Offices were conducted, focusing on 1) the overall workflow of construction data collection/management; 2) project data collected during the construction stage of project delivery; 3) technologies, tools, and methods used for collecting construction project data; and 4) other sources of construction data beside field data collection. Additionally, a group interview was conducted with the Maintenance and Bridge departments to identify their current practices in collecting and managing asset data and the status of the transitioning to EAMS. Furthermore, the research team undertook an extensive review of documents shared by those offices, such as agency manuals, sample tabulations, construction inspection forms, specifications, and software applications to cross-validate the input provided by the experts.

4.2. Key Findings

4.2.1. SCDOT's Construction Data Management

a. Construction Data Collection and Management

The SCDOT Construction Department follows a well-defined workflow for collecting and managing construction data. The process begins with resident construction engineers receiving a set of plans. To facilitate efficient communication and collaboration, they contact the designer to obtain electronic copies of the plans. Any revisions or updates are then incorporated into the plans, and copies are provided to the contractor to ensure everyone is working with the latest information. During the construction stage, construction data is captured, updated, and stored in many systems. Some major data sources include design files, bid tabulations, daily work reports, and as-built plans.

Design files are an integral part of the construction process, providing essential information for planning, executing, and completing a project. Design files serve as a blueprint, capturing the vision of the project and guiding the construction process. They include surface design (LandXML surface model) and structure design (CADD files). Bid tabulations record the bids received, and they include information on project and work activities, which are helpful in the evaluation and selection of the contractor. SCDOT also maintains detailed daily work reports. These reports capture essential information such as payment, weather conditions, equipment used, and personnel involved in the construction activities. A snapshot of the daily work report in the AASHTOWare Project SiteManager is depicted in Figure 22. As construction projects progress, as-built plans are developed, documenting the final state of the project upon completion. Resident construction engineers carefully review and sign off on these plans, ensuring their accuracy and compliance with project specifications. Table 22 provides an overview of construction data and their major data sources.

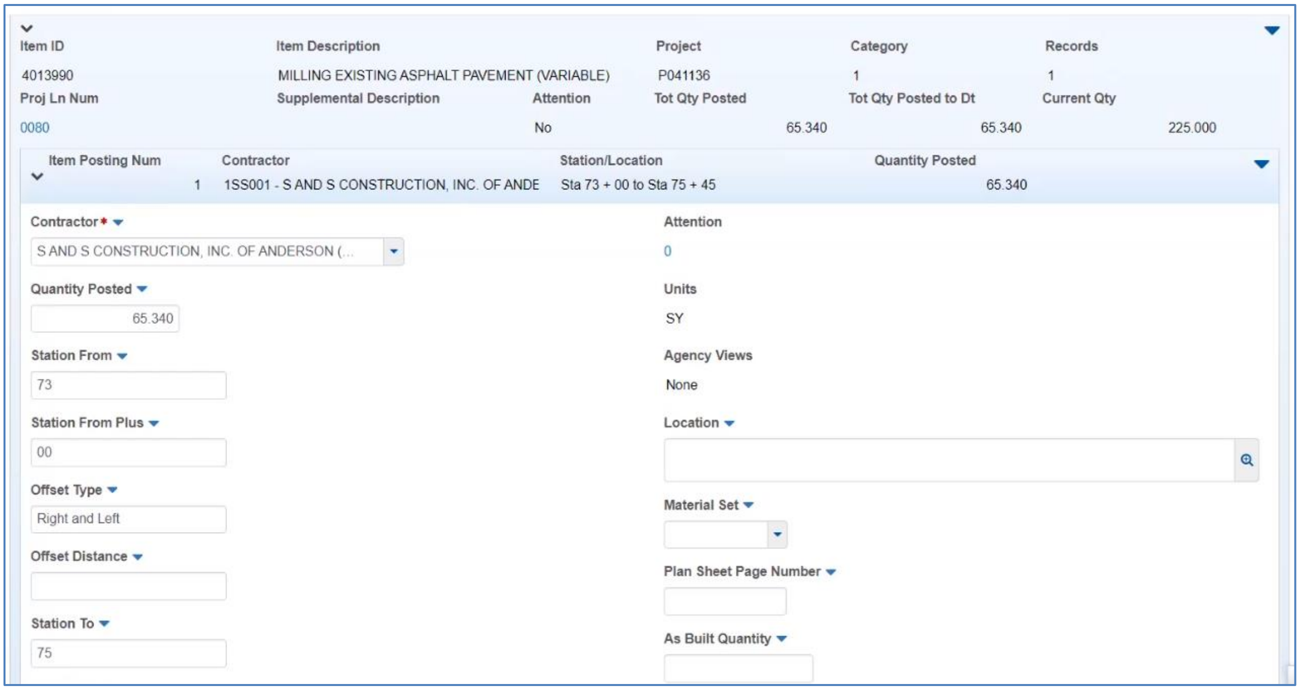


Figure 22. A snapshot of the daily work report in the AASHTOWare Project SiteManager

Table 22. Construction data and major data sources

No	Construction data	Data source			
		Design files	Bid tabulations	Daily work reports	As-built plans
1	Project identification	✓	✓	✓	✓
2	Location	✓	✓	✓	✓
3	Material	✓	✓	✓	✓
4	Geometry	✓			✓
5	Quantity		✓	✓	
6	Equipment			✓	
7	Cost		✓	✓	
8	Personnel			✓	
9	Weather			✓	
Total		4	5	8	4

Project identification, including project ID and contract ID, is a fundamental aspect of construction management. It enables efficient communication, facilitates project tracking and financial management, supports collaboration, and ensures compliance with legal and contractual obligations. That information has been defined at the beginning of a project and maintained in all construction documents and systems.

Location, as indicated in the table, emphasizes the significance of accurately documenting and tracking position within the overall project. Survey information is crucial in verifying the specific contractor's location installations beyond information of County and City. The electronic survey files are received from the designer and are utilized to create models for verification purposes. While some surveys are conducted electronically, others still rely on handwritten notes for verification. This survey data is carefully entered into AASHTOWare Project SiteManager for tracking, reporting, and analysis. At the moment, the SCDOT primarily relies on stations for location verification instead of GPS. By setting up designated stations and offsets, they can precisely determine distances from specific points and the project's centerline. This method provides a reliable means of verifying object locations, utilizing both simple and advanced surveying equipment.

In the above table, material indicates a construction data category, and it can be found from design files, bid tabulations, daily work reports, and as-built plans. Design files provide detailed specifications and drawings that outline the materials required for various components of the project. Bid tabulations capture the bids submitted by contractors, including their proposed materials and associated costs. Daily work reports document the activities performed on the construction site, including the materials used each day. These reports provide a record of the materials delivered, consumed, or stored on-site. As-built plans, which depict the final constructed state of the project, include information about the materials that were used.

Apart from major data sources shown in Table 22, many construction forms are used to manage and support construction progress, such as the Daily Report of Asphalt Roadway Inspection and Construction Completion & Acceptance Form. The classification of construction forms is based on groups of activities. As shown in Figure 23, construction forms are categorized into eight groups. Figure 24 shows a demonstration for construction forms under the "100 – Project Records" group.

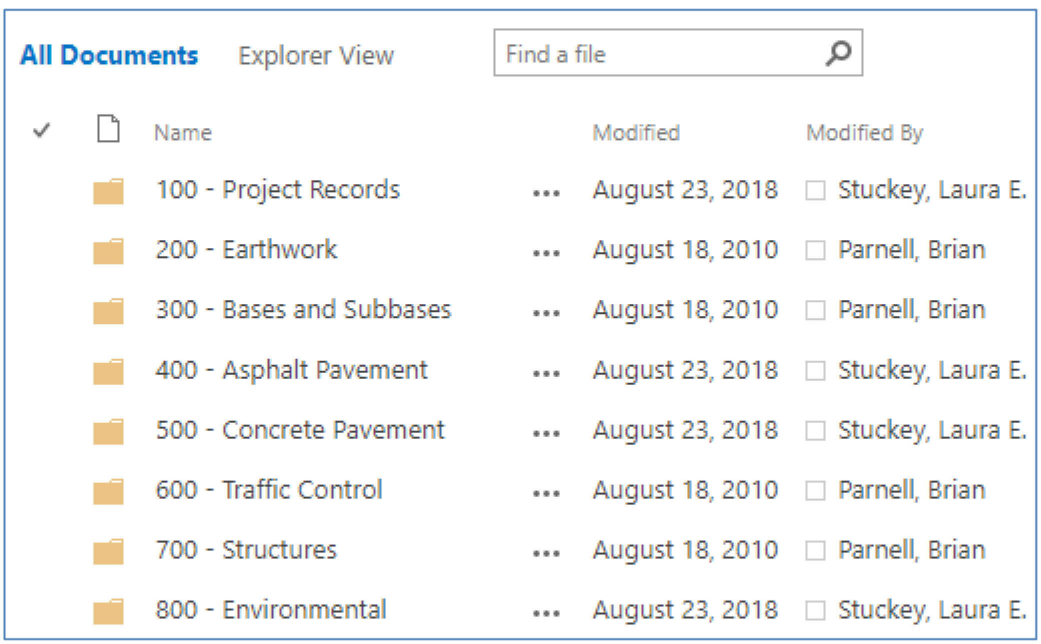


Figure 23. The classification of construction forms

✓		Name		Modified	Modified By
		100.01 PRECONSTRUCTION CHECKLIST	•••	July 19, 2022	Yuhas, Matthew J.
		100.02 PRELIMINARY LETTER OF CERTIFICATION	•••	July 19, 2022	Yuhas, Matthew J.
		100.03 CONSTRUCTION PROJECT COMPLETION AND ACCEPTANCE FORM	•••	March 14	Yuhas, Matthew J.
		100.04 CONTRACTOR NOTICE OF CLAIM	•••	July 19, 2022	Yuhas, Matthew J.
		100.04A CERTIFICATE OF CLAIM	•••	July 19, 2022	Yuhas, Matthew J.
		100.05 CONTRACTOR CONCURRENCE FORM	•••	November 9, 2022	Yuhas, Matthew J.
		100.06 DISTRIBUTION OF PAYMENT	•••	July 19, 2022	Yuhas, Matthew J.
		100.07 WAGE REGULATION REPORT	•••	July 19, 2022	Yuhas, Matthew J.
		100.08 NUCLEAR GAUGE MONTHLY REPORT	•••	July 19, 2022	Yuhas, Matthew J.
		100.09 REPORT OF DISPOSITION OF MATERIAL FAILING TO MEET SPECIFICATIONS	•••	July 19, 2022	Yuhas, Matthew J.
		100.10 MATERIAL CERTIFICATION LOG	•••	July 19, 2022	Yuhas, Matthew J.
		100.11 MATERIAL SAMPLING AND TESTING LOG	•••	September 6, 2022	Yuhas, Matthew J.
		100.12 UTILITY AGREEMENT	•••	July 19, 2022	Yuhas, Matthew J.
		100.13 UTILITY FIELD DAILY DIARY	•••	July 19, 2022	Yuhas, Matthew J.
		100.13A RESIDENT ENGINEER and INSPECTOR'S DIARY	•••	July 19, 2022	Yuhas, Matthew J.
		100.14 SLOPE PERMISSION	•••	July 19, 2022	Yuhas, Matthew J.
		100.15 CONTRACTOR'S EROSION CONTROL PLAN	•••	July 19, 2022	Yuhas, Matthew J.
		100.20 FINAL ESTIMATE PACKAGE LIST	•••	July 19, 2022	Yuhas, Matthew J.
		100.24 FINAL INSPECTION ACCEPTANCE REPORT-RR	•••	July 19, 2022	Yuhas, Matthew J.
		100.25 REPORT OF ACCEPTANCE OF SMALL QUANTITY OF MATERIALS	•••	July 19, 2022	Yuhas, Matthew J.
		100.26 DBE COMMERCIALLY USEFUL FUNCTION (CUF) REVIEW - Print Only	•••	February 16	Yuhas, Matthew J.
		100.26 DBE COMMERCIALLY USEFUL FUNCTION (CUF) REVIEW	•••	February 16	Yuhas, Matthew J.
		NORFOLK SOUTHERN CONTRACTOR RIGHT OF ENTRY AGREEMENT	•••	July 19, 2022	Yuhas, Matthew J.

Figure 24. Construction forms of the Project records group

b. Tools and Technologies

The SCDOT relies on a range of tools and technologies to support daily operations and data management processes. One main tool utilized by the department is tablets, which enable personnel to access digital copies of PDF files. This technology empowers them to efficiently determine the precise location and dimensions of various project elements, enhancing their overall project understanding. Additionally, SCDOT is using various platforms to manage construction data. Table 23 highlights four main platforms used in construction projects. These applications aid in documenting and organizing crucial construction information such as daily work reports, as-built plans, design files, bid tabulations, and construction forms. By utilizing these platforms, SCDOT personnel can enhance data management, streamline collaboration, improve documentation accuracy, and ensure that essential construction data is easily accessible when needed.

AASHTOWare Project SiteManager, along with ProjectWise and other applications are used for managing and organizing project data. AASHTOWare Project SiteManager provides are to record and track daily construction activities, including progress updates, materials used, equipment utilized, and labor hours. It is also a solution that plays a pivotal role in managing and documenting changes in contract quantities. This powerful tool allows for seamless updating of contract quantities once change orders are approved, ensuring accurate and up-to-date information throughout the project lifecycle. ProjectWise is a software application primarily used for document management and collaboration in construction projects. It allows teams to store, organize, and share project-related documents, including construction forms.

SCDOT Intranet/Extranet refers to an internal or external network provided by the SCDOT. This network offers platforms for managing construction data. Specifically, it serves as a source for numerous construction documents, including design files, bid tabulations, and construction forms.

After resident construction engineers carefully review and sign off on as-built plans to ensure their accuracy and compliance with project specifications, those plans are scanned and stored in the SCDOT Plans Online Library, a dedicated system for archiving and retrieving project-related documents. This central repository allows for easy access and reference in the future.

Table 23. Platforms used for managing construction data

No	**Platforms used for managing construction data**	**Construction data source**				
		Design files	**Bid tabulations**	**Daily work reports**	**As-built plans**	**Construction forms**
1	AASTOWare Project SiteManager			✓		
2	ProjectWise					✓
3	SCDOT Intranet/Extranet	✓	✓			✓
4	SCDOT Plans Online Library				✓	

c. Challenges and Limitations

While a mobile inspector phone application is available, it is not extensively utilized by the department at present. Although tablets and phones have the potential to streamline data entry in the field, the majority of personnel still enter data in the office. The use of mobile devices for field data entry is not widespread, and SCDOT is still exploring the extent to which individuals actively utilize this capability.

While GPS technology offers the potential for precise location data, its use is currently limited due to factors such as availability and personnel constraints. Not everyone in the department possesses the necessary expertise to operate GPS units effectively, which can impact the overall accuracy of the collected data. While the department currently encounters limitations with GPS technology, they remain open to exploring its potential benefits and addressing the challenges associated with its implementation. They understand that advancements in GPS technology, along with adequate training and availability, could significantly enhance the accuracy and efficiency of their data collection and verification processes.

SCDOT currently utilizes AASHTOWare Project SiteManager for contract management; however, there has been limited usage due to restrictions on remote access. The connection to AASHTOWare Project SiteManager outside the office is only permitted through a virtual private network (VPN), which has created challenges in its practical use. The SCDOT Construction Department is committed to improving practices by embracing technology and exploring ways to enhance efficiency and accuracy. They continue to evaluate the use of mobile devices for field data entry and are actively seeking solutions to overcome limitations in remote access to AASHTOWare Project SiteManager.

4.2.2. SCDOT's Asset Inventory Data Management

a. Asset Data Collection and Management

SCDOT encompasses several specialized departments, all working cohesively to achieve the state's missions. These departments within SCDOT collaborate closely with each other and with other government agencies, local communities, and private partners to achieve a comprehensive and integrated approach to transportation planning, development, and management.

The Road Data Services department is responsible for managing various types of assets and their associated data. The office uses different platforms and tools to collect, maintain, and update asset data repositories. By utilizing advanced technologies and information systems, SCDOT gathers valuable insights that aid in informed decision-making regarding infrastructure planning, maintenance, and upgrades. The data enables SCDOT to optimize routes, improve traffic flow, and enhance overall transportation efficiency.

The Bridge and Maintenance departments have been split into different departments. The Maintenance Office was identified as the owner of the current Highway Maintenance Management System (HMMS), which is used to capture a significant amount of data related to work orders and requests. The Maintenance Office is in the process of transitioning to the use of the Agile asset management system, where they will begin building inventories of highly prioritized assets. The Maintenance department plays a vital role in preserving and improving South Carolina's transportation infrastructure on a day-to-day basis. This department is responsible for routine maintenance tasks, including roadway repairs, pothole patching, signage installation, and landscaping along highways. By promptly addressing maintenance needs and proactively identifying potential issues, the Maintenance department ensures the continued smooth operation of the transportation system, promoting safety and convenience for all road users.

The Bridge department focuses specifically on bridges throughout the state. Their expertise lies in assessing structural integrity, conducting inspections, and implementing necessary repairs or replacements to ensure the safety and longevity of bridge infrastructure. By staying up-to-date with engineering advancements and best practices, the Bridge department aims to enhance bridge safety, reliability, and functionality. The Bridge Office has a more comprehensive approach to managing bridges as assets, with each bridge having a unique ID and a set of federally required data points collected. Bridge data is primarily viewable and collected in HMMS (work ticket), ITMS, and RIMS. SCDOT is also using AASHTOWare™ Bridge Management (BRM) for inspections but not fully until Fall 2023. By 2024, they will likely be using BRM's asset management capability.

The SCDOT manages various types of assets and their data. These assets include roads and bridges, as well as other assets such as signs, traffic signals, culverts, and guardrails. Table 24 provides insights into various data types across different asset types. The values in the table indicate the total count of data types associated with each asset type. The highest count is seen for the Bridge asset type with 11 data types, implying a robust data collection and management approach for bridges. On the other hand, the Traffic signal asset type has the lowest count with only 3 data types, suggesting a narrower focus on specific aspects of traffic signal management. The absence of data types such as Cost, Load, and Traffic for most asset types indicates that these specific data aspects might not be extensively captured or prioritized within the current data management system. It is worth noting that the absence of a data type does not necessarily imply its insignificance or lack of relevance in asset management.

Table 24. Asset types and their data types

No	Data type	Asset type					
		Highway	Bridge	Signs	Culverts	Guardrails	Traffic signal
1	Classification	✓	✓	✓	✓	✓	
2	Cost		✓				
3	Geometry	✓	✓	✓	✓	✓	
4	Identification	✓	✓	✓	✓	✓	✓
5	Inspection	✓	✓	✓	✓	✓	
6	Key date	✓	✓	✓	✓		✓
7	Load		✓		✓		
8	Location	✓	✓	✓	✓	✓	✓
9	Material	✓	✓	✓	✓	✓	
10	Quantity	✓	✓	✓		✓	
11	Traffic	✓	✓				
Total		9	11	8	8	7	3

Asset data collection within SCDOT involves a combination of in-house staff and contracted vendors. The specific methods employed for data collection vary depending on the nature of the asset being captured. The sources of data collected can be design files, as-built plans, pdf reports, or imagery. The pavement management group goes out and collects the imagery on a two-year cycle for all of the public roads that are maintained.

The asset data at SCDOT are updated through a combination of manual input and automated imports. Depending on the specific asset type and its associated requirements, updates can be performed on a varying frequency. Certain assets may necessitate frequent updates, such as daily or weekly, to reflect any changes or modifications accurately. Other assets may undergo less frequent updates, typically on an annual basis, to capture any substantial changes or developments over time. This systematic approach to updating the asset data repositories guarantees the accuracy and currency of the information, enabling SCDOT to make informed decisions based on the most up-to-date data available.

b. Tools and Technologies

SCDOT employs a diverse range of platforms to effectively manage asset data, while each platform serves a specific purpose in facilitating the storage, organization, and analysis of asset data. Table 25 provides the information on the platforms used for managing asset data, along with the corresponding asset types. For highway assets, a total of eight platforms are utilized, indicating a comprehensive approach to their management. Bridge assets are also well-covered, with seven dedicated platforms. However, the management of signs, culverts, guardrails, and traffic signals seems to be less diverse, with only one or two platforms for each category. It may be worth considering further platform implementation or integration to ensure efficient and comprehensive management across all asset types. Additionally, software tools like ProjectWise and MicroStation are utilized for efficient document management, ensuring seamless access and retrieval of crucial project information. The use of ProjectWise stands out as it encompasses all asset types, highlighting its significance as a comprehensive asset data source.

Table 25. Platforms used for managing asset data

No	Platforms used for managing asset data	Asset type					
		Highway	Bridge	Signs	Culverts	Guardrails	Traffic signal
1	AASHTOWare™ Bridge Management (BRM)		✓				
2	Dedicated Roads	✓					
3	Geographic Information System (GIS)	✓	✓				
4	Highway Maintenance Management System (HMMS)	✓	✓	✓	✓	✓	
5	Inventory Manager	✓					
6	Integrated Transportation Management System (ITMS)		✓				✓
7	MicroStation	✓					
8	Performance Viewer	✓	✓				
9	ProjectWise	✓	✓	✓	✓	✓	✓
10	Roadway Information Management System (RIMS)	✓	✓				
Total		8	7	2	2	2	2

c. The transition from HMMS to Agile Asset

Current Highway Maintenance Management System (HMMS)

The current HMMS is owned by the maintenance office. Through work orders and work requests, HMMS gathers a considerable amount of data. While the system aids in budget forecasting, its primary function is not as an asset management tool. Despite its limitations, HMMS has proven valuable for the maintenance office in documenting their activities and managing their budget. Data within HMMS are primarily stored in two main modules: the Daily Work Report (refer to Figure 25) and the Work Request (refer to Figure 26). Table 26 provides an overview of the data available in HMMS, categorized into seven groups: identification, location, geometry, key date, classification, quantity, and cost.

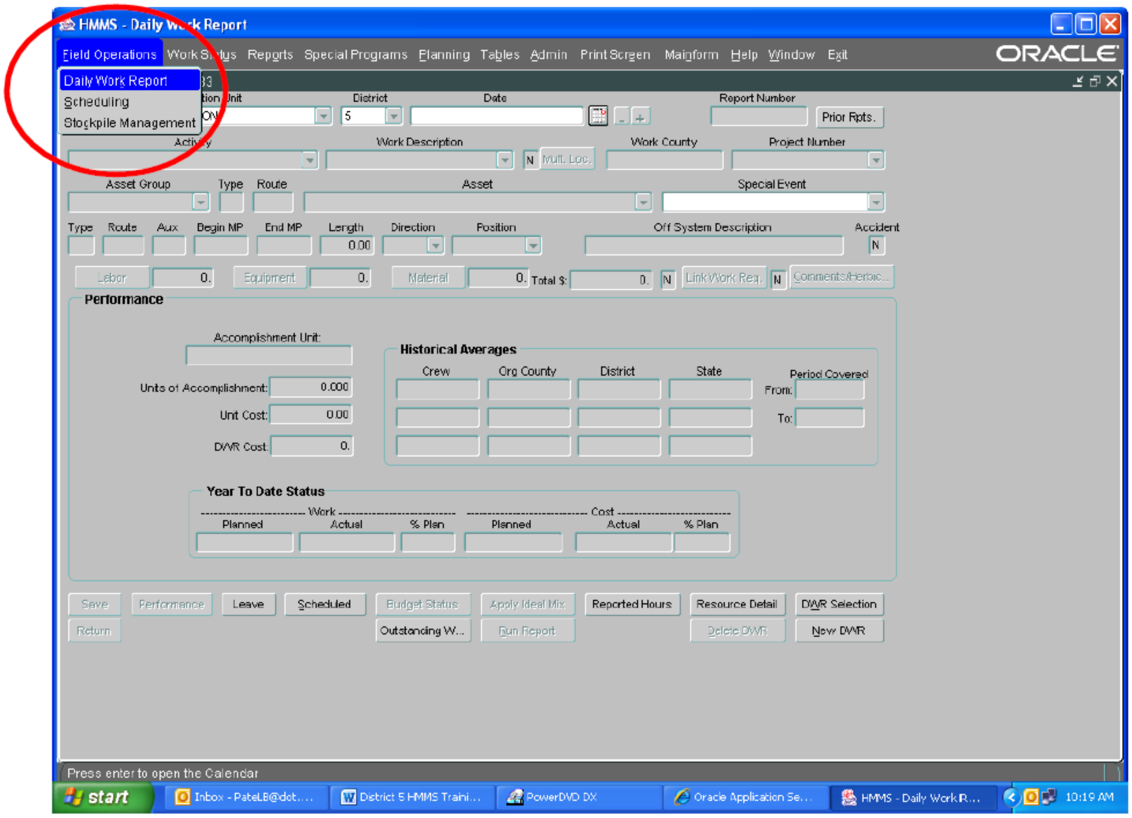


Figure 25. HMMS Daily Work Report

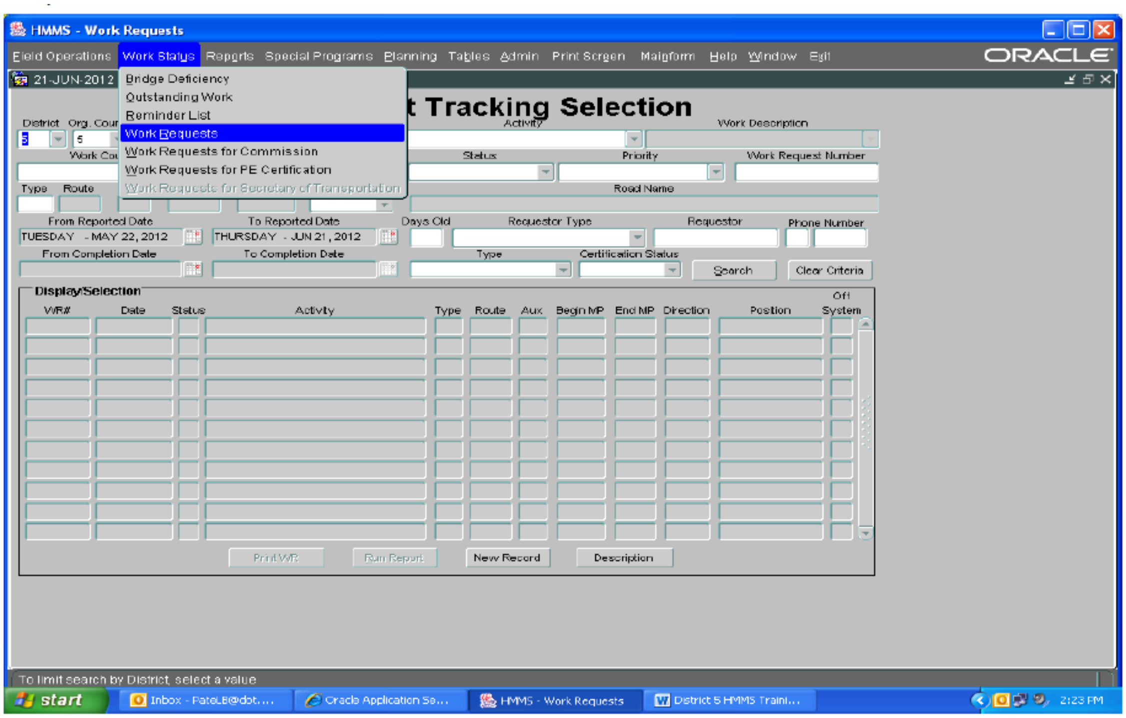


Figure 26. HMMS Work Request

Table 26. Data available in HMMS

No	Data attribute	Data type	Unit	Data format
1	County	Identification	N/A	Text (e.g., Darlington)
2	Project Number	Identification	N/A	Numeric (e.g., 416)
3	Route	Location	N/A	Numeric (e.g., 41)
4	Begin mile point	Location	N/A	Numeric (e.g., 3.85)
5	End mile point	Location	N/A	Numeric (e.g., 5.75)
6	District	Location	N/A	Numeric (e.g., 5)
7	Direction	Location	N/A	Text (e.g., E)
8	Position	Location	N/A	Text (e.g., Roadway)
9	Length	Geometry	Mile	Numeric (e.g., 1.900)
10	Date	Key date	N/A	Date/Time (e.g., Monday - Jun 18, 2012)
11	Activity	Classification	N/A	Text (e.g., 800 - Bridge Construction)
12	Quantity	Quantity	TONS	Numeric (e.g., 100)
13	Material cost	Cost	$	Numeric (e.g., 295)
14	Total cost	Cost	$	Currency (e.g., 198)
15	Hour	Cost	$	Numeric (e.g., 10)
16	Labor cost	Cost	$	Numeric (e.g., 831)
17	Equipment cost	Cost	$	Numeric (e.g., 441)

The transition to Agile Asset System

SCDOT is in the process of transitioning to the EAMS system to optimize the use of its current asset data. The introduction of Agile Asset has brought a substantial transformation for SCDOT. The shift from HMMS to Agile Asset signifies a departure from the traditional approach to data-driven asset management within the maintenance office of the department.

Agile Asset is an enterprise asset management system that provides a comprehensive solution for the management of physical assets. The system is designed to support the management of the complete lifecycle of assets, including planning, design, construction, operations, maintenance, and replacement. Agile Asset offers several benefits over the current HMMS system. Firstly, Agile Asset offers robust data management capabilities, allowing the maintenance office to capture and store critical data about its assets. This data can be used to support decision-making and asset management processes, as well as to track asset performance over time. Another key benefit of Agile Asset is the support for digital work orders. The system enables the maintenance office to capture and manage work requests electronically, streamlining the process and reducing the risk of errors or lost information. Additionally, Agile Asset offers support for asset tracking, which is essential for ensuring that assets are properly maintained and performing optimally.

The maintenance department intends to initiate a pilot program involving the ten most critical assets, associated with 54 maintenance tasks categorized with codes ranging from 102 to 991. An Excel file was created using Microsoft Office to illustrate the correlation between these assets and activities (illustrated in Table 27). As shown in Figure 27, road sections and bridges are the most important assets for the SCDOT since they have been involved in almost all maintenance activities. By contrast, sign face and sign assembly together occupy the smallest number of maintenance activities.

Table 27. EAMS Work Activities by Asset Type

ACTIVITIES	ASSET TYPES						
	ATTENUATORS (ATN)	...	GUARDRAIL (GRD)	ROAD SECTIONS (ROUTE-BMP-EMP)	TERMINALS (GRT)	SIGN ASSEMBLY (SGA)	SIGN FACE (SGF)
102 - LEVELING/STRENGTHENING		...		x			
103 - POTHOLE PATCHING		...		x			
107 - CHIP SEAL		...		x			
108 - MILLING		...		x			
110 - BASE REPAIR		...		x			
111 - RECLAMATION		...		x			
120 - CRACK SEAL PAVEMENT		...		x			
130 - MACHINE EARTH ROADS		...		x			
202 - SLOPES	x	...	x	x	x		
203 - SHOULDERS/DITCHES	x	...	x	x	x		
305 - DRAINAGE STRUCTURES		...		x			
306 - DRAINAGE PIPE		...		x			
400 - ROAD MAINTENANCE	x	...	x	x	x	x	x
401 - MOWING	x	...	x	x	x	x	x
402 - HERBICIDE APPLICATION	x	...	x	x	x	x	x
405 - LIMB MANAGEMENT		...		x			
407 - LITTER CONTROL	x	...	x	x	x	x	x
408 - TREE REMOVAL	x	...	x	x	x		
409 - SPEC EVENT DEBRIS REMOVAL	x	...	x		x		
410 - ROADWAY CLEANING		...		x			
501 - DRIVEWAYS		...		x			
504 - CONCRETE STRUCTURES		...		x			
603 - SIGNS	x	...	x	x	x	x	x
604 - TRAFFIC SIGNAL		...		x			
605 - FLASHERS		...		x			
606 - PAVEMENT MARKING		...		x			
607 - HAND PLACE MARKINGS		...		x			
610 - GUARDRAIL	x	...	x	x	x		
611 - WALLS/FENCE		...		x			
613 - IMPACT ATTENUATORS/TERMIN	x	...	x	x	x		
614 - HIGHWAY LIGHTING		...		x			
701 - HAZARDOUS CONDITIONS	x	...	x		x	x	x
800 - BRIDGE CONSTRUCTION	x	...	x	x	x		
801 - DECK REPAIR		...		x			
802 - BRIDGE RAIL REPAIR	x	...	x	x	x		
803 - SUPERSTRUCTURE ELEMENT		...		x			
805 - BRIDGE EXPANSION JOINTS		...		x			
806 - BRIDGE BEARING ASSEMBLIES		...		x			
807 - BRIDGE MAINTENANCE	x	...	x	x	x	x	x
809 - BRIDGE PILES AND CAPS		...		x			
815 - BRIDGE INSPECTION		...		x			
901 - TRAINING		...					

902 - ENVIRONMENTAL/SAFETY MANA		...					
903 - BUILDING AND GROUNDS		...		x			
904 - PERMIT MANAGEMENT		...					
906 - TRAFFIC CONTROL		...					
907 - ADMINISTRATION		...					
908 - INSPECTIONS	x	...	x		x	x	x
909 - CONTRACT INSPECTIONS	x	...	x		x	x	x
910 - EQUIPMENT MANAGEMENT		...		x			
920 - STOCKPILE MANAGEMENT		...		x			
960 - RADIO MAINTENANCE		...		x			
970 - EQUIPMENT REPAIR		...		x			
991 - EQUIPMENT ADMINISTRATIVE		...		x			
TOTAL ACTIVITIES	**17**	...	**17**	**45**	**17**	**9**	**9**

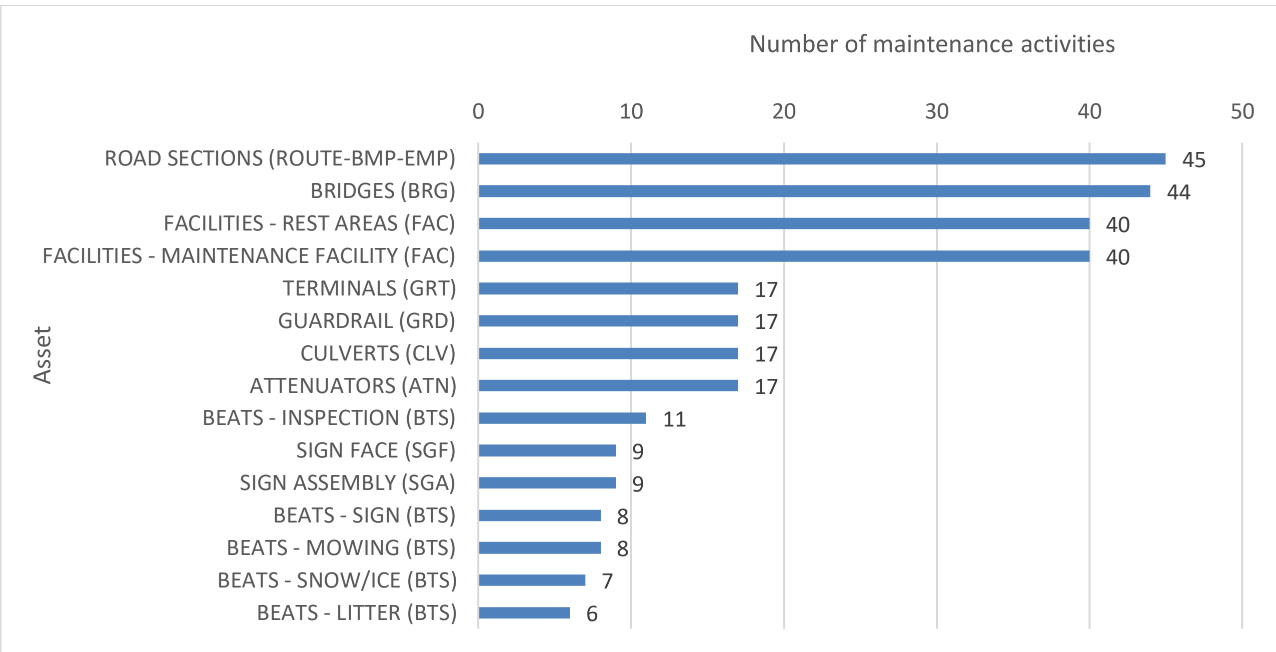


Figure 27. Number of maintenance activities of the 10 most important assets used for the Agile assets

A description of the 54 maintenance activities was documented by the maintenance office to support the transition to EAMS. An example of a maintenance activity description is shown in Table 28. The initial column indicates the code of activity, followed by the name of the activity in the second column. The third column describes the work performed. Besides, instructions about using descriptions and business rules are provided.

Table 28. Maintenance Activity Description Example

Act.	Activity Description	Work Description	Unit of Measure	When is this Work Description Used?	Business Rule	Revisions
107	Chip Seal	Single	**Square Yards**	This work includes an application of one layer of polymer modified asphalt emulsion followed by one layer of lightweight aggregate. Refer to the standard specifications for material specs and application rates.	This activity includes the maintenance of a wearing surface composed of one or more layers of an application of a polymer modified cationic emulsion (CRS-2P) and an application of aggregate, constructed on an existing road surface. This is an item that is reported to the Commission by the Secretary of Transportation under SC Code of Law (Section 57-1-460). The accomplishment quantity should be recorded in square yards (SY) and should be the measure of the area of roadway treated, not the sum of the number of passes necessary to accomplish the work. Work performed to prepare the roadway for the chip seal operation should be recorded under the appropriate activity. (i.e. pulling shoulders would be recorded as Activity 203). The daily production is based on the application of a single treatment.	07/01/2019
		Double		This work includes an application of one layer of polymer modified asphalt emulsion followed by one layer of aggregate followed by a second layer of polymer modified asphalt emulsion followed by a second layer of aggregate. Refer to the standard specifications for application rates and aggregate options.		
		Triple		This work includes an application of one layer of polymer modified asphalt emulsion followed by one layer of aggregate, then a second layer of polymer modified asphalt emulsion followed by a second layer of aggregate, then a third layer of polymer modified asphalt emulsion followed by a third layer aggregate. Refer to the standard specifications for application rates and aggregate options.		
110	Base Repair	Full Depth Asphalt	**Square Yards**	This work includes the repair of asphalt or bituminous surfaced road.	This activity includes the repair of base or sub-grade failures with suitable material to include the paved surface. Work performed under this activity includes the replacement of the permanent riding surface. The unit of accomplishment should only be counted on the last Daily Work Report when all work is completed.	07/01/2019
		Full Depth Concrete	**Square Yards**	This work includes the repair of concrete surfaced road.		

With the assistance of Agile Assets, all information of assets can be stored systematically; then, the maintenance activities will be performed smoothly. The use of complete and current asset inventory data can help reduce various risks, including:

- Cost risks: Having clear and detailed information about the project budget and resources can help reduce the risk of cost overruns.
- Schedule risks: Having a well-defined project timeline and schedule can help reduce the risk of delays.
- Technical risks: Having a thorough understanding of the project requirements and technology can help reduce the risk of technical failures.
- Stakeholder risks: Early engagement with stakeholders can help reduce the risk of misunderstandings or changes in their expectations.
- Resource risks: Early identification of resource needs can help reduce the risk of unavailability of critical resources.

As shown earlier, having this information early on in a project may help the maintenance and construction offices proactively manage and mitigate these risks, leading to a higher likelihood of project success. Overall, the transition to Agile Asset represents a positive change for SCDOT. The new system offers several benefits over the current HMMS system and will provide the maintenance office with the tools they need to better manage and maintain the assets of the department.

d. Challenges and Limitations

In the current practice, the maintenance department does not utilize a data-driven asset management program in determining what needs to be done to improve infrastructure conditions. They simply get work done from work requests. They have some high levels of inventories on assets from the statewide level, but they use that mainly for budget allocation rather than asset management.

HMMS captures a significant amount of data through work orders and work requests; however, it is not a comprehensive data inventory system. HMMS primarily serves as a means for the maintenance office to document and receive payment for their work, including documenting the time, equipment, and materials used in repairs and other tasks. The maintenance department is currently in an early stage of asset management, primarily reacting to work requests and inspections, but with the new Agile system, they hope to become more proactive in planning maintenance work.

The transition to Agile Asset also presents some challenges. The agency will need to work closely with the vendor and relevant business offices to identify and collect relevant data attributes for each asset for the new system. This will require a significant effort, specifically for reviewing existing data sources and gathering information from other departments within SCDOT. The transition will also require a change in processes and workflows to ones suitable to the new system. The personnel would need to be trained in order to take full advantage of the new capabilities.

Chapter 5: Asset Data Needs Identification and Data Mapping Matrix Development

5.1. Method

The interviews with SCDOT staff revealed that the agency has yet to adopt a data-centric asset management system, resulting in a lack of formal documentation regarding asset data requirements. To address the research objective of identifying these needs, the research team dedicated additional effort to reviewing numerous technical documents on asset management. Table 29 offers a comprehensive summary of the diverse documents utilized to identify asset data needs. These documents serve as valuable references for comprehending the specific requirements and standards related to various types of assets:

- Bridges
  - SCDOT Bridge Inspection Guidance: This document outlines the guidelines and protocols for inspecting bridges, providing crucial information about their structural condition and maintenance needs.
  - Specifications for the FHWA National Bridge Inventory: This set of specifications pertains to the national inventory of bridges, offering standardized criteria for their assessment and categorization.
  - SCDOT Data Services Data Dictionary: This reference likely contains a comprehensive list of data attributes and their definitions specific to bridges within the SCDOT's data services.
- Culverts
  - FHWA Culvert Inspection Manual: This manual offers detailed instructions and guidelines for the inspection of culverts, ensuring their structural integrity and functionality.
  - SCDOT Culvert Inspection Guide: Specific to SCDOT, this guide provides additional insights into culvert inspection practices tailored to the agency's needs.
- Guardrails
  - SCDOT Guardrail, Cable Barrier, and Crash Attenuator Inspection and Repair Guidelines: This document outlines the guidelines for inspecting and maintaining guardrails, cable barriers, and crash attenuators, ensuring their effectiveness in enhancing road safety.
- Highways
  - Highway Performance Monitoring System (HPMS): This system is a national database that collects data on various aspects of highway performance, enabling the assessment and management of the highway network's condition and performance.
  - SCDOT Data Services Data Dictionary: This likely contains specific data attributes related to highways within the SCDOT's data services.
- Signs
  - FHWA Guidelines for the Installation, Inspection, Maintenance, and Repair of Structural

Supports for Highway Signs, Luminaires, and Traffic Signals: This set of guidelines covers the installation, inspection, maintenance, and repair of structural supports for various highway signage and traffic signals.

- Highway Maintenance Management System (HMMS): This system likely contains data related to maintenance activities, including those related to signs.

➢ Traffic Signals

- SCDOT Road Data Service Data Dictionary: This reference is likely a repository of data attributes specific to traffic signals within the SCDOT's road data services.

Table 29. Documents for asset data needs identification

No	Asset	References
1	Bridges	- SCDOT Bridge Inspection Guidance - Specifications for the FHWA National Bridge Inventory - SCDOT Data Services Data Dictionary
2	Culverts	- FHWA Culvert Inspection Manual - SCDOT Culvert Inspection Guide
3	Guardrails	- SCDOT Guardrail, Cable Barrier, and Crash Attenuator Inspection and Repair Guidelines
4	Highways	- Highway Performance Monitoring System (HPMS). - SCDOT Data Services Data Dictionary
5	Signs	- FHWA Guidelines for the Installation, Inspection, Maintenance and Repair of Structural Supports for Highway Signs, Luminaires, and Traffic Signals. - Highway Maintenance Management System (HMMS)
6	Traffic signals	- SCDOT Road Data Service Data Dictionary
7	Hydraulic pipe, Barriers and ITS devices	MnDOT’s EAMS data dictionary

Furthermore, the research team examined multiple construction documents utilized by the SCDOT to identify those containing asset data, listed as follows:

- Bid Tabulation: the bid tabulation document typically contains detailed information about the bids submitted by different contractors. From this document, data related to quantity and cost estimates, location, and project scope can be extracted.
- As-Built Plans: as-built plans provide a record of the final constructed project. They offer critical data on the actual layout, dimensions, and specifications of the completed assets, allowing for accurate documentation of the project's final state.
- Daily Work Report: daily work reports capture day-to-day activities on the construction site. They can yield information on labor hours, equipment usage, materials used, and progress achieved, providing valuable insights into project implementation.
- Preconstruction Checklist: this checklist outlines the necessary steps and requirements before construction commences. It may contain data regarding permits, inspections, safety measures, and other preconstruction considerations.
- Construction Project Completion and Acceptance Form: this form signifies the completion of the construction project. It often includes critical data on the final acceptance status, compliance with specifications, and any outstanding work or issues to be addressed.
- Resident Engineer and Inspector's Diary: the diary is a record of daily observations and activities made by the resident engineer and inspector. It can contain notes on inspections, quality control measures, and any deviations from the original plans.
- Contractor Concurrence Form: this form is used to obtain the contractor's agreement or consent on specific project matters. It may contain data related to changes in project scope, materials, or methodologies.
- Concrete Pour Inspector's Checklist: this checklist is used during concrete pouring activities to ensure compliance with specifications. It can provide data on concrete mixtures, curing methods, and quality control measures.
- Daily Report of Asphalt Roadway Inspection: this report documents inspections of asphalt roadway construction. It may include data on asphalt quality, compaction levels, and adherence to specifications.
- Posting Advice: a posting advice document may contain information about updates, notices, or changes related to the construction project. It could include data on revisions to project plans or schedules.
- Master Contract Document Tracker: this tracker is used to monitor and manage various contract-related documents. It can provide data on document statuses, revisions, and approvals throughout the project.
- Project Proposal: the project proposal outlines the initial plan, scope, and objectives of the construction project. It may contain data on project goals, timelines, and budget estimates.
- CAD/LandXML Design Files: computer-aided design (CAD) and LandXML files serve as the digital blueprints for the project. They contain detailed data on the design specifications, dimensions, and layout of the assets to be constructed.

5.2. Key Findings

5.2.1. Data Matrix

A data mapping spreadsheet was developed, including over 600 instances for six asset types: bridge, culvert, guardrail, highway, sign, and traffic signal. In this document, the research team also incorporated the results of required asset data recommended for Hydraulic pipes, Barriers, and ITS devices by MnDOT. The mapping matrix for each asset includes 11 main fields: data attribute, description, reference, data type, currently stored in digital repositories/document management systems, available in construction documents/construction field inspection/maintenance work orders, method to transfer existing asset data to EAMS, method to transfer data in maintenance work orders to EAMS, effort level to transfer construction data to EAMS, level of effort for transferring existing digital data to EAMS, level of effort for transferring data in maintenance work orders to EAMS. Figures 28 and 29 illustrate an example for the data matrix for bridge.

Data attribute	Description	Refercence	Data type	Currently stored in digital repositories	Currently stored in document management systems	Available in construction documents
Asset ID	NBI: **Bridge ID**. Record the unique bridge number assigned according to agency policy for each bridge. **NBI item ID: B.ID.01** SCDOT Dictionary: **Bridge Asset ID** SCDOT Inspection: **Bridge ID**	SCDOT Guidelines National Bridge Inventory (NBI) SCDOT Data Dictionary	Identification	Roadway Information Management System (RIMS) Performance Viewer GISTRANS	ProjectWise Other PDF documents	As-built Plans
Asset Name	NBI: **Bridge Name** Record the commonly known name(s) for the bridge. For more than one name, record all names with the most common name first. **NBI item ID: B.ID.02**	National Bridge Inventory (NBI)	Identification	#N/A	ProjectWise Other PDF documents	Daily Work Report As-built Plans
Previous Bridge Number	NBI: **Previous Bridge Number**. Report the bridge number previously associated with the bridge that has been replaced by the inventoried bridge, or when the inventoried bridge number has changed. **NBI item ID: B.ID.03**	National Bridge Inventory (NBI)	Identification	#N/A	ProjectWise Other PDF documents	#N/A
County Code	NBI: **County Code**. Record the Federal Information Processing Series (FIPS) code for the county, parish or borough in which the bridge is located. **NBI item ID: B.L.02** SCDOT Dictionary: **FIPS County Code**	National Bridge Inventory (NBI) SCDOT Data Dictionary	Location	Roadway Information Management System (RIMS) Performance Viewer GISTRANS	ProjectWise Other PDF documents	#N/A
Border Bridge Number	NBI: **Border Bridge Number**. Report the neighboring State's exact bridge number as used in their Item B.ID.01 (Bridge Number). For the purposes of the NBI, only bridges that cross a State or international border are considered border bridges. **NBI Item ID B.L.07** SCDOT Dictionary: **Border Bridge Structure Number**	National Bridge Inventory (NBI) SCDOT Data Dictionary	Location	Roadway Information Management System (RIMS) Performance Viewer	ProjectWise Other PDF documents	#N/A
Border Bridge State or Country Code	NBI: **Border Bridge State or Country Code.** Report the neighboring State code using the codes listed in Item B.L.01 (State Code). Use this item to indicate bridges crossing borders of States or countries. **NBI Item ID B.L.08**	National Bridge Inventory (NBI) SCDOT Data Dictionary	Location	Roadway Information Management System (RIMS) Performance Viewer	ProjectWise Other PDF documents	#N/A
Border Bridge Inspection Responsibility	NBI: **Border Bridge Inspection Responsibility**. Report the border bridge inspection responsibility for any entity within the State geographical boundaries, regardless of ownership, using one of the following codes. **NBI Item ID B.L.09** Code 0 No responsibility 1 Shared responsibility with bordering State or country 2 Full responsibility	National Bridge Inventory (NBI)	Location	#N/A	ProjectWise Other PDF documents	#N/A

Figure 28. Snapshot of data matrix for bridge

Available in construction field inspection	Available in maintenance work orders	Method to transfer construction data to EAMS	Method to transfer existing asset data to EAMS	Method to transfer data in maintenance work orders to EAMS	Level of effort for transferring construction data to EAMS (1-Low,2-Medium, 3-High)	Level of effort for transferring existing digital data to EAMS (1-Low,2-Medium, 3-High)	Level of effort for transferring data in maintenance work orders to EAMS (1-Low,2-Medium, 3-High)
#N/A	#N/A	Manual extraction	Automated extraction	#N/A	High	Medium	#N/A
#N/A	#N/A	Automated extraction	Manual extraction	#N/A	Low	#N/A	#N/A
#N/A	#N/A	#N/A	Manual extraction	#N/A	#N/A	#N/A	#N/A
#N/A	#N/A	#N/A	Automated extraction	#N/A	#N/A	Medium	#N/A
#N/A	#N/A	#N/A	Automated extraction	#N/A	#N/A	Medium	#N/A
#N/A	#N/A	#N/A	Automated extraction	#N/A	#N/A	Medium	#N/A
#N/A	#N/A	#N/A	Manual extraction	#N/A	#N/A	#N/A	#N/A

Figure 29. Snapshot of data matrix for bridge (continued)

5.2.2. Asset Inventory Data Needs

Figure 30 outlines the data attributes necessary for each asset type. Bridges and highways have the highest data requirements, with 218 and 203 attributes, respectively. Culverts and hydraulic pipes, crucial for water flow beneath roadways, also have significant data requirements, with 72 and 70 attributes, respectively. Traffic devices like signs, traffic signals, and barriers necessitate 41, 41, and 43 data attributes, respectively. ITS devices have a relatively lower number of required data attributes at 39. Guardrails require the fewest data attributes, with a count of 22.

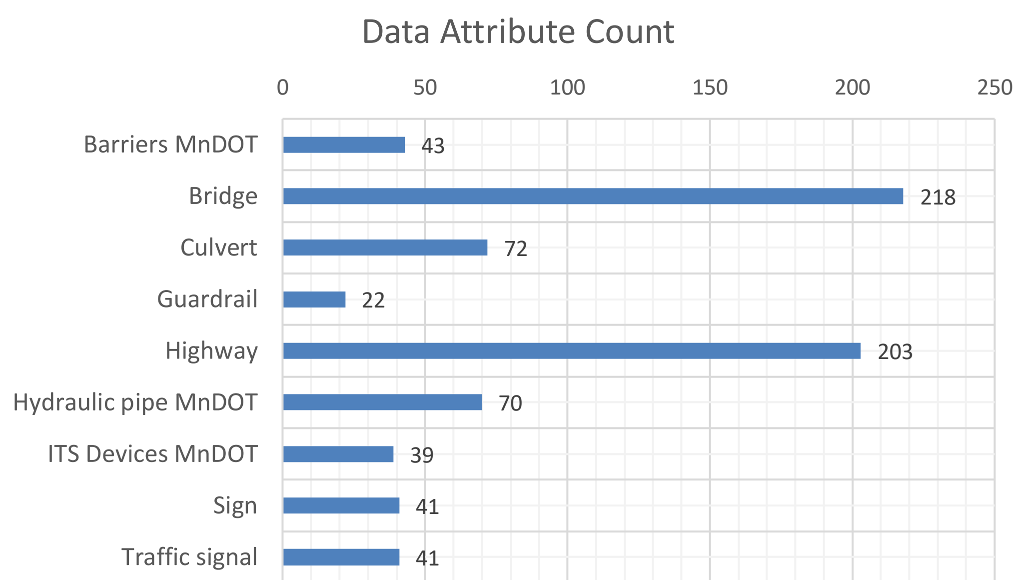


Figure 30. Required data attribute count

Figure 31 offers a comprehensive breakdown of data attribute counts, organized according to different asset data management guidelines. The SCDOT Data Dictionary holds significant importance, outlining data requirements for various assets such as traffic signals, highways, and bridges, which constitute a substantial portion of the dataset. Federal manuals provide additional sets of necessary attributes. For instance, the HPMS dictates many data requirements for highways, while the NBI serves as a primary source for bridge-related data. Other FHWA guidelines also contribute significantly to the required asset inventory attributes, particularly for signs and culverts. Lastly, attributes for ITS devices, hydraulic pipes, and barriers were exclusively adopted from the MnDOT data dictionary.

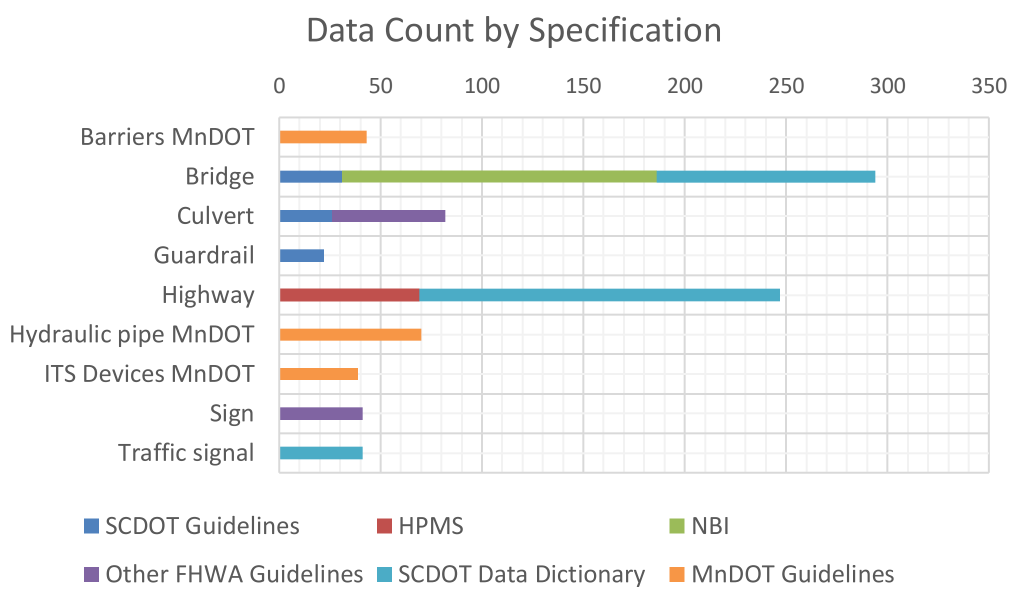


Figure 31. Required data attribute count by specification

Figure 32 provides a thorough breakdown of data attributes categorized by data type for various assets. As depicted in the figure, the primary focus of required data involves geometry and location. Load data holds particular significance for bridges, highways, and hydraulic pipes. The necessity for identification data appears to be less prominent for most asset types, except for traffic signals.

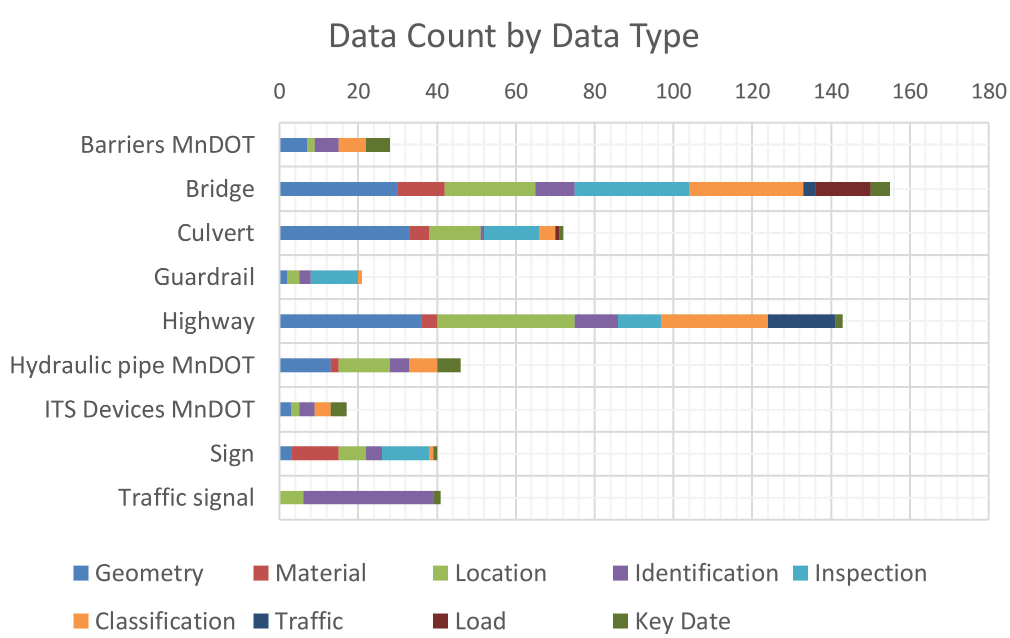


Figure 32. Required data attribute count by data type

Figure 33 and Table 30 provides a comparison of the data attribute counts available in SCDOT's current data repositories. It is noteworthy that none of the existing systems contain the required data for culverts, guardrails, and signs. This indicates that substantial effort will be needed to acquire the necessary data for these assets. On the other hand, systems like RIMS, Performance Viewer, and P2S serve as primary sources of the required data for bridges and highways. This presents a significant opportunity to utilize existing data to benefit the new EAMS system. Leveraging these existing sources can streamline the transition process and enhance the effectiveness of the new system with minimized data collection cost.

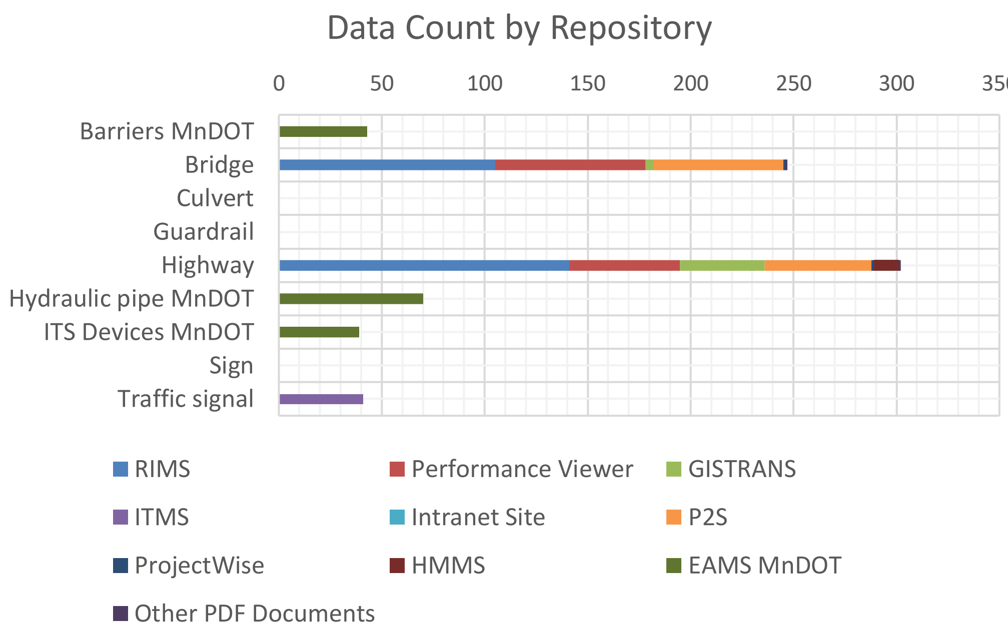


Figure 33. Required data attribute count by repository

Table 30. Existing repositories of required asset inventory data

No	Platforms used for managing asset data	Asset type					
		Highway	Bridge	Signs	Culverts	Guardrails	Traffic signal
1	AASHTOWare™ Bridge Management (BRM)		✓				
2	Dedicated Roads	✓					
3	Geographic Information System (GIS)	✓	✓				
4	Highway Maintenance Management System (HMMS)	✓	✓		✓	✓	
5	Inventory Manager	✓					
6	Integrated Transportation Management System (ITMS)		✓				✓
7	MicroStation	✓					
8	Performance Viewer	✓	✓				

9	ProjectWise	✓	✓	✓	✓	✓	✓
10	Roadway Information Management System (RIMS)	✓	✓				
Total		8	7	1	2	2	2

Table 31 outlines the classification of crucial data attributes relevant to various types of transportation assets. These attributes are grouped into categories including Classification, Cost, Geometry, Identification, Inspection, Key date, Load, Location, Material, Quantity, and Traffic. Notably, identification and location emerge as dominant attributes, as they are obligatory for all asset types, spanning highways, bridges, signs, culverts, guardrails, traffic signals, hydraulic pipes, barriers, and ITS devices. Conversely, attributes like cost, load, quantity, and traffic are specific to certain asset types. Cost and load data are primarily associated with bridges, while quantity data applies to highways and guardrails. Traffic data is typically pertinent to both highways and bridges.

Table 31. Data Attributes by Asset Type

No	Data type	Asset type								
		Highway	**Bridge**	**Signs**	**Culverts**	**Guardrails**	**Traffic signal**	**Hydraulic pipe**	**Barriers**	**ITS Devices**
1	Classification	✓	✓	✓	✓	✓		✓	✓	✓
2	Cost		✓							
3	Geometry	✓	✓	✓	✓	✓		✓	✓	✓
4	Identification	✓	✓	✓	✓	✓	✓	✓	✓	✓
5	Inspection	✓	✓	✓	✓	✓				
6	Key date	✓	✓	✓	✓		✓	✓	✓	✓
7	Load		✓		✓					
8	Location	✓	✓	✓	✓	✓	✓	✓	✓	✓
9	Material	✓	✓	✓	✓	✓		✓		
10	Quantity	✓	✓	✓		✓				
11	Traffic	✓	✓							
Total		9	11	8	8	7	3	6	5	5

Regarding the availability of necessary asset data in construction documents, the results are synthesized in Table 32. This table specifically compares the number of asset data attributes obtainable from various construction documents, including Design Files, Bid Tabulations, Daily Work Reports, As-built Plans, Construction Forms, and Maintenance Work Orders. Notably, identification, location, and material attributes are consistently present in all six types of data sources. Geometry data predominantly originates from Design Files and As-built Plans, while quantity data is primarily documented in Bid Tabulations and Maintenance Work Orders. Equipment and cost attributes are notably prevalent in Daily Work Reports.

Table 32. Construction Data Sources for Asset Attributes

No	Asset data type	Data source					
		Design files	Bid tabulations	Daily work reports	As-built plans	Construction forms	Maintenance work order
1	Identification	✓	✓	✓	✓	✓	✓
2	Location	✓	✓	✓	✓	✓	✓
3	Material	✓	✓	✓	✓	✓	✓
4	Geometry	✓			✓	✓	
5	Quantity		✓	✓			✓
6	Equipment			✓		✓	
7	Cost		✓	✓			✓
Total		4	5	6	4	5	5

Figure 34 offers additional insights into the variance between required and accessible data attributes. Among the 749 required attributes, only 378 are found across multiple existing repositories. Notably, traffic signals, hydraulic pipes, highways, bridges, and culverts demonstrate a significant presence in these repositories. Conversely, signs, ITS devices, guardrails, and barriers lack required data stored in existing repositories. This suggests a potential need for enhancement in terms of archiving and preserving data related to these specific assets.

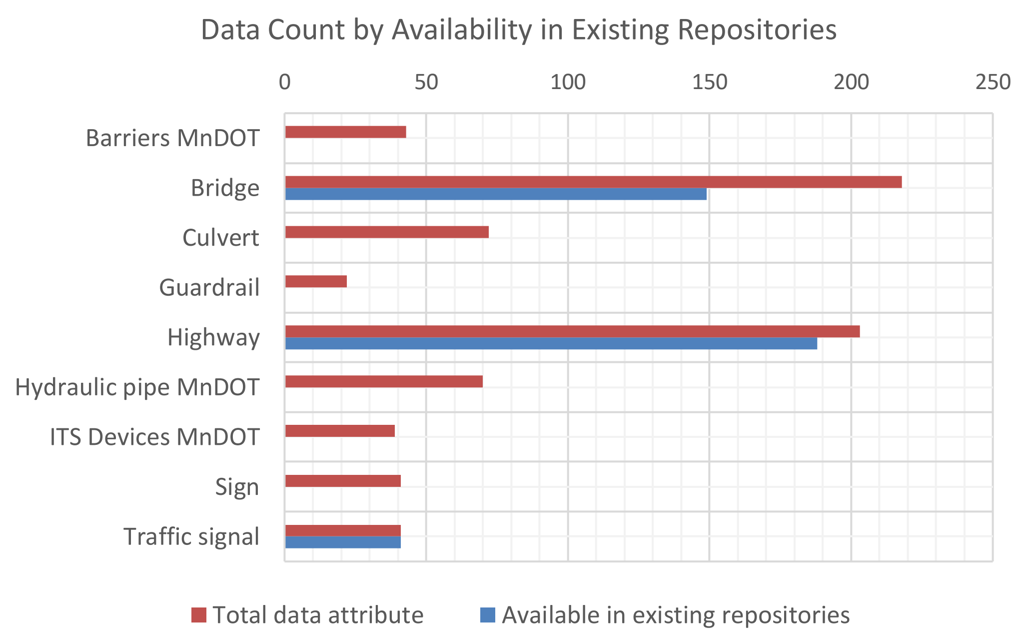


Figure 34. Required data attribute count by availability

5.2.3. Mapping Asset Data Needs and Construction Data Sources

The developed data attribute spreadsheet includes additional fields assessing the feasibility for mapping an asset data attribute to construction data sources, as listed below.

1. Available in Construction Documents/Construction Field Inspection/Maintenance Work Orders: this specifies whether a data attribute is available in a certain construction source.
2. Method to transfer construction data to EAMS: This describes how the data should be transferred from construction sources to the EAMS, as shown in Table 33.

Table 33. Method to transfer construction data to EAMS

Construction data source	Method to transfer construction data to EAMS	Notes
Daily Work Report (AASTOWare Project SiteManager)	Automated extraction	Data can be automatically transferred to EAMS
GPS, GIS	Semi-automated extraction	Data can be automatically transferred to EAMS but still needs human involvement in processing or transformation
Construction document PDF files	Manual extraction	Data is extracted from pdf files and input to EAMS manually

3. Method to transfer existing asset data to EAMS: This describes how the data can be transferred from current repositories to the EAMS, as shown in Table 34.

Table 34. Method to transfer existing asset data to EAMS

Asset data repository	Method to transfer existing asset data to EAMS	Notes
Digital repositories (Roadway Information Management System (RIMS), Highway Maintenance Management System (HMMS), Performance Viewer, GISTRANS, Project Programming System (P2S), Integrated Transportation Management System (ITMS)	Automated extraction	Data can be automatically transferred to EAMS
GPS, GIS	Semi-automated extraction	Data can be automatically transferred to EAMS but still needs human involvement in processing or transformation
Document management systems (ProjectWise, MS SharePoint etc.)	Manual extraction	Data is extracted and input to EAMS manually

4. Method to transfer data in maintenance work order to EAMS: This describes how the data in maintenance can be transferred to the EAMS, as shown in Table 35.

Table 35. Method to transfer data in maintenance work order to EAMS

Asset data source	Method to transfer data in maintenance work orders to EAMS	Notes
Digital repositories (Highway Maintenance Management System (HMMS))	Automated extraction	Data can be automatically transferred to EAMS
None	Semi-automated extraction	Data can be automatically transferred to EAMS but still needs human involvement in processing or transformation
Document management systems (ProjectWise, MS SharePoint etc.)	Manual extraction	Data is extracted and input to EAMS manually

5. Level of effort for transferring construction data to EAMS: This rates the effort required for transferring construction data to EAMS, as shown in Table 36.

Table 36. Level of effort for transferring construction data to EAMS

Construction data source	Level of effort for transferring construction data to EAMS	Justification
Daily Work Report (AASTOWare Project SiteManager)	Low	EAMS can use construction data directly after additional mapping
GPS, GIS	Medium	EAMS can use construction data after additional processing and converting
Construction document PDF files	High	EAMS can use construction data after manual input

6. Level of effort for transferring existing digital data to EAMS: This rates the effort required for transferring existing digital data to EAMS, as shown in Table 37.

Table 37. Level of effort for transferring existing digital data to EAMS

Digital data repository	Level of effort for transferring existing digital data to EAMS	Justification
None	Low	EAMS can use existing digital data directly
Roadway Information Management System (RIMS), Highway Maintenance Management System (HMMS), Performance Viewer, GISTRANS, Project Programming System (P2S), Integrated Transportation Management System (ITMS)	Medium	EAMS can use existing digital data after additional mapping
GPS, GIS	High	EAMS can use existing digital data after additional processing and converting

7. Level of effort for transferring data in maintenance work orders to EAMS: This rates the effort required for transferring data in maintenance work orders to EAMS, as shown in Table 38.

Table 38. Level of effort for transferring data in maintenance work orders to EAMS

Maintenance work order source	Level of effort for transferring data in maintenance work orders to EAMS	Justification
Digital repositories (Highway Maintenance Management System (HMMS))	Low	EAMS can use data after additional mapping
None	Medium	EAMS can use data after additional processing and converting
Document management systems (ProjectWise, MS SharePoint etc.)	High	EAMS can use data after manual input

Figure 35 contrasts the number of essential data attributes with those accessible from construction documents. It shows that only a minor portion of the necessary data can be derived from these documents and maintenance work orders. Notably, the retrievable attributes are associated with traffic signals, signs, ITS devices, hydraulic pipes, highways, guardrails, culverts, bridges, and barriers. This underscores a noteworthy opportunity for leveraging construction data for these specific assets.

In terms of construction data repositories, the SCDOT Intranet/Extranet emerges as a principal source (refer to Table 39), encompassing Design Files, Bid Tabulations, and Construction Forms. Conversely, AASHTOWare Project SiteManager primarily facilitates access to Daily Work Reports data. ProjectWise is primarily dedicated to Construction Forms. Finally, HMMS primarily handles Maintenance Work Orders, highlighting its pivotal role in managing construction-related maintenance activities.

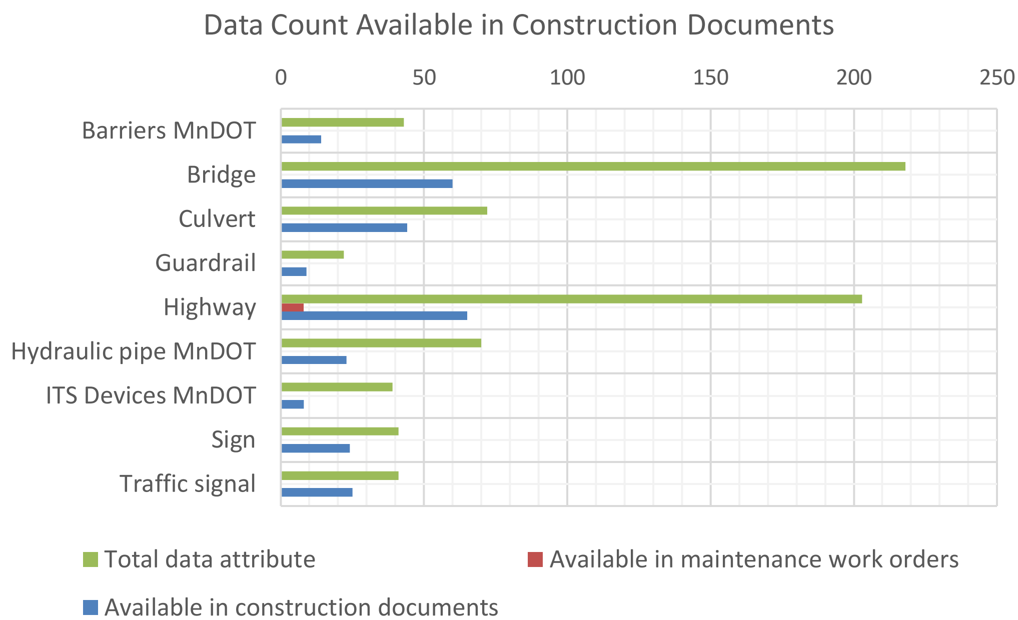


Figure 35. Required data attribute count by source

Table 39. Construction Data Sources by Platform

No	Platforms	Construction data source					
		Design files	Bid tabulations	Daily work reports	As-built plans	Construction forms	Maintenance WO
1	AASHTOWare Project SiteManager			✓			
2	ProjectWise					✓	
3	SCDOT Intranet/Extranet	✓	✓			✓	
4	SCDOT Plans Online Library				✓		
5	Highway Maintenance Management System (HMMS)						✓

5.3. Challenges in Extracting Asset Data from Construction Documents

One of the main hurdles encountered in asset data collection during the construction phase is the prevalent use of unstructured formats, particularly PDFs, for archiving construction data. This poses significant challenges in efficiently extracting and utilizing data. Hence, there arises a need for alternative data collection methodologies capable of capturing a broader spectrum of relevant information in construction documents. Moreover, Location Reference Systems (LRS) have traditionally, served as the primary method for tracking asset locations in construction projects, with latitude and longitude data often taking a secondary role. However, GPS coordinates are frequently deemed unnecessary for the majority of construction engineering tasks. Furthermore, it's common for many pay items to not require location information, despite its inclusion in Daily Work Reports (DWR).

Another notable challenge stems from the fact that only a fraction of asset data can be directly extracted from construction records. Additionally, in the current practices of SCDOT, the utilization of mobile devices for on-site data collection has been surprisingly underused. This limitation impedes the agency's ability to collect data in real-time, which is crucial for accurate decision-making and project management. Furthermore, no formal documentation developed for the SCDOT outlining prioritized assets and the specific data types. In essence, the lack of knowledge regarding what types of data need to be inventoried and how they are utilized further compounds the challenges associated with asset data collection during the construction phase. Addressing these issues will be crucial in establishing a robust and effective asset data collection framework. Effort is required by business offices to verify the identified asset inventory data attributes found in this study and identify highly prioritized ones for the new enterprise asset data management system.

Chapter 6: Asset Data Extraction from Construction Documents

6.1. Method

This chapter outlines the creation of a data translator designed to facilitate the extraction of asset data items from pay items recorded in DWRs accessible through AASHTOWare Project FieldManager and SiteManager. To achieve this, we employed a developed data mapping spreadsheet, which delineates the mapping of data between various systems used in construction and asset management. The primary challenges encountered in this process stemmed from interoperability issues between construction management and asset management systems, primarily due to disparities in data representation. Another key challenge arose from the fact that a single instance of a pay item in DWRs is typically associated with multiple assets for work progress tracking purposes, whereas asset management systems treat each asset or segment of an asset (such as a pavement segment) as an individual data record.

To tackle the issue of data interoperability, we devised several reasoning rules, including keyword matching, to deduce the corresponding asset data from construction records. Utilizing FME, a widely recognized data integration platform, we created the data translator. The data entities, relations, and reasoning rules outlined in the data mapping model were meticulously designed to accurately capture the connection between pay items and asset data items. It's important to note that only essential asset data was retrieved from construction pay items. FME was chosen due to its robust software solution renowned for its capabilities in data integration and transformation. It revolutionizes the transfer, translation, and transformation of data across diverse formats such as PDF, XML, and Excel. For instance, simplifying the conversion of location data from GIS-based to LRS-based format or vice versa is crucial, and FME streamlines this process through a user-friendly graphical interface, eliminating the need for extensive coding.

The process of developing a data translator involves several essential stages:

1. The Inputs Stage: This encompasses understanding data requirements, including source and target formats. Following this, a workspace is created within the FME Workbench, providing a graphical interface for defining the workflow and connecting data sources. Data integration from diverse sources, such as databases, files, and specialized software, is also conducted during this stage.
2. The Translation Stage: This phase follows the Inputs Stage and involves several key steps. Firstly, a range of tools and transformers within FME are employed to manipulate and transform data. This may entail tasks like restructuring, cleaning, and altering data attributes. Secondly, logic, rules, and conditions are established within FME to manage complex transformations, such as defining reasoning rules for inferring asset data from construction records. Iterative testing is then conducted to ensure the accuracy and efficiency of the process.
3. Specifying the Output Format and Structure: This involves determining the format and structure of the output data and directing the transformed data to its destination.
4. Execution and Automation: The process is executed, and automation may be implemented to perform data transformations. This can include scheduled or automated executions for routine tasks.
5. Output and Optimization: The final step involves maintaining and optimizing the process by continuously refining the workspace and fine-tuning it for improved performance as new data requirements emerge. This ensures the accuracy of data translation, such as converting

construction data into formats compatible with asset management systems.

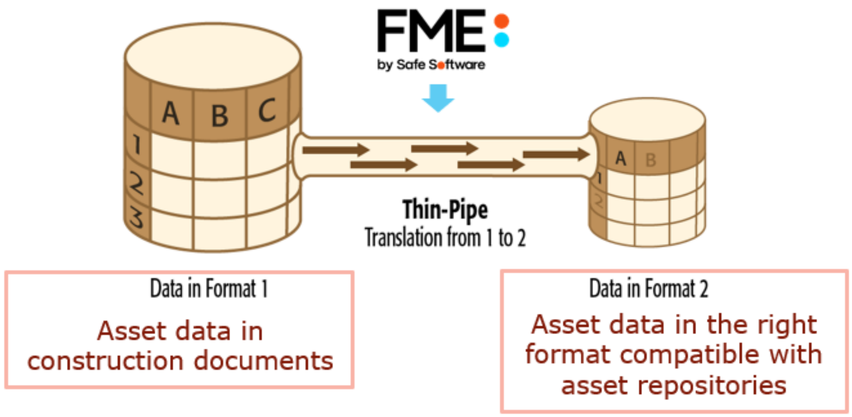


Figure 36. FME Pipeline

6.2. Key Findings

6.2.1. Construction to Asset Data FME Models

After carefully reviewing all main construction documents, the research team developed seven data translators. As shown in Table 40, there are limited data extractable from construction documents. Among them, only DWR can be used to identify asset data for each type of asset since that document contains keywords and information indicating the type of asset. By contrast, the remaining documents only provide data for contract administration rather than for asset management. In the case of as-built plans, this type of document is in the form of a PDF or physical paper rather than a digital format. We did not find any reliable tool that can extract asset data from them.

Table 40. Data translator development

No	Construction documents	Format	Data extractable from construction documents	A translator developed?
1	As-built Plans	PDF	District, County, Direction, Latitude, Longitude, Asset ID, Route number, Route name	No
2	Bid Tabulations	PDF	District, County, Year built	Yes
3	Daily Report of Asphalt Roadway Inspection	PDF	County, Route number, City	Yes
4	Daily work report (DWR)	CSV	Route number, County, City, Year built, Road system, Route, Latitude, Longitude, Geometry	Yes
5	Master Contract Document Tracker	CSV	Year built	Yes
6	Posting Advice	PDF	County, Year built, Route Begin MilePoint, Route End MilePoint, Route number	Yes
7	Project proposal	PDF	County, Year built	Yes
8	Project geometry surface model	XML	Route number	Yes

In this report, we presented the case study for the data translator for DWR, as shown in Figure 37. The data translator includes Input, Translation, and Output.

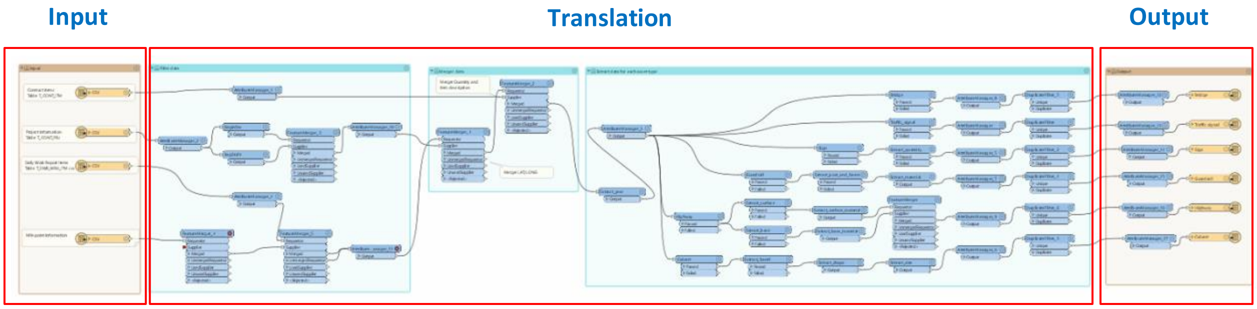


Figure 37. Data translator for extracting asset data from DWRs

a. Input

This is to import the necessary data into the translator, whereas each data source is allocated to a reader object (see Figure 38).

- Three readers for three tables (CSV file) from DWR used to extract asset data include: T_CONT_ITEM, T_CONT_PNJ, and T_DWR_WRK_ITM.

  + T_CONT_ITEM (see Figure 39): this table contains contract ID and project ID that are used as reference keys to merge tables. Besides, the Item code is used as an index to merge the description with another table.

  + T_CONT_PNJ (see Figure 40): this table contains contract ID, project ID, latitude, longitude, and project beginning station.

  + T_DWR_WRK_ITM (see Figure 41): this table contains contract ID, project ID, location of installed work items (i.e., beginning station and ending station), and work item description.

- An additional reader for an additional table (see Figure 42) extracted from the current system in SCDOT (e.g., P2S) providing beginning milepoint was fed as input to help map asset data to repositories.

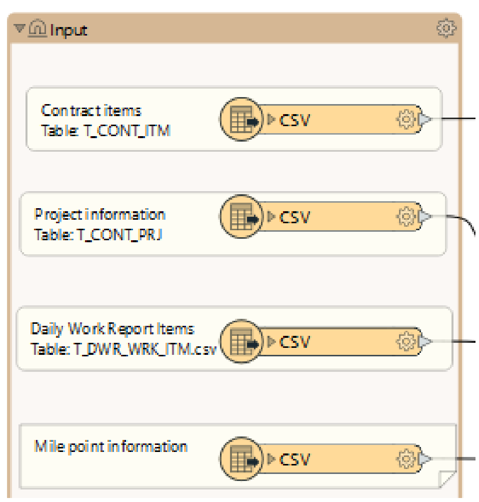


Figure 38. Readers for input data

A	B	C	D	AE	AF	AG	AH	AI	AJ	AI
CONT_ID	PRJ_NBR	LN_ITM_N	ITM_CD	NET_C_O_	QTY_INSTI	QTY_PD_TO_DT	LAST_MOI	LAST_MOI	DESC1	UNT_
8.038779	038779RD01	170	2022000	0	1	1	SYSTEM	20140607	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	180	2022000	0	1	1	SYSTEM	20140607	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	190	2022000	0	1	1	SYSTEM	20140607	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	200	2022000	0	1	1	SYSTEM	20140704	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	210	2022000	0	1	1	SYSTEM	20140607	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	220	2022000	0	1	1	SYSTEM	20140607	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	230	2022000	-1	0	0	clarkrt	20170314	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	240	2022000	0	1	1	SYSTEM	20140704	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	250	2022000	0	1	1	SYSTEM	20140805	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	260	2022000	0	1	1	SYSTEM	20140704	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	270	2022000	0	1	1	SYSTEM	20140805	REMOVAL & DISPOSAL ITEM NO.	LS
8.038779	038779RD01	280	2024100	0	7987	7987	SYSTEM	20170213	REMOVAL & DISPOSAL OF EXISTING CURB	LF
8.038779	038779RD01	290	2025000	0	7100.28	7100.28	SYSTEM	20161208	REMOVAL & DISPOSAL OF EXISTING ASPHALT PAVEMEI	SY
8.038779	038779RD01	300	2027000	0	769.5	769.5	SYSTEM	20170111	REMOVAL & DISPOSAL OF EXISTING CONCRETE	CY
8.038779	038779RD01	310	2031000	-1963.63	146.37	146.37	guesstb	20180117	UNCLASSIFIED EXCAVATION	CY
8.038779	038779RD01	320	2031200	0	1	1	SYSTEM	20170314	SITE EXCAVATION	LS
8.038779	038779RD01	330	2033000	56373.14	77373.14	77373.137	guesstb	20180117	BORROW EXCAVATION	CY
8.038779	038779RD01	340	2034000	35332.52	59908.52	59908.519	guesstb	20180117	MUCK EXCAVATION	CY
8.038779	038779RD01	350	2034512	0	0	0	walkerrm	20140317	12" DIAMETER PIPE ADDITIONAL FOUNDATION WORK	LF
8.038779	038779RD01	360	2034515	0	872.5	872.5	SYSTEM	20161208	15" DIAMETER PIPE ADDITIONAL FOUNDATION WORK	LF
8.038779	038779RD01	370	2034518	-629.5	12546.5	12546.5	guesstb	20180117	18" DIAMETER PIPE ADDITIONAL FOUNDATION WORK	LF
8.038779	038779RD01	380	2034524	0	4794	4794	SYSTEM	20161104	24" DIAMETER PIPE ADDITIONAL FOUNDATION WORK	LF
8.038779	038779RD01	390	2034530	0	1434.7	1434.7	SYSTEM	20160908	30" DIAMETER PIPE ADDITIONAL FOUNDATION WORK	LF
8.038779	038779RD01	400	2034536	0	2106	2106	SYSTEM	20160908	36" DIAMETER PIPE ADDITIONAL FOUNDATION WORK	LF
8.038779	038779RD01	410	2034542	0	1655.03	1655.03	SYSTEM	20161104	42" DIAMETER PIPE ADDITIONAL FOUNDATION WORK	LF
8.038779	038779RD01	420	2034560	0	383	383	SYSTEM	20161104	60" DIAMETER PIPE ADDITIONAL FOUNDATION WORK	LF
8.038779	038779RD01	430	2036000	-21889	0	0	clarkrt	20170314	GEOTEXTILE FOR SEPARATION OF SUBGRADE&SUBBASI	SY

Figure 39. Snapshot of T_CONT_ITEM table

A	B	C	D	E	F	Y	Z	
CONT_ID	PRJ_NBR	FED_ST_PI	DESC1	DESC2	LOC_DESC	LAT	LNGTD	REL
8.038779	038779RD01	BERK	SEE LAST F	WIDENIN(	Midpoint	330208	800530	
882221	0039389RD01	EM13001	SEE LAST F	Henry Bro	MIDPOINT	325859	800012	
883961	0039390RD01	39390	SEE LAST F	Clements		0	0	
1880980	0042915RD01	SA18012	U120XE22(	S- 58 WIDI	MIDPOINT	330156	801527	
1981260	0036773RD01	SU19001	SEE LAST F	US 25 WID	MIDPOINT	334013	815239	
21.037239A	037239RD01	FLOR	WIDENIN(			340834	795504	
21.037239A	37239BR01	FLOR	REPLACE S			340835	795504	
2180390	0037271RD01	37271	US 378 SE(		MIDPOINT	335301	793420	
2180401	0037272RD01	37272	U120000C:	US 378 SE(	MIDPOINT	335259	792855	
2180730	037241BR01	037241BR(	Replace B		MIDPOINT	341436	794445	
2180730	037241RD01	21.037241	WIDENIN(		MIDPOINT	341303	794546	
2182040	038191CRD03	038191C	U120000C:	SC 51 (PAI		0	0	
2182040	038191DRD04	038191D	U120000C:	SC 51 (PAI		0	0	
2182040	P039157	2182040	.	Extension	Extension	0	0	
2182290	038191ARD01	038191A	U120000C:	SC 51 (PAI	MIDPOINT	340612	794209	
2182290	038191BRD02	038191B	U120000C:	SC 51 (PAI	MIDPOINT	340144	793811	
2183611	0034955RD01	FLMB006	SEE LAST F	S- 29 Sout		0	0	
2350832	0037686RD01	GPAT002	Batesville			0	0	
2379781	0037685RD01	GPAT001	SEE LAST F	SC 101 WII	MIDPOINT	345642	821537	
2383520	0038112RD01	GPAT010	SEE LAST F	Salters Rd	MIDPOINT	344922	821909	
2384020	0041443RD01	SU23008	SEE LAST F	SC 14 (At F		0	0	
2384030	P041338	2384030	Extension		Extension	0	0	

Figure 40. Snapshot of T_CONT_PNJ table

	A	C	D	E	F	G	H	W	
1	CONT_ID	PRJ_NBR	DWR_DT	LN_ITM_N	LOC_SEQ_	LOC_INSTLD	RMRKS_ID	ITM_CD	L
22	8.038779	038779RD	20150731	1760	1	S-62	downerba	7204100	d
23	8.038779	038779RD	20150731	1760	2	S-62	downerba	7204100	d
24	8.038779	038779RD	20150731	1760	3	S-62	downerba	7204100	d
25	8.038779	038779RD	20150731	1750	1	S-62	downerba	7203220	d
26	8.038779	038779RD	20150731	1770	1	S-62	downerba	7205000	d
27	8.038779	038779RD	20150803	790	1	S-567		6092155	d
28	8.038779	038779RD	20150803	790	2	S-62		6092155	d
29	8.038779	038779RD	20150803	710	1	S-567		609115B	d
30	8.038779	038779RD	20150803	710	2	S-62		609115B	d
31	8.038779	038779RD	20150803	700	1	S-567		609115A	d
32	8.038779	038779RD	20150803	700	2	S-62		609115A	d
33	8.038779	038779RD	20150804	2480	1	S-62		8153090	d
34	8.038779	038779RD	20150804	2480	2	S-62		8153090	d
35	8.038779	038779RD	20150804	2480	3	S-62		8153090	d
36	8.038779	038779RD	20150804	2480	5	Semester		8153090	d
37	8.038779	038779RD	20150804	2480	4	S-62		8153090	d
38	8.038779	038779RD	20150804	2480	6	S-62		8153090	d
39	8.038779	038779RD	20150804	2480	7	Shadowbrook		8153090	d
40	8.038779	038779RD	20150804	2480	8	S-62		8153090	d
41	8.038779	038779RD	20150804	2480	9	S-62		8153090	d
42	8.038779	038779RD	20150806	1540	1	S-62	downerba	7191605	d

Figure 41. Snapshot of T_DWR_WRK_ITM table

A	B	C
projectid	endmp	begmp
0039390RD01	7.536	1.387
0042915RD01	4.356	1.023
0036773RD01	10.623	3.256
037239RD01	4.325	1.253
37239BR01	6.384	2.362
0037271RD01	7.912	1.258
0037272RD01	6.027	1.653
037241RD01	4.963	6.324
037241BR01	8.026	1.025

Figure 42. Snapshot of milepoint information extracted from the current system in SCDOT

b. Translation

This step includes three blocks for filtering data, merging tables, and extracting asset data. The first block (as shown in Figure 43) contains various transformer objects that receive raw data from the Input block and then remove irrelevant data (see Figure 44).

In the current practice at SCDOT, the beginning station of a project is assigned a value greater than 00+00, such as 35+15. This value was then converted into feet (ft), as demonstrated in Figure 45, to streamline the identification of the milepoint for each installed work item in the subsequent translation stage. For instance, the initial station 35+15 is converted to 35x100 + 15 = 3515 (ft). Similarly, the station locations of installed work items also were converted to feet (as shown in Figure 46).

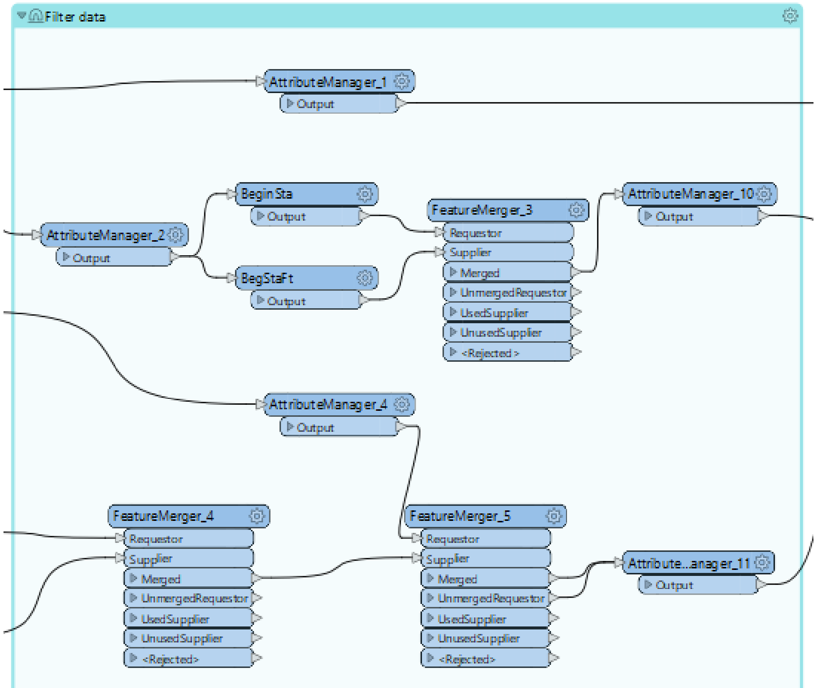


Figure 43. Filter data block

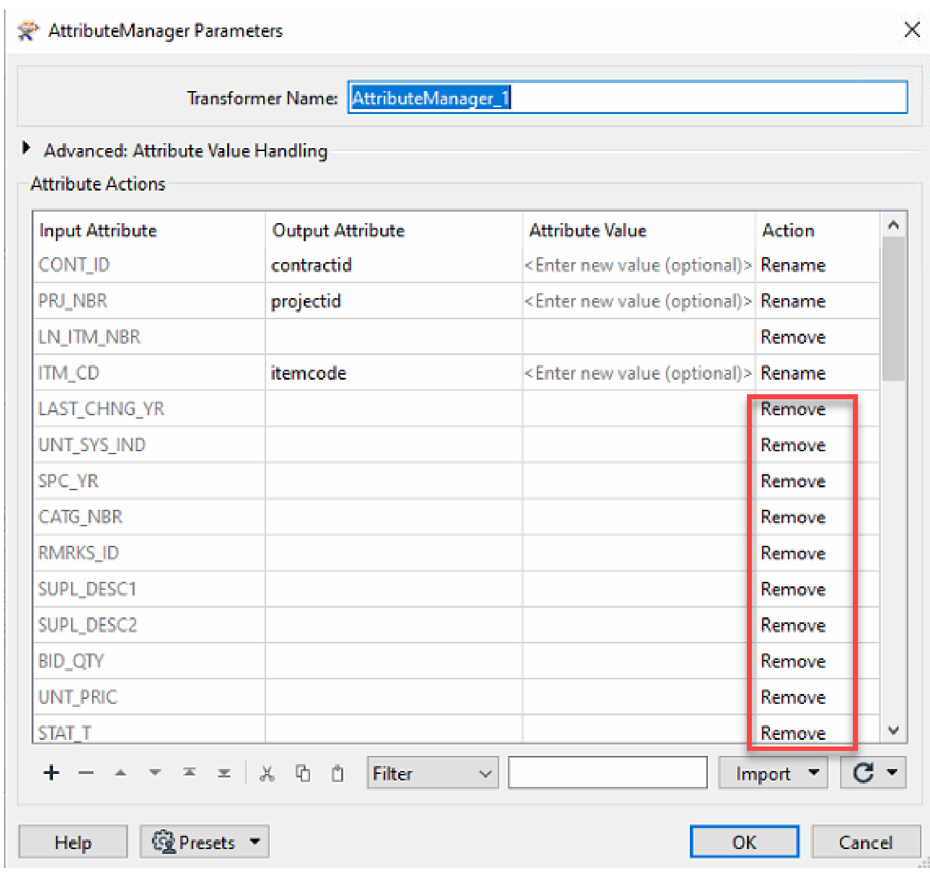


Figure 44. Transformer object for irrelevant data removal

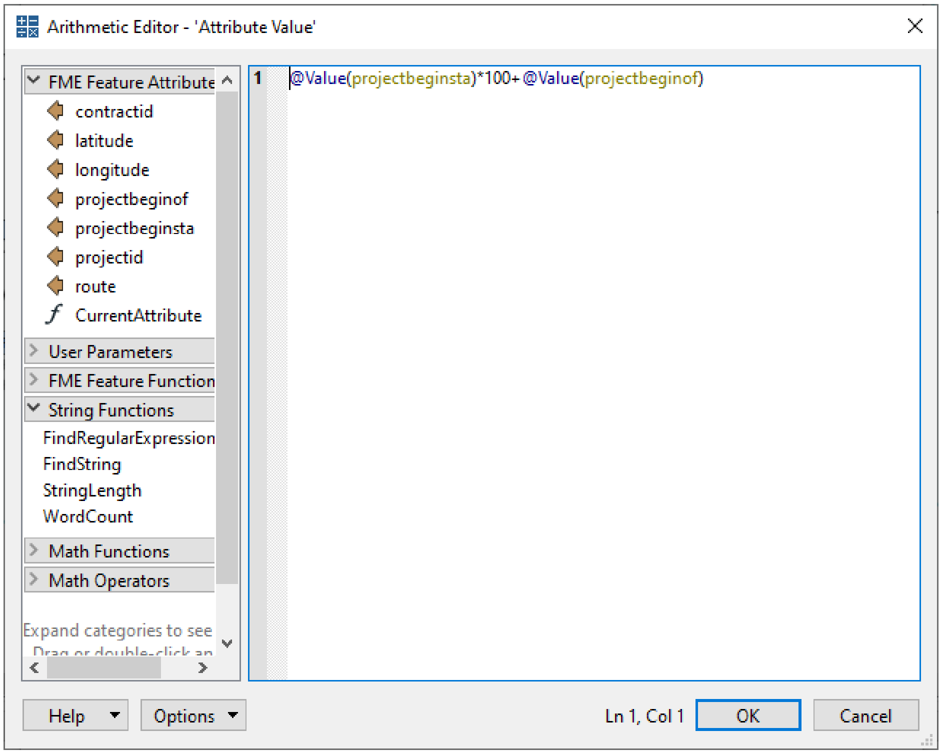


Figure 45. Converting the input project beginning station to feet (ft)

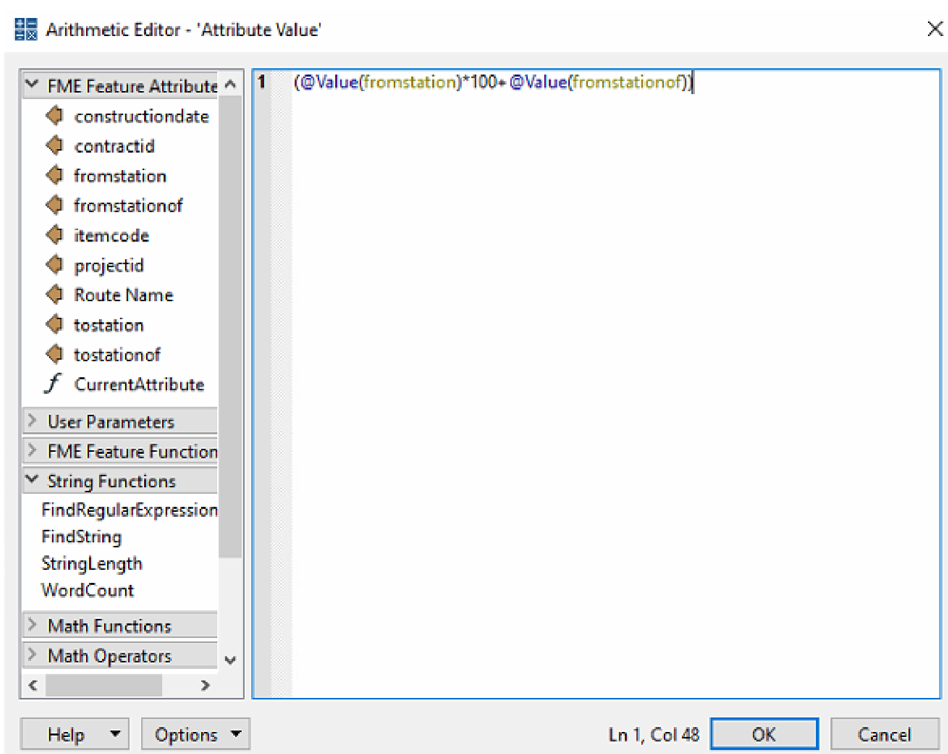


Figure 46. Converting the installed work item station to feet (ft)

Next, the second block, called the merger data block, contains merger transformer objects that help merge all the input DWR tables into one single table (see Figure 47). As shown in Figure 48, we used Contract ID and Project ID as reference key to merge tables.

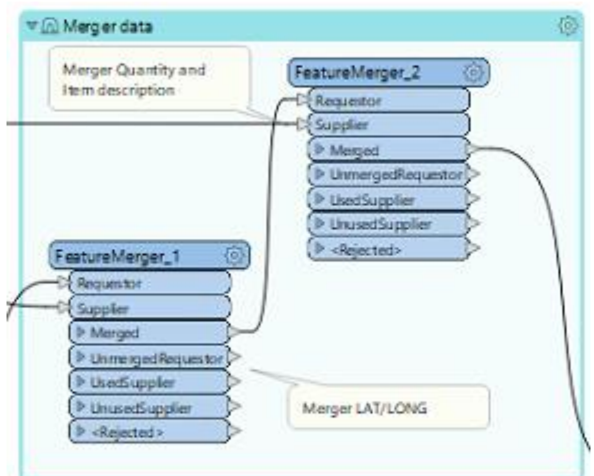


Figure 47. Merger data block

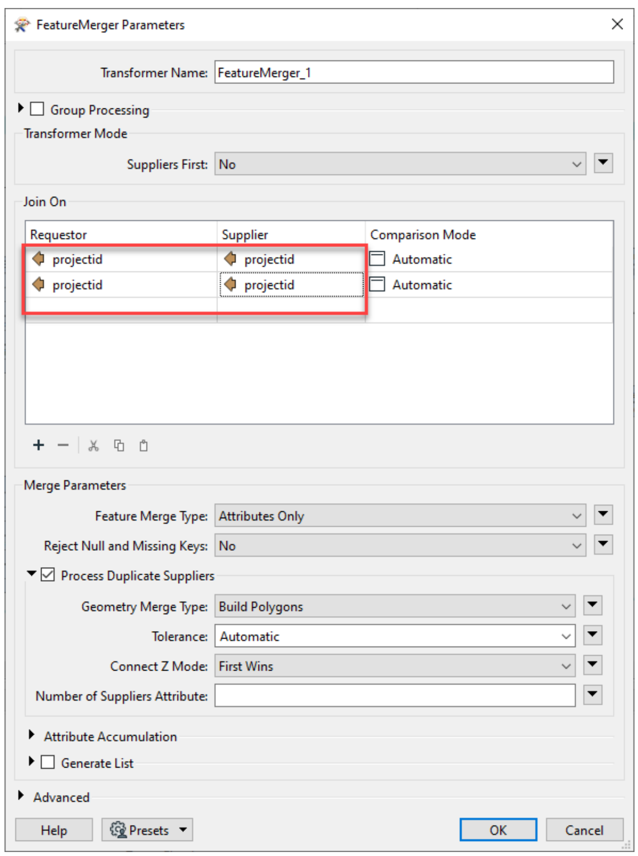


Figure 48. Merging parameters setting

As illustrated in Figure 49, the third block includes various transformer objects that allow setting rules to extract asset data from the unified and cleaned DWR table. Initially, the status of assets (i.e., new asset, replacement or removal) was determined by using keywords from pay item descriptions (as depicted in Table 41). Figure 50 indicates the rules developed in the FME. Next, the asset types were identified by utilizing keywords found in pay item descriptions, as outlined in Table 42. Figure 51 demonstrates an example for the keyword rules for culvert asset identification. Keyword-based rules are further employed to extract data for each asset type, as shown in Table 43. These rules involve keywords based on pay item descriptions and other DWR fields. As shown in Figure 52, we used keywords to extract shape and material from culvert asset. Similarly, the barrel size of culvert asset also was extracted as shown in Figure 53.

To identify milepoint information for each asset that helps map asset data to repositories, an arithmetic calculation rule (as shown in Figure 54) was developed to compute the milepoint value of each asset, as follows:

$$m = (is - ps)/5280 + pm$$

where m = milepoint of an asset (mile); is = station location of the installed item for which extracts the asset from DWRs (ft); ps = beginning station of the project that contains the asset (ft); pm = beginning milepoint of the project that contains the asset (mile).

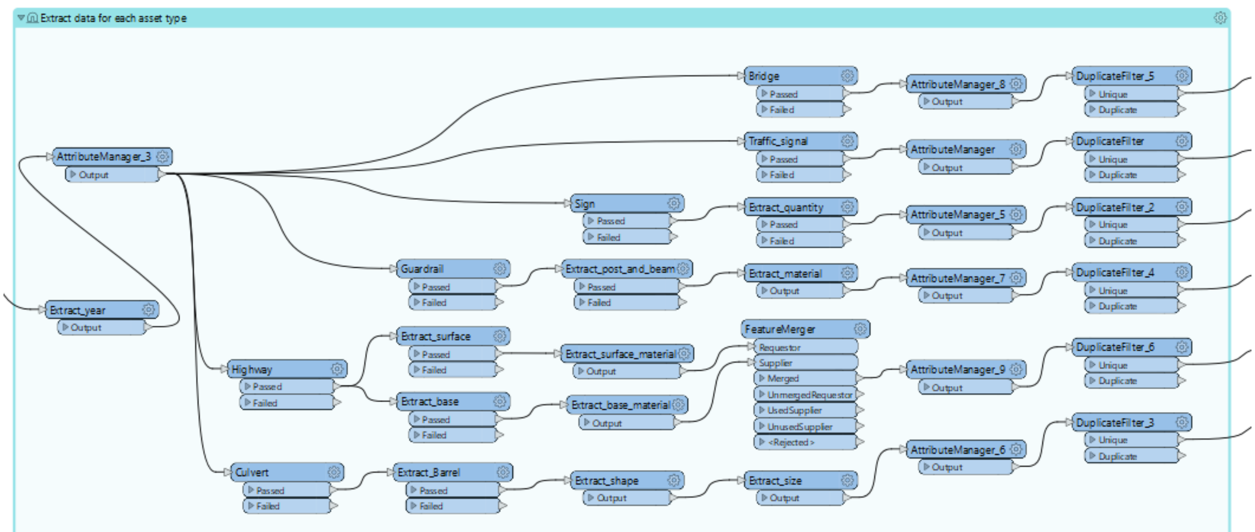


Figure 49. Data extracting block

Table 41. Keywords for asset status identification

Construction type	Keyword
New asset	*Default*
Replacement	“replace”
Removal	“remove”, “removal”, “disposal”

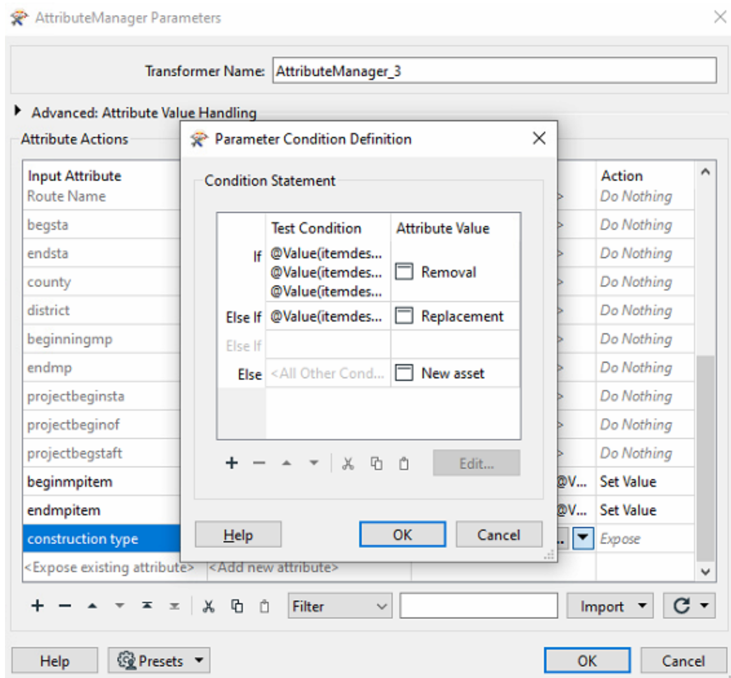


Figure 50. Rules for identifying construction type

Table 42. Keywords for asset identification

Asset	Keyword
Highway	"asphalt", "pavement", "HMA", "broken lines", "solid lines", "word message"
Bridge	"bridge", "shoring", "piling", "pile"
Guardrail	"guardrail"
Culvert	"culvert"
Sign	"sign"
Traffic signal	"signal"

Table 43. Keywords for asset data extraction

Asset	Asset data	Keyword/rule
Highway	Material	"surface course", "base course"
Guardrail	Component	"beam", "post"
	Material	"steel", "wood"
Culvert	Barrel type	"box", "pipe"
	Shape	"rectangular", "cicular"
	Material	"concrete", "PE"
	Size	Substring Extractor Function

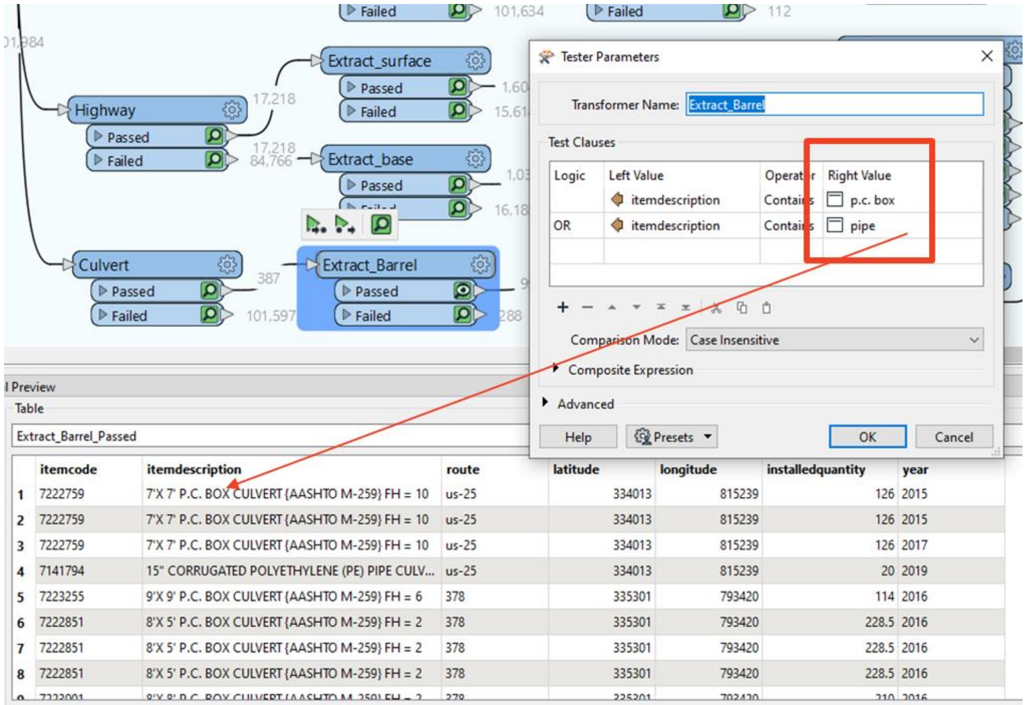


Figure 51. Rules for identifying culvert

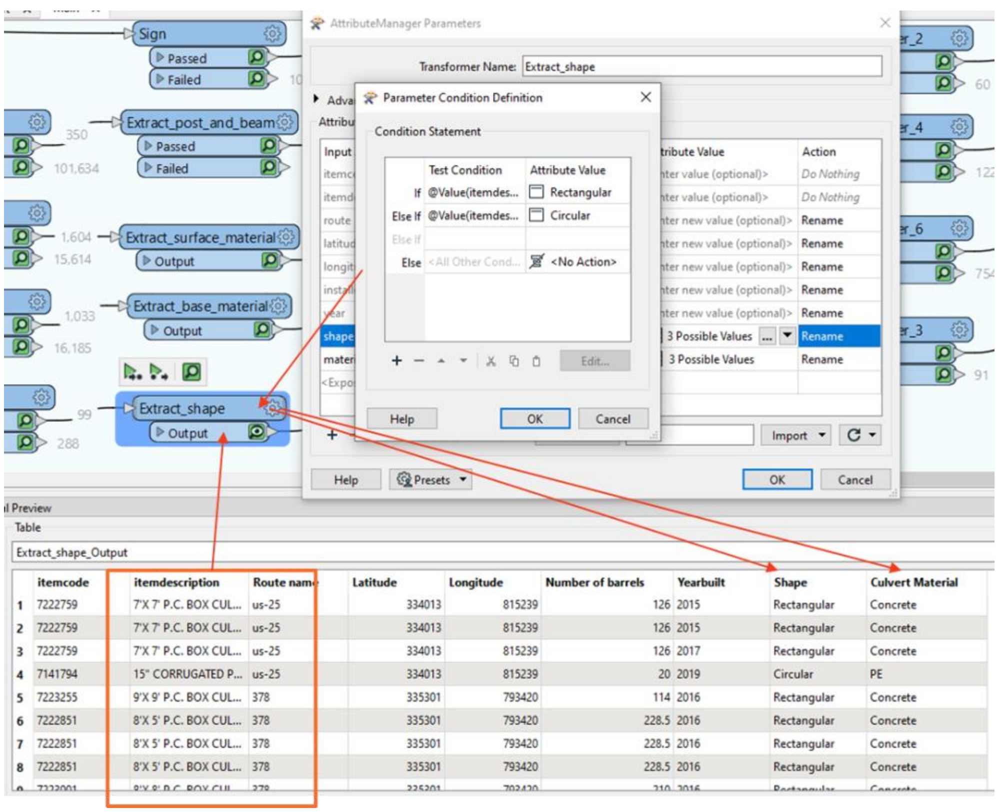


Figure 52. Rules for identifying asset data for culvert

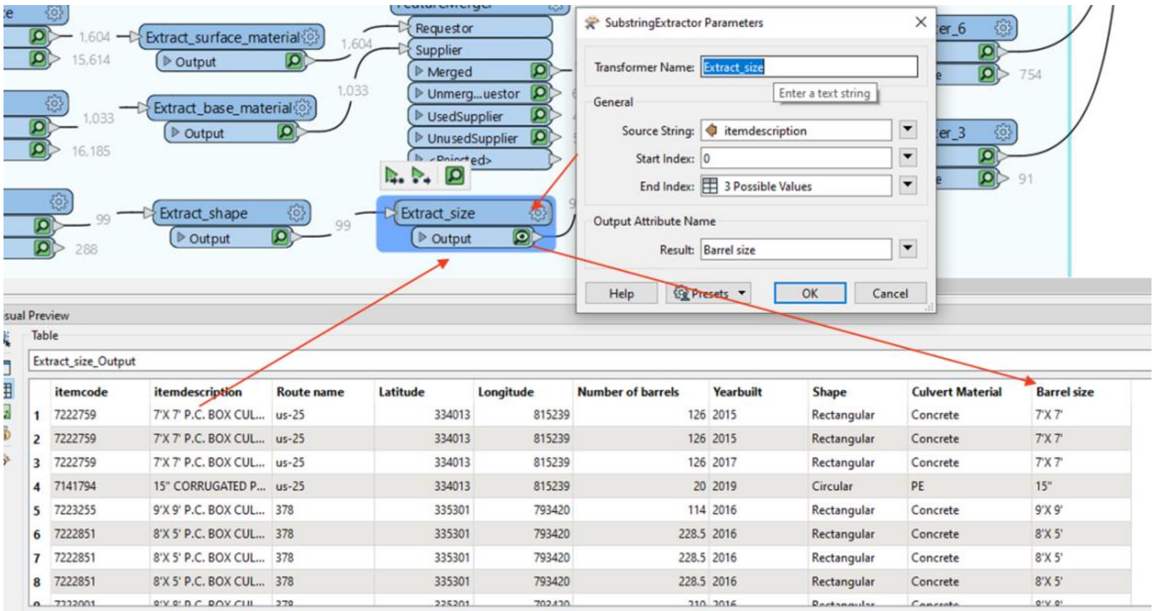


Figure 53. Rules for identifying asset data for culvert (continued)

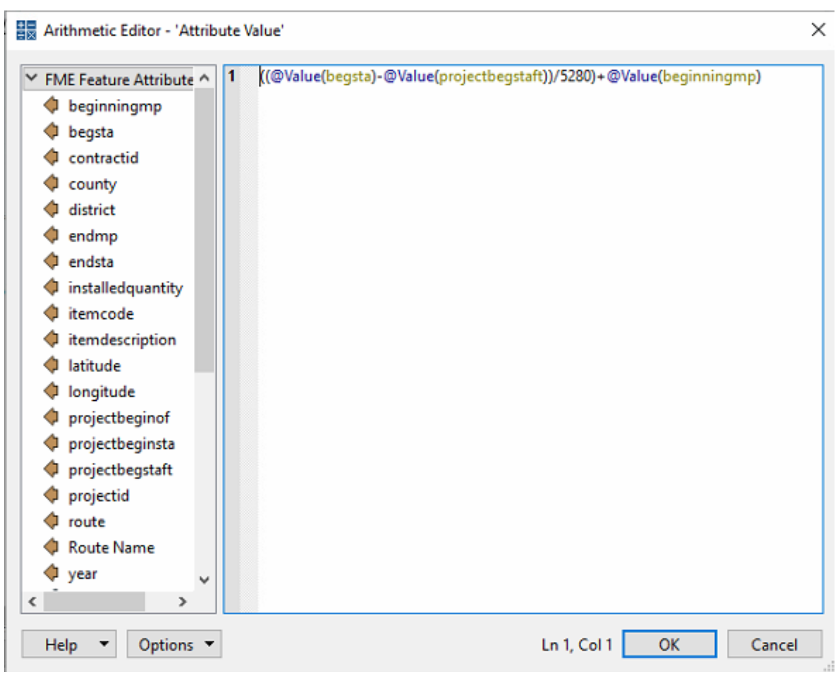


Figure 54. Milepoint calculation

c. Output

After establishing rules to extract data for each asset type, relying on the type of asset, we proceed to export to separate files (Figure 55). These exporters will convert output files into a standardized format (e.g., CSV) interoperable with existing asset databases. Tables 44 – 49 illustrate extracted data from the developed translator.

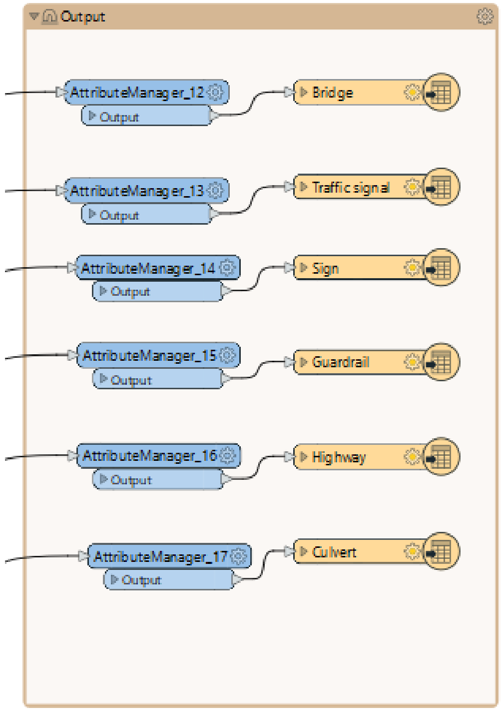


Figure 55. Data exporting block

Table 44. Extracted data for bridges

Route number	Latitude	Longitude	Year built	County	District	Milepoint	Construction type
S-62	330208	800530	2015	Aiken	District 7		New
	325859	800012	2016	Berkeley	District 6		New
			2019	Aiken	District 7		Removal
	334013	815239	2015	Aiken	District 7		New
S-62	340834	795504	2014	Berkeley	District 6	2.72	New
S-62	340835	795504	2015	Aiken	District 7		New
	335301	793420	2015	Berkeley	District 6		New
	335259	792855	2015	Aiken	District 7		Removal
	341303	794546	2014	Aiken	District 7	4.92	New
	341436	794445	2014	Berkeley	District 6		New
	340612	794209	2016	Berkeley	District 6		Removal
	340144	793811	2016	Aiken	District 7		New
	344922	821909	2016	Berkeley	District 6		Removal
	333706	785930	2014	Aiken	District 7		New
S-62	335700	812539	2014	Berkeley	District 6		New
SC-707	333842	790135	2015	Berkeley	District 6		New
SC-707	333527	790326	2015	Aiken	District 7		New
S-62	330208	800530	2015	Aiken	District 7		New
	325859	800012	2016	Berkeley	District 6		New

Table 45. Extracted data for culverts

Route Number	Latitude	Longitude	Shape	Material	Size	Year built	County	District	Milepoint	Construction type
	334013	815239	Rectangular	Concrete	7'X 7'	2015	Aiken	District 7		New
	335301	793420	Rectangular	Concrete	9'X 9'	2016	Berkeley	District 6		New
	335259	792855	Rectangular	Concrete	10'X 5'	2016	Aiken	District 7		New
			Rectangular	Concrete	6'X 4'	2017	Aiken	District 7		Removal
	340612	794209	Rectangular	Concrete	10'X 7'	2016	Berkeley	District 6		New
	340144	793811	Rectangular	Concrete	9'X 9'	2018	Aiken	District 7		Removal
S-62	335700	812539	Rectangular	Concrete	8'X 6'	2014	Berkeley	District 6		New
SC-707	333842	790135	Rectangular	Concrete	7'X 5'	2016	Berkeley	District 6	2.21	New

Table 46. Extracted data for guardrails

Route number	Beam material	Post material	Year built	County	District	Beginning milepoint	End milepoint	Construction type
	Steel		2016	Aiken	District 7			New
	Steel		2016	Aiken	District 7			New
			2017	Aiken	District 7			New
	Steel		2016	Berkeley	District 6			New
S-62	Steel		2018	Berkeley	District 6	2.55	2.78	New
S-62	Steel		2016	Berkeley	District 6	2.69	2.77	New
SC-707	Steel	Steel	2016	Aiken	District 7			New
SC-707	Steel		2017	Berkeley	District 6	1.92	1.99	New

Table 47. Extracted data for highway

Route number	Surface material	Base material	Year built	County	District	Beginning milepoint	End milepoint	Construction type
S-62	Hot mix asphalt surface course type c	Hot mix asphalt base course type a	2015	Aiken	District 7	1.73	1.73	New
S-62	Hot mix asphalt surface course type b	Hot mix asphalt base course type a	2015	Aiken	District 7			New
S-62	Hot mix asphalt surface course type b	Hot mix asphalt base course type a	2015	Aiken	District 7	1.39	1.77	New
S-62	Hot mix asphalt surface course type c	Hot mix asphalt base course type a	2016	Aiken	District 7	2.43	2.54	New
S-62	Hot mix asphalt surface course type c	Hot mix asphalt base course type a	2016	Aiken	District 7			New
S-62	Hot mix asphalt surface course type d	Hot mix asphalt base course type a	2016	Aiken	District 7	1.73	2.24	New

Table 48. Extracted data for signs

Route Number	Latitude	Longitude	Year built	County	District	Milepoint	Construction type
S-62	330208	800530	2016	Aiken	District 7	1.68	New
			2018	Aiken	District 7		New
	330156	801527	2014	Berkeley	District 6		New
	341303	794546	2017	Aiken	District 7	1.37	New
	340144	793811	2018	Aiken	District 7		New
	340612	794209	2018	Berkeley	District 6		New
	345642	821537	2016	Aiken	District 7		New
SC-707	333410	790209	2017	Aiken	District 7		New
SC-707	333842	790135	2018	Berkeley	District 6	6.14	New
SC-707	333527	790326	2019	Aiken	District 7		New
	341025	820347	2015	Aiken	District 7		New
	345011	821634	2016	Aiken	District 7		New

Table 49. Extracted data for traffic signals

Route Number	Latitude	Longitude	Year built	County	District	Milepoint	Construction type
S-62	330208	800530	2016	Aiken	District 7	1.73	New
	325859	800012	2020	Berkeley	District 6		New
			2017	Aiken	District 7		New
S-62	340834	795504	2015	Berkeley	District 6	3.26	New
	341303	794546	2016	Aiken	District 7	2.35	New
	340144	793811	2018	Aiken	District 7		New
	340612	794209	2018	Berkeley	District 6		Removal
	345642	821537	2015	Aiken	District 7		New
	344922	821909	2017	Berkeley	District 6		New
	345011	821634	2015	Aiken	District 7		New
	333706	785930	2016	Aiken	District 7		Removal
	341710	803728	2018	Berkeley	District 6		New

6.3. Gaps of DWR Data for Asset Data Extraction

To document the limitations of DWR data for asset data collection, the research team reviewed historical DWRS and developed a spreadsheet providing insights into the use of DWRs for asset data extraction (see Figure 56). The spreadsheet provides the following information related to asset data and their corresponding data sources in the DWR:

1. Asset Data Attribute: This column lists the specific attributes of asset data, such as Latitude, Longitude, Year Built, Route Number, Material, etc. These attributes are essential for managing and analyzing transportation assets.
2. Data Type: This column indicates the nature of the data attribute, such as Location, Key Date,

Material, Geometry, etc. Understanding the data type helps in interpreting and utilizing the information effectively.

3. DWR Table Name: This column specifies the name of the table within the Daily Work Reports (DWR) where the data for the respective attribute is stored. For example, T_CONT_PRJ and T_DWR_WRK_ITM are specific tables within the DWR.
4. Field Name in DWR Table: This column provides the specific field or column name within the DWR table where the data for the attribute can be found. For instance, LAT, LNGTD, DWR_DT, ROUTE_NBR, etc.
5. Data Source in DWR Table: This column gives information about the source or origin of the data within the DWR table. It helps in understanding where the information is derived from within the dataset.
6. Bridge, Culvert, Guardrail, Highway, Sign, Traffic Signal: These columns are marked with a check (✓) to indicate which types of assets the respective attribute is relevant to. For example, "Latitude" and "Longitude" are applicable to all types of assets.
7. Data Availability in DWR: This column indicates the percentage of availability of data for the respective attribute in the DWR.
8. Data Example from DWR: This column provides an example of actual data from the DWR for the respective attribute.
9. New Construction, Reconstruction, 3R: These columns indicate which types of construction projects (New Construction, Reconstruction, and 3R) the respective attribute is relevant to.
10. Example for Project Type from DWR: This column provides an example of the project type from the DWR where the attribute is applicable.
11. Note: This column provides additional notes or comments about the attribute, including any specific considerations or contexts in which the data may be used.

No	Asset Data Attribute	Data type	DWR Table Name	Field Name in DWR Table	Data Source in DWR Table	Bridge	Culvert	Guardrail	Highway	Sign	Traffic signal
1	Latitude	Location	T_CONT_PRJ	LAT	Field value	✓	✓	✓	✓	✓	✓
2	Longitude	Location	T_CONT_PRJ	LNGTD	Field value	✓	✓	✓	✓	✓	✓
3	Beginning station	Location	T_CONT_PRJ	BEG_STA_NBR	Field value	✓	✓	✓	✓	✓	✓
4	Ending station	Location	T_CONT_PRJ	END_STA_NBR	Field value	✓	✓	✓	✓	✓	✓
5	From station	Location	T_DWR_WRK_ITM	FR_STA_ITM FR_STA_DSTNC	Field value	✓	✓	✓	✓	✓	✓
6	To station	Location	T_DWR_WRK_ITM	TO_STA_ITM TO_STA_DSTNC	Field value	✓	✓	✓	✓	✓	✓
7	Year built	Key date	T_DWR_WRK_ITM	DWR_DT	Field value	✓	✓	✓	✓	✓	✓
8	Route number	Location	T_CONT_PRJ	ROUTE_NBR	Field value	✓	✓	✓	✓	✓	✓
9	Beam material	Material	T_CONT_ITM	DESC1	Work item description	Not required	Not required	✓	Not required	Not required	Not required
10	Surface material	Material	T_CONT_ITM	DESC1	Work item description	Not required	Not required	Not required	✓	Not required	Not required
11	Base material	Material	T_CONT_ITM	DESC1	Work item description	Not required	Not required	Not required	✓	Not required	Not required
12	Barrel shape	Geometry	T_CONT_ITM	DESC1	Work item description	Not required	✓	Not required	Not required	Not required	Not required
13	Barrel size	Geometry	T_CONT_ITM	DESC1	Work item description	Not required	✓	Not required	Not required	Not required	Not required
14	Culvert material	Material	T_CONT_ITM	DESC1	Work item description	Not required	✓	Not required	Not required	Not required	Not required
15	District	Location	Not available	Not available	Not available	Not available	Not available	Not available	Not available	Not available	Not available
16	County	Location	Not available	Not available	Not available	Not available	Not available	Not available	Not available	Not available	Not available
17	Mile point	Location	Not available	Not available	Not available	Not available	Not available	Not available	Not available	Not available	Not available
18	State Code	Location	Not available	Not available	Not available	Not available	Not required	Not required	Not available	Not required	Not required
19	Direction	Location	Not available	Not available	Not available	Not required	Not required	Not available	Not available	Not available	Not required

Figure 56. Snapshot for DWR Data for Asset Data Extraction

As shown in Figure 57, among the asset categories, bridges have the highest total count at 126, followed by highways with 88. Culverts and guardrails have a total of 71 and 30, respectively, while signs and traffic signals are relatively lower in number, with 47 and 23, respectively. In terms of data availability in the DWRs, culverts have the highest count at 11, closely followed by bridges with 8. As shown, the number of asset data extractable from DWRs is relatively low.

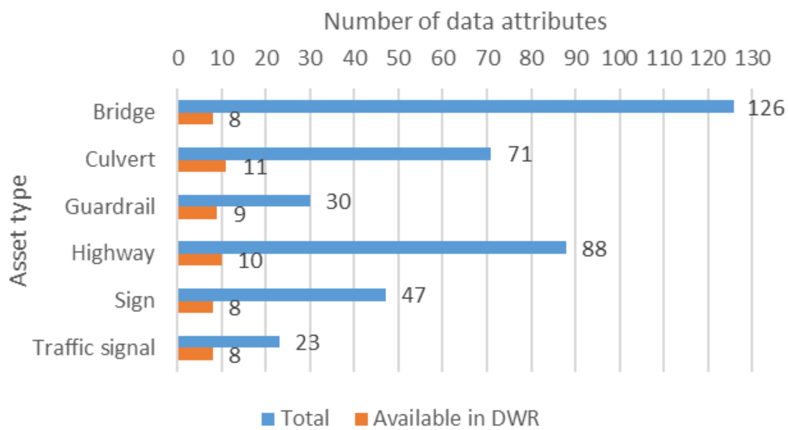


Figure 57. Count of data attributes extractable from DWRS

Figure 58 provides a breakdown of extractable attributes by data type. Among these attributes, location is consistently documented in DWRs for all assets. Besides, key date is also recorded in DWRs. On the other hand, attributes like classification, cost, geometry, identification, inspection, load, material, quantity, and traffic show minimal or no recorded instances across the assets.

	Classification	Cost	Geometry	Identification	Inspection	Key date	Load	Location	Material	Quantity	Traffic
Bridge	0	0	0	0	0	1	0	7	0	0	0
Culvert	0	0	2	0	0	1	0	7	1	0	0
Guardrail	0	0	0	0	0	1	0	7	1	0	0
Highway	0	0	0	0	0	1	0	7	2	0	0
Sign	0	0	0	0	0	1	0	7	0	0	0
Traffic signal	0	0	0	0	0	1	0	7	0	0	0

Count: 0–7

Figure 58. Data extracted count by data type

Figure 59 illustrates the distribution of extractable asset data attributes for different types of construction projects, including new construction, reconstruction, and 3R (resurfacing, restoration, and rehabilitation) for bridges, culverts, guardrails, highways, signs, and traffic signals. Among these, 3R projects are the most prevalent, with the highest number of extractable attributes across all assets. New construction projects are the second most common, followed closely by reconstruction.

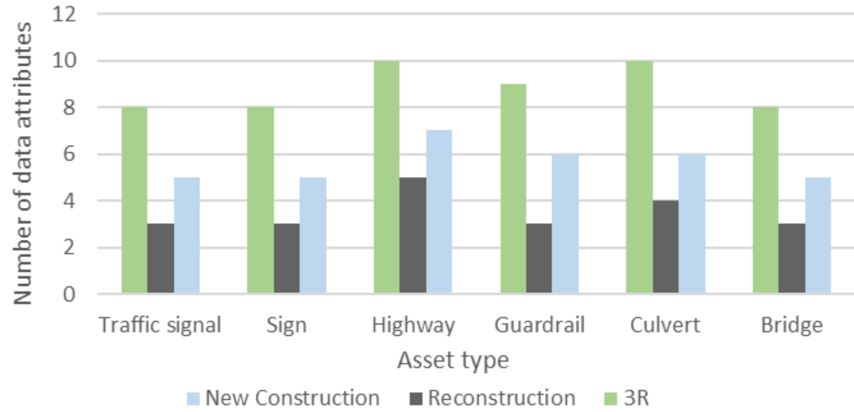


Figure 59. Extractable data count by project type

Chapter 7: Recommendations

Based on the challenges and limitations outlined in this report, below are some recommendations for SCDOT to enhance efficiency, accuracy, and data management processes across the department.

- Firstly, to address the underutilization of the mobile inspector phone application, it is crucial to actively promote its adoption among department personnel. This can be achieved through targeted training sessions and workshops to familiarize employees with the application's features and benefits. By emphasizing the efficiency and accuracy gains associated with mobile data entry in the field, SCDOT can encourage a shift towards more widespread use of this technology.
- In order to overcome limitations with GPS technology, it is recommended that SCDOT invests in comprehensive training programs for employees. Providing ongoing support and resources to enhance their expertise in operating GPS units will be essential for ensuring accurate location data. Additionally, the department should consider partnering with experts or providing specialized training sessions to address any skill gaps and increase confidence in using this technology effectively. Besides, construction inspectors should utilize mobile applications equipped with GPS capabilities to automatically record the latitude and longitude coordinates of assets during installation. This real-time data capture ensures accuracy and timeliness in asset information.
- Contractors should be required to furnish 3D As-Built and 3D GIS As-Built models as part of their deliverables. These comprehensive representations offer invaluable insights into the as-constructed state of assets, facilitating more efficient data streaming.
- To improve remote access to AASHTOWare Project SiteManager, SCDOT should explore alternative methods beyond the current reliance on a virtual private network (VPN). This may involve investigating cloud-based solutions or other secure remote access methods that facilitate easier usage for department personnel. Collaborating with the IT department to explore technological solutions can also play a key role in enhancing the accessibility and usability of the system.
- It is recommended for SCDOT to consider adopting the best practices on asset collection and management as well as ongoing efforts and future directions from the results of the statewide survey documented in this report. Furthermore, SCDOT should establish a culture of continuous technological evaluation and adoption. This involves regularly assessing emerging technologies and software updates to stay current with industry best practices. Piloting new technologies within specific departments before widespread implementation can help gauge their effectiveness and address any potential challenges early on.
- As part of the project deliverables, the data mapping spreadsheet provides comprehensive details on highly prioritized assets along with their required asset data attributes. SCDOT is recommended to adopt and tailor the results according to the real data needs for the agency's future asset management programs, which is currently missing. Despite the demonstrated potential of DWRs for automated retrieval of asset inventory data, the study found that the number of asset data attributes extractable from digital DWRs is relatively small compared to what is required. SCDOT is recommended to use other data collection methods simultaneously, including field data collection using mobile apps and LiDAR to collect those not readily available in construction documents.
- With respect to the transition to Agile Asset, proactive planning becomes a priority. Field personnel should receive training on editing asset data within the EAMS during maintenance and repair activities. This empowers them to contribute to the accuracy and completeness of

the asset database in real-time. The maintenance department should establish a collaborative partnership with the vendor team to ensure a seamless transition. This involves verifying the data required attributes for each asset found in this study to effectively integrate them into the new system. A dedicated effort will be required to review the research deliverable of asset attributes by relevant business offices to refine asset attribute requirements. Additionally, personnel training is imperative to ensure they fully grasp the capabilities of the new system. Adapting workflows and processes to align with Agile Asset's functionalities will be crucial in maximizing its benefits and improving overall operational efficiency. By investing in these recommendations, SCDOT can significantly enhance its asset management practices, moving from a reactive to a proactive approach and, ultimately, ensuring the longevity and effectiveness of its infrastructure.

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Appendices

Appendix 1: Web-based Nationwide Survey Questionnaire

SPR 759 Best Practices on Collecting Asset Information from The Construction Stage

SURVEY FORM

As part of the research project *SPR 759: Best Practices on Collecting Asset Information from The Construction Stage* sponsored by the South Carolina Department of Transportation (SCDOT), Clemson University and SCDOT are conducting a nationwide survey to identify state-of-practice technologies and procedures for reducing duplicated efforts in collecting transportation asset inventory information by directly leveraging those data that could have been already captured during the construction stage of project delivery or maintenance activities.

Survey Procedure*:* Your part will be to answer the questions in a mobile-friendly survey on Qualtrics.

Participation Time: It will take you about 20 minutes to be in this survey.

Eligibility: Personnel who work in the following offices of a state DOT will qualify to participate in this survey: Construction and Materials, Data/Information Administration and Services, Maintenance, and Asset Management.

Contact Information: For additional information, please contact PI Dr. Tuyen (Robert) Le (Assistant Professor, Glenn Department of Civil Engineering at Clemson University) at (864) 656-3316 or tuyenl@clemson.edu

Consent*:* By participating in the survey, you indicate that you have read the information written above, been allowed to ask any questions, and you are voluntarily choosing to take part in this survey. You do not give up any legal rights by taking part in this survey.

Survey Link: https://clemson.ca1.qualtrics.com/jfe/form/SV_9Y7EBPVhiD7cDT8.

Thank you,

Participant Information

1. Please provide the following contact information

Name: ____
Position: ____
Office: ____
State DOT: ____
Phone: ____
E-Mail: ____

2. First, please select sections below that best fit your knowledge and experience. You will not see questions from unselected sections. <u>**Select all that apply**</u>.

□ Section A: Asset Inventory Data Collection and Management
□ Section B: Construction Project Data Collection and Management

Section A: Asset Inventory Data Collection and Management

This section includes questions regarding your agency's current practices of collecting and managing transportation asset inventory data for use in asset management.

A.1. For which assets does your agency collect inventory data? **Select all that apply**

□ Bridges
□ Culverts
□ Drainage
□ Guardrails
□ Pavements
□ Signs
□ Traffic signals
□ Other, specify below

A.2. What software applications does your agency use to manage asset inventory data? **Select all that apply.**

□ AgileAssets Enterprise Asset Management (EAM)
□ Esri ArcGIS (Roads and Highways)
□ Microsoft Access
□ Microsoft Excel
□ ProjectWise
□ Roadway Information Management System (RIMS)
□ SharePoint
□ SQL databases
□ Other, specify below

A.3. Which methods below does your agency use to collect asset inventory data? **Select all that apply.**

□ Method a: Regular statewide field asset inventory collection at a predefined frequency
□ Method b: Field asset inventory data collection during the construction stage of project delivery
□ Method c: Asset inventory data extraction from construction documents (e.g., as-built plans/models and daily reports of work items)
□ Method d: Asset inventory data extraction from asset maintenance work orders
□ Other, specify below

Method a: Regular statewide field asset inventory data collection

A.4. What asset inventory data does your agency capture using Method a: Regular statewide field asset inventory data collection?

____

A.5. What technologies and tools does your agency use for Method a: Regular statewide field asset inventory data collection? **Select all that apply.**

□ GPS devices
□ LiDAR (airborne)
□ LiDAR (terrestrial)
□ LiDAR (drone)
□ Manual data collection (e.g., field books)
□ Mobile devices (e.g., smartphones, tablets)
□ Data collection vans
□ Other - Specify below

A.6. What mobile applications does your agency use for Method a: Regular statewide field asset inventory data collection? **Select all that apply**.

□ Agile Materials Manager
□ Agile Structures Inspector
□ Agile Work Manager
□ Other - Specify below
□ Esri ArcGIS Collector
□ Esri ArcGIS Quick Capture
□ Esri ArcGIS Survey123

A.7. Who performs asset inventories using Method a: Regular statewide field asset inventory data collection? **Select all that apply.**

□ External consultants
□ In-house field maintenance staff
□ Other, specify below

Method b: Field asset inventory data collection during the construction stage of project delivery

A.8. What asset inventory data does your agency collect using Method b: Field asset inventory data collection during the construction stage of project delivery?

____

A.9. What mobile applications does your agency use for Method b: Field asset inventory data collection during the construction stage of project delivery? **Select all that apply.**

□ AASHTOWare Project Mobile Tester
□ Agile Materials Manager
□ Agile Structures Inspector
□ Agile Work Manager
□ Other - Specify below
□ Esri ArcGIS Collector
□ Esri ArcGIS Quick Capture
□ Esri ArcGIS Survey123
□ Infotech Mobile Inspector

A.10. Who performs asset inventories using Method b: Field asset inventory data collection during the construction stage of project delivery? **Select all that apply.**

□ Contracted consultant
□ Highway construction contractor
□ In-house construction engineers
□ In-house field maintenance staff
□ Other, specify below

A.11. What are the drawbacks of asset inventories using Method b: Field asset inventory data collection during the construction stage of project delivery?

____

Method c: Asset inventory data extraction from construction documents (e.g., as-built plans/models and daily reports of work items)

A.12. What asset inventory data does your agency collect using Method c: Asset inventory data extraction from construction documents?

____

A.13. What construction project documents does your agency use to extract asset inventory data? **Select all that apply.**

□ As-built plans
□ Daily work reports
□ Design plans
□ Other, specify below

A.14. List the name of software applications from which construction documents are obtained?

____

A.15. How does your agency extract asset inventory data from construction project documents?

□ Automatically
□ Manually
□ Semi-automatically
□ Other comments

A.16. Please describe <u>key challenges</u> with the use of construction documents for updating transportation asset inventories.

____

Method d: Asset inventory data extraction from maintenance work orders

A.17. What asset inventory data does your agency capture using Method d: Asset inventory data extraction from maintenance work orders

____

A.18. What format of maintenance work orders does your agency use? **Select all that apply.**

□ Digital forms available in a software application
□ Hard-copy paper forms
□ PDF forms

A.19. List the name of software applications from which maintenance work orders are obtained?

____

A.20. How does your agency extract asset inventory data from maintenance work orders?

□ Automatically
□ Manually
□ Semi-automatically
□ Other, specify below

A.21. Please describe <u>key challenges</u> with the use of maintenance work orders for updating transportation asset inventories.

____

Additional comments and suggestions

A.22. Please provide a rough estimate of the annual budget spent for asset inventory data collection at your agency (type “unsure” if you have no answer to this question).

____

A.23. Please provide additional comments regarding what and how asset inventory data are currently collected at your agency.

____

A.24. Please provide a few recommendations for reducing field asset inventory data collection by leveraging existing data sources including construction project data and maintenance work orders.

Recommendation 1: ____
Recommendation 2: ____
Recommendation 3: ____

Section B: Construction Project Data Collection and Management

This section includes questions on what and how construction data is collected and managed.

B.1. What project data does your agency currently collect during the construction stage of project delivery?

____

B.2. What types of as-built drawings does your agency use? **Select all that apply.**

□ Direct updates on digital design plans (e.g., CAD or Microstation files)
□ Redline paper plans
□ Redline PDF plans
□ Other, specify below

B.3. What technology, tools, and methods does your agency use for collecting construction project data? **Select all that apply.**

□ Contractor's submittals
□ Mobile devices (e.g., smartphones or tablets)
□ Laptops with AASHTOWare Project SiteManager/AASHTOWare Project FieldManager
□ Paper field books
□ Other, specify below

B.4. What mobile applications does your agency use for field collection of construction project data? **Select all that apply.**

□ AASHTOWare Project Mobile Tester
□ Agile Materials Manager
□ Agile Structures Inspector
□ Agile Work Manager
□ Infotech Mobile Inspector
□ Other, specify below

B.5. What software applications does your agency use for managing construction data? **Select all that apply.**

□ AASHTOWare Project Construction & Materials

□ AASHTOWare Project SiteManager

□ AASHTOWare Project FieldManager

□ Microsoft Access

□ Microsoft Excel

□ ProjectWise

□ Other, specify below

B.6. What construction documents do you think can be used for extracting asset inventory data?

____

Section C: Additional Information and Follow-Up

C.1 May we contact you to further discuss your agency's practice regarding the collection of asset inventory data during the construction stage?

○ Yes
○ No

This is the end of this survey.

Thank you for participating!

Appendix 2: Follow-up Survey to Pioneering States

Survey Follow-Up Questions to Further Understand Innovative Practices among Pioneering States

Sponsored by the South Carolina Department of Transportation

Conducted by Clemson University

I. State and innovative data inventory method
1. State:
2. Innovative asset inventory data collection practice:

II. Please answer the following questions about the above innovative method
1. Please elaborate further on the workflow of asset inventory data collection using the method (e.g., Who does it and when? What supporting tools are used for the task?)

2. Compared with the traditional asset inventory data collection method when the data is re-collected by field inspection staff after the project is open to the public, please rate the effectiveness of the method.

Effectiveness Criterion	(1) Significantly worse	(2) Slightly worse	(3) No Change	(4) Slightly better	(5) Significantly better
Data collection cost					
Data collection effort					
Data quality					

3. For what project types does your agency collect inventory data using the method? **Select all that apply.**

□ New construction
□ Reconstruction
□ Rehabilitation
□ Preservation
□ Other (please specify)

4. For what assets does your agency collect inventory data using the method? **Select all that apply.**

□ Bridges
□ Culverts
□ Drainage
□ Guardrails
□ Pavements
□ Signs
□ Traffic signals
□ Other, specify below

5. What asset data types does your agency collect using the method? **Select all that apply.**

□ Location
□ Identification and classification
□ Geometry
□ Material
□ Quantity
□ Condition (e.g., damages)
□ Cost
□ Key dates (e.g., installation date, inspected date)

6. Is your agency currently adopting any specific guidelines on how to collect inventory using the method? If yes, please email us the documents or provide the download links in the text box below.

This is the end of this survey form.

Thank you for participating!

Appendix 3: Survey Results

1. Participant Information

Table 50. Knowledge and experience of participants

Section	States
Section A: Asset Inventory Data Collection and Management	New Mexico, Wyoming, Minnesota, Alaska, Missouri, California, Indiana, New York, Washington, Delaware, Vermont, District of Columbia, Michigan, Kentucky, Idaho, Arizona, Oregon, Ohio.
Section B: Construction Project Data Collection and Management	Wyoming, California, New York, Maine, Delaware, Arkansas, Kentucky, Idaho, Oregon.

2. Section A: Asset Inventory Data Collection and Management

2.1. Asset inventory data collection types

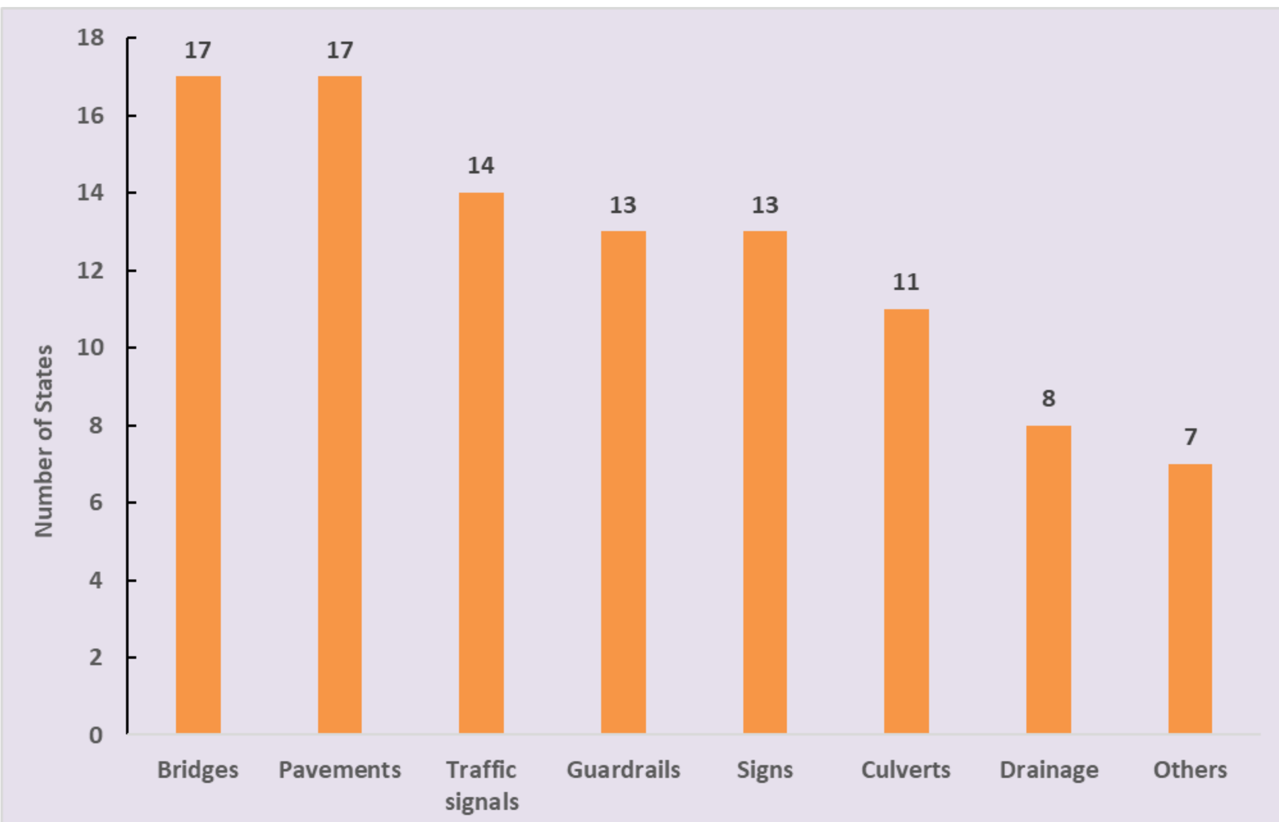

Figure 60. Asset inventory data collection types

Table 51. Type of asset inventory data collected by states

Asset Inventory Data Collection	States
Bridges	New Mexico, Wyoming, Minnesota, Alaska, Missouri, California, Indiana, New York, Washington, Delaware, Vermont, District of Columbia, Michigan, Kentucky, Arkansas, Ohio, Nevada
Pavements	New Mexico, Wyoming, Minnesota, Alaska, Missouri, California, Indiana, New York, Washington, Delaware, Vermont, District of Columbia, Michigan, Kentucky, Arkansas, Ohio, Nevada
Traffic signals	New Mexico, Minnesota, Missouri, California, Indiana, New York, Washington, Delaware, Vermont, Michigan, Kentucky, Arkansas, Ohio, Nevada
Guardrails	New Mexico, Minnesota, Missouri, Indiana, New York, Delaware, District of Columbia, Michigan, Kentucky, Arkansas, Vermont, Ohio, Nevada
Signs	New Mexico, Minnesota, Missouri, Indiana, New York, Washington, Delaware, District of Columbia, Michigan, Arkansas, Vermont, Ohio, Nevada
Culverts	New Mexico, Minnesota, Missouri, California, Indiana, New York, Delaware, Vermont, Michigan, Arkansas, Ohio
Drainage	New Mexico, Minnesota, Missouri, Indiana, New York, Delaware, Arkansas, Vermont
Others	Minnesota, Missouri, California, New York, Arkansas, Vermont, Nevada

2.2. Asset inventory data management software

Table 52. Software Applications Used to Manage Asset Inventory Data by state agencies

Software Applications	States
Esri ArcGIS (Roads and Highways)	New Mexico, Minnesota, Alaska, California, Indiana, New York, Washington, Delaware, District of Columbia, Michigan, Kentucky, Vermont, Idaho, Ohio, Nevada
Others	Minnesota, Missouri, California, Indiana, Delaware, Vermont, Michigan, Kentucky, Arizona, Oregon, Arkansas
AgileAssets Enterprise Asset Management System (EAM)	New Mexico, Wyoming, Minnesota, Alaska, Indiana, New York, Idaho, Ohio, Nevada
Microsoft Excel	Alaska, New York, Washington, Vermont, Kentucky, Arkansas
Roadway Information Management System (RIMS)	New Mexico, New York, Washington
SQL databases	Washington, Vermont, Arkansas
SharePoint	New York, Arkansas
ProjectWise	California, New York, Idaho
Microsoft Access	Minnesota, Missouri, California, Indiana, Delaware, Vermont, Michigan, Kentucky, Arkansas

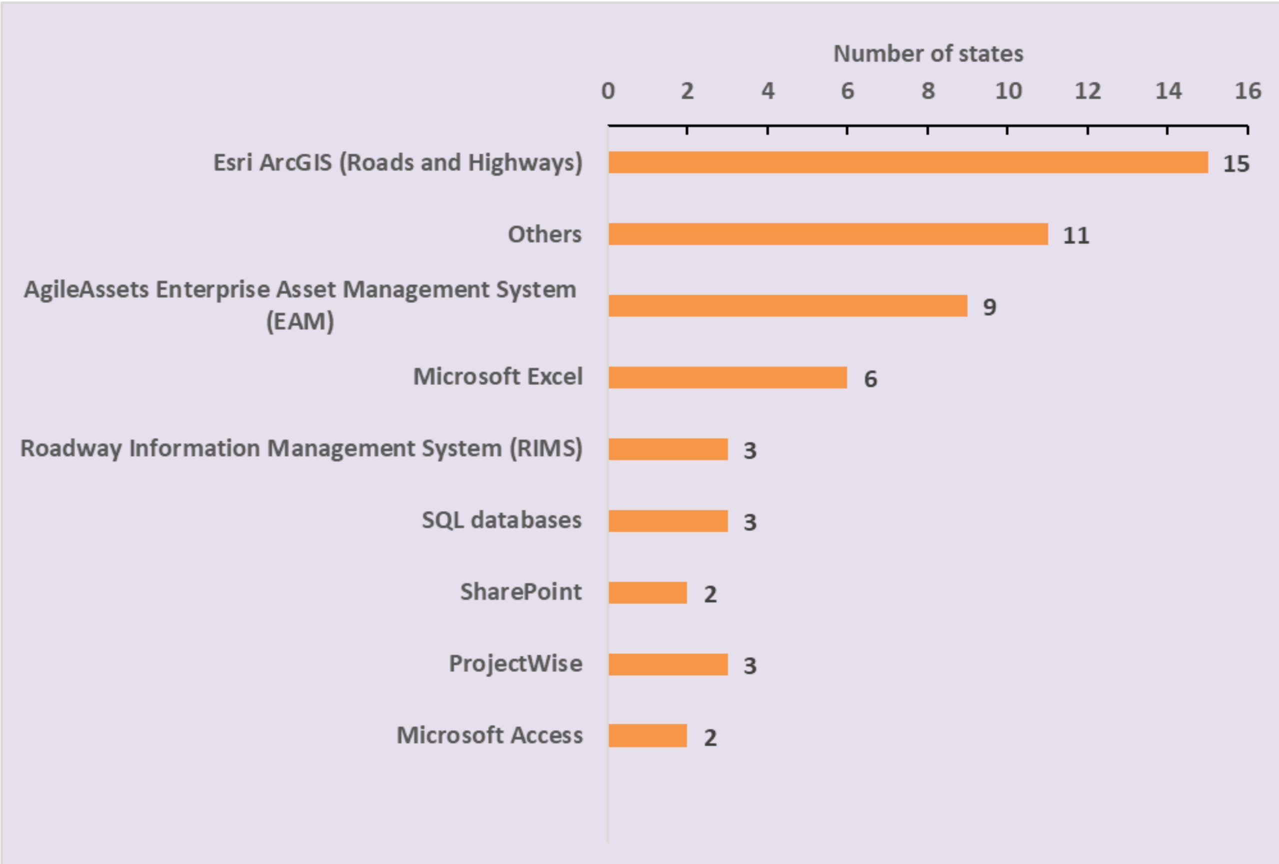

Figure 61. Software Applications used to manage asset inventory data

2.3. Asset inventory data collection methods

Table 53. Asset inventory data collection methods

Method	States
Method a: Regular statewide field asset inventory collection at a predefined frequency	New Mexico, Wyoming, Minnesota, Alaska, Missouri, California, Indiana, New York, Washington, Delaware, Vermont, District of Columbia, Kentucky, Arkansas, Idaho, Arizona, Ohio
Method b: Field asset inventory data collection during the construction stage of project delivery	New Mexico, Minnesota, California, New York, Delaware, Michigan, Arkansas, Vermont, Ohio
Method c: Asset inventory data extraction from construction documents (e.g., as-built plans/models and daily reports of work items)	New Mexico, Wyoming, Missouri, California, Indiana, Vermont, Arkansas, Idaho, Oregon, Ohio
Method d: Asset inventory data extraction from asset maintenance work orders	New Mexico, California, Delaware, Vermont, Arkansas
Others	Minnesota, Missouri, New York

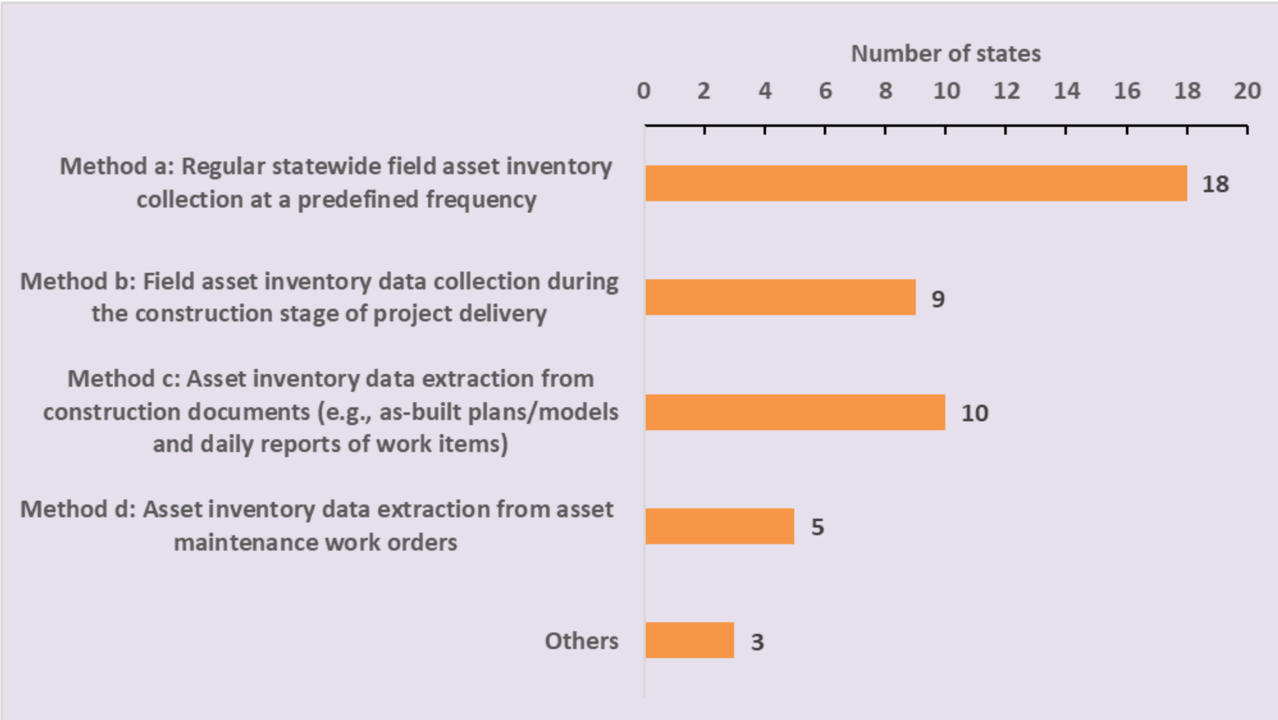

Figure 62. Asset Inventory Data collection method

2.4. Method a: Regular statewide field asset inventory data collection

a. Asset inventory data collection

Table 54. Asset inventory data collection using Method a

States	Asset inventory data collection
New Mexico	Bridges and Highways
Wyoming	Pavement Conditions
Minnesota	Location, condition
Alaska	Centerline, Pavement conditions, Bridge condition
California	Pavement Distress, Roadway Characteristics (surface type, no. lanes, etc)
Indiana	Bridges, Culverts, Drainage, Signs, Pavement Condition
New York	Pavements on an annual cycle. Structures and Large Culverts on a biennial cycle. All other assets on a four year cycle.
Delaware	Pavement, guardrail, adjacent pipes w/ span >20' (bridges)
Arkansas	Various including: Culverts, Signs, ADA Ramps, etc…
Vermont	Pavement, Bridges, Small Culverts, Rail, Aviation, Park & Rides, Stormwater, Rock slopes, Pavement, Retaining walls
District of Columbia	Pavement condition data (including distress and smoothness data), Bridge inventory and condition
Kentucky	Bridges, Culverts, Drainage, Guardrails, Pavement, Signs, Traffic signals
Ohio	IRI & Rutting/Cracking/Faulting, and Pavement Condition Rating (PCR). These pavement ratings are the only assets rated on an annual or semi-annual basis. All other assets are inventoried and/or inspected on a defined lifecycle or other frequency.
Nevada	Location, condition

b. Data collection tools and technologies

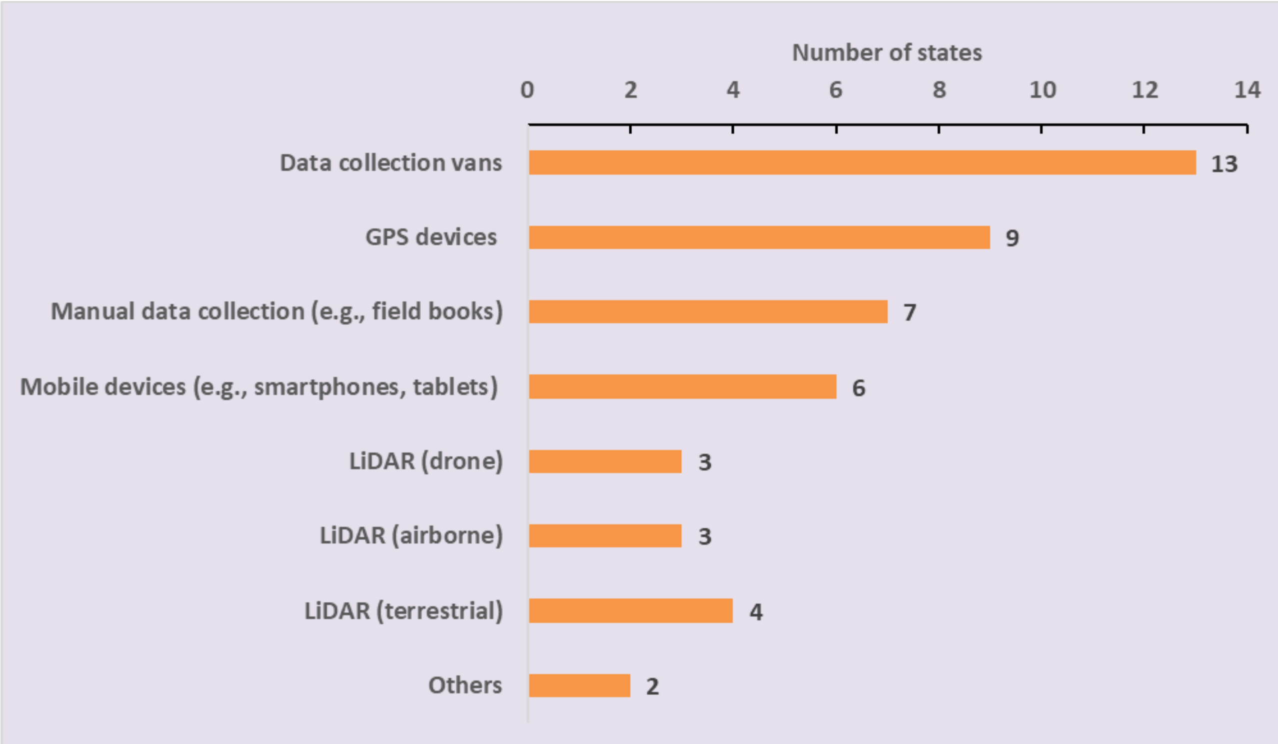

Figure 63. Technologies and Tools used in Method a

Table 55. Data collection tools and technologies

Tools and technologies	States
Data collection vans	New Mexico, Wyoming, Alaska, California, Indiana, Delaware, Vermont, District of Columbia, New York, Kentucky, Arkansas, Idaho, Ohio
GPS devices	New Mexico, Wyoming, California, Indiana, District of Columbia, Kentucky, Arkansas, Vermont, Arizona
Manual data collection (e.g., field books)	New Mexico, Wyoming, Alaska, Indiana, Delaware, District of Columbia, Minnesota
Mobile devices (e.g., smartphones, tablets)	New Mexico, Indiana, Vermont, Arkansas, Ohio, Nevada
LiDAR (airborne)	New Mexico, Kentucky, Vermont
LiDAR (drone)	Kentucky, Arkansas, Vermont
LiDAR (terrestrial)	New Mexico, Delaware, Idaho, Minnesota
Others	New York, Arkansas

c. Mobile applications

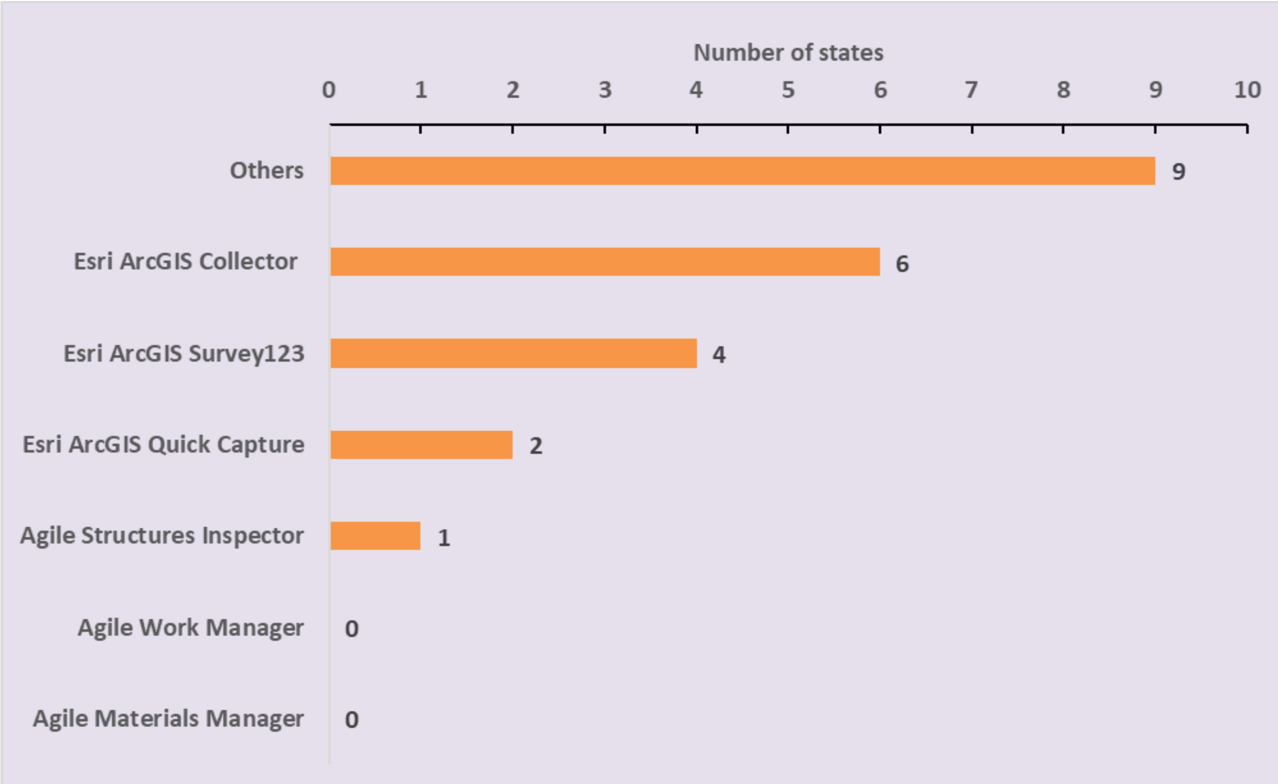

Figure 64. Mobile Applications Used for Method a

Table 56. Other mobile applications used by state agencies in Method a

Mobile applications	States
Others	New Mexico, Wyoming, Alaska, California, Delaware, District of Columbia, New York, Vermont, Arizona
Esri ArcGIS Collector	Indiana, Vermont, New York, Kentucky, Idaho, Ohio, Nevada
Esri ArcGIS Survey123	Indiana, Vermont, Arkansas, Minnesota
Esri ArcGIS Quick Capture	Arkansas, Vermont
Agile Structures Inspector	New York
Agile Materials Manager	
Agile Work Manager	

Table 57. Other mobile applications used in Method a

States	Other mobile applications
Vermont	Inspect X
New York	Fugro-Roadware iVision Asset Extraction (A manual process based on geolocated photolog pictures)
District of Columbia	PAVER, HPMS
California	ARAN Van, Trimble w/ Go Pro
Delaware	Unsure
Alaska	None
New Mexico	N/A
Wyoming	N/A

d. Asset inventories performers

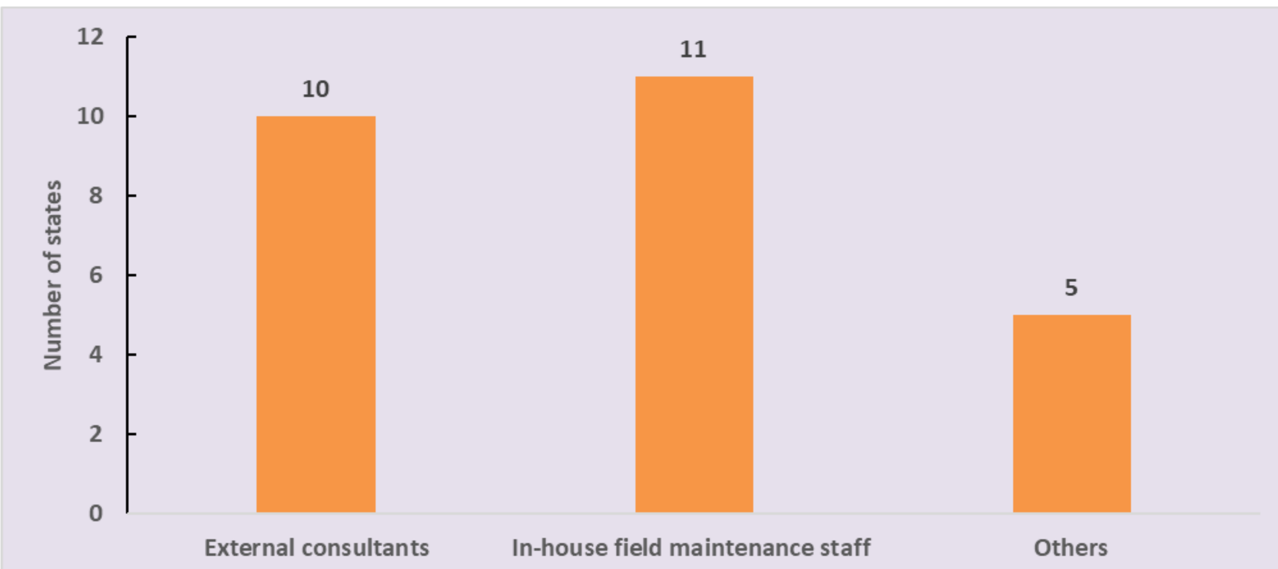

Figure 65. Asset Inventories Performers

Table 58. Asset inventory data performers in Method a

Performers	States
External consultants	New Mexico, Wyoming, Alaska, California, Indiana, Delaware, Vermont, District of Columbia, New York, Kentucky
In-house field maintenance staff	New Mexico, California, Indiana, Delaware, Vermont, Kentucky, Arkansas, Idaho, Ohio, Nevada, Minnesota
Others	Alaska, Arkansas, Vermont, Arizona, Nevada

Table 59. Other asset inventory data performers in Method a

States	Other asset inventories performers
Vermont	Structures inspection team
Alaska	In-house bridge inspectors & engineers
Arkansas	Interns as needed
Arizona	In House Features Inventory Service Team

Table 60. Summarizing Innovative practices among Pioneering states using Method a

States	Respondents	Method a: Regular statewide field asset inventory collection at a predefined frequency			
		Assets	Tools and Technologies	Mobile applications	Performers
Alaska	Jillian Nicolazzo	-Centerline, -Pavement conditions, -Bridge condition	-Manual data collection (e.g., field books), -Data collection vans	None	- External consultants, - In house bridge inspectors & engineers
Indiana	Derek Fuller	-Bridges, -Culverts, -Drainage, -Signs, -Pavement Condition	-GPS devices, -Manual data collection (e.g., field books), -Mobile devices (e.g., smartphones, tablets), -Data collection vans	- Esri ArcGIS Collector, - Esri ArcGIS Survey123	- External consultants, - In-house field maintenance staff
Minnesota	Trisha Stefanski	N/A	N/A	N/A	N/A
New Mexico	Hao Yin	Bridges and highways	-GPS devices, -LiDAR (airborne), -LiDAR (terrestrial), -Manual data collection (e.g., field books), -Mobile devices (e.g., smartphones, tablets), -Data collection vans	N/A	- External consultants, - In-house field maintenance staff
New York	Mike Rossi	-Pavements on an annual cycle. -Structures and Large Culverts on a biennial cycle. -All other assets on a four-year cycle.	-Data collection vans, -Structures and large culverts are collected via in-person inspection	- Agile Structures Inspector, - Esri ArcGIS Collector, - Fugro-Roadware, - iVision, - Asset Extraction	- External consultants
New York	Brett Dean	N/A	N/A	N/A	N/A
Wyoming	Wes Bybee	-Pavement Conditions	-GPS devices, -Manual data collection (e.g., field books), -Data collection vans	N/A	- External consultants
Idaho	Dorothy Aydelotte	- Bridge - Pavements	- Data collection vans - Lidar (terrestrial)	- Esri ArcGIS Collector,	In-house field maintenance staff
Ohio	Ian Kidner	- Pavements (annual or semi-annual) - Other assets (other frequency)	- Data collection vans - Mobile devices (e.g., smartphones, tablets),	- Esri ArcGIS Collector,	In-house field maintenance staff

2.5. Method b: Field asset inventory data collection during the construction stage of project delivery

a. Asset inventory data collection

Table 61. Asset inventory data collection using Method b

States	Asset inventory data collection
New Mexico	Bridges and Highways
Michigan	Currently, mainly location information. We are working on getting statewide asset collection guides developed with a statewide data schema for everyone to be collecting the same data on the assets.
California	Location info, Roadway Characteristics, and some HPMS-specific items.
Delaware	Storm Water Management Facilities, Storm Sewer Structures, New Bridges
Vermont	Type A signs, Pavement, small culverts, Bridges
Arkansas	Various, including Utility, Pavement
Ohio	A couple years ago, ODOT developed an FME process to extract asset data from construction plans. This process creates initial inventory records in the Collector / Field Maps systems, and then District staff then perform field visits to complete the inventory and/or initial inspection. ODOT has not yet begun receiving “As Built” information from the construction teams. We are currently evaluating this through our BIM initiative.

b. Mobile applications

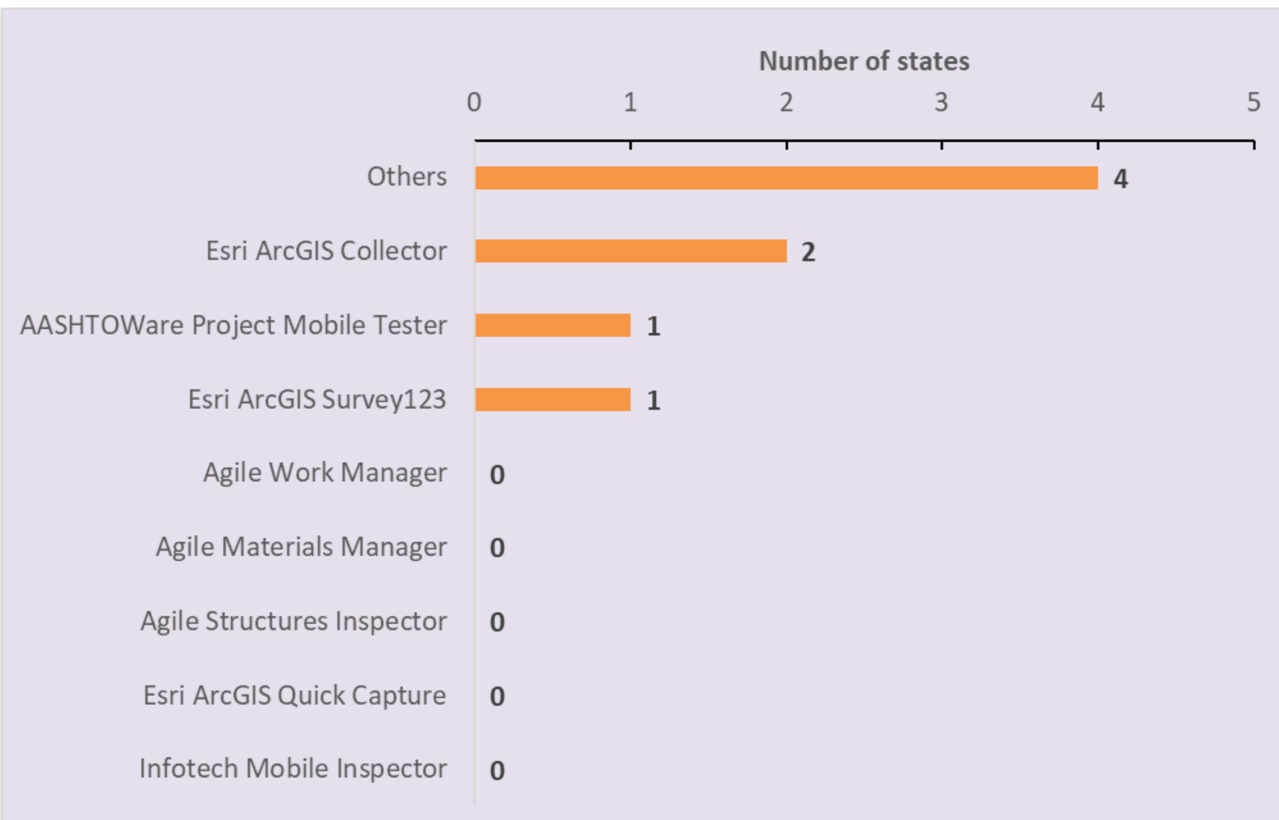

Figure 66. Mobile Applications Used in Method b

Table 62. Mobile applications used in Method b

States	Mobile applications
New Mexico	AASHTOWare Project Mobile Tester
Michigan	Esri ArcGIS Collector, Esri ArcGIS Survey123
Delaware	None - Import from GPS Survey into Esri
Arkansas	Outside Sources
California	Trimble w/ Go Pro Dash Cam
Vermont	VPins data, project summary pay items.

c. Asset inventories performers

Figure 67. Asset Inventories Performers

Table 63. Asset inventories performers in Method c

Performers	States
Contracted consultant	New Mexico, Delaware, Michigan, Arkansas, Ohio
In-house field maintenance staff	New Mexico, California, Michigan, Vermont, Ohio
Highway construction contractor	New Mexico, Delaware, Vermont, Ohio
In-house construction engineers	New Mexico, Delaware, Vermont
Others	Michigan

Asset inventory data are performed by contracted consultants, in-house field maintenance staff, in-house construction engineers, and highway construction contractors.

d. Drawbacks

Table 64. Drawbacks of asset inventories using Method b

States	Drawbacks
Delaware	Burden on construction staff. No clean, uniform method of acquiring the data yet.
Michigan	It creates another additional task that field staff must perform on top of their standard inspection duties. Looking to leverage current workflows with AASHTOWare digital measurement to capture asset information
California	Travel, periodic overnight costs, vehicle maintenance/gas
Vermont	work in progress
Ohio	Current obstacles to implementing are primarily organizational change. Currently, construction vendors can "non-perform" updating design plans, and it is unknown what the cost to the agency would be to require As-Built information.

Table 65. Summarizing Innovative practices among Pioneering states using Method b

States	Respondents	Method b: Field asset inventory data collection during the construction stage of project delivery			
		Assets	Mobile applications	Performers	Drawback
Alaska	Jillian Nicolazzo	N/A	N/A	N/A	N/A
Indiana	Derek Fuller	N/A	N/A	N/A	N/A
Minnesota	Trisha Stefanski	N/A	N/A	N/A	N/A
New Mexico	Hao Yin	- Bridges and Highways	- AASHTOWare Project Mobile Tester	-Contracted consultant, -Highway construction contractor, -In-house construction engineers, -In-house field maintenance staff	N/A
New York	Mike Rossi	N/A	N/A	N/A	N/A
New York	Brett Dean	N/A	N/A	N/A	N/A
Wyoming	Wes Bybee	N/A	N/A	N/A	N/A
Idaho	Dorothy Aydelotte	N/A	N/A	N/A	N/A
Ohio	Ian Kidner	N/A	Esri ArcGIS Collector	Contracted consultant, In-house construction engineers, In-house field maintenance staff	N/A

2.6. Method c: Asset inventory data extraction from construction documents (e.g., as-built plans/models and daily reports of work items)

a. Asset inventory data collection

Table 66. Asset inventory data collection using Method c

States	Asset inventory data collection
New Mexico	Bridges and Highways
Wyoming	Culverts, Roadway Thicknesses, Bridge Rehabilitation
Indiana	Drainage, Smaller assets
Vermont	Rumble strips
California	As much as possible

b. Construction documents

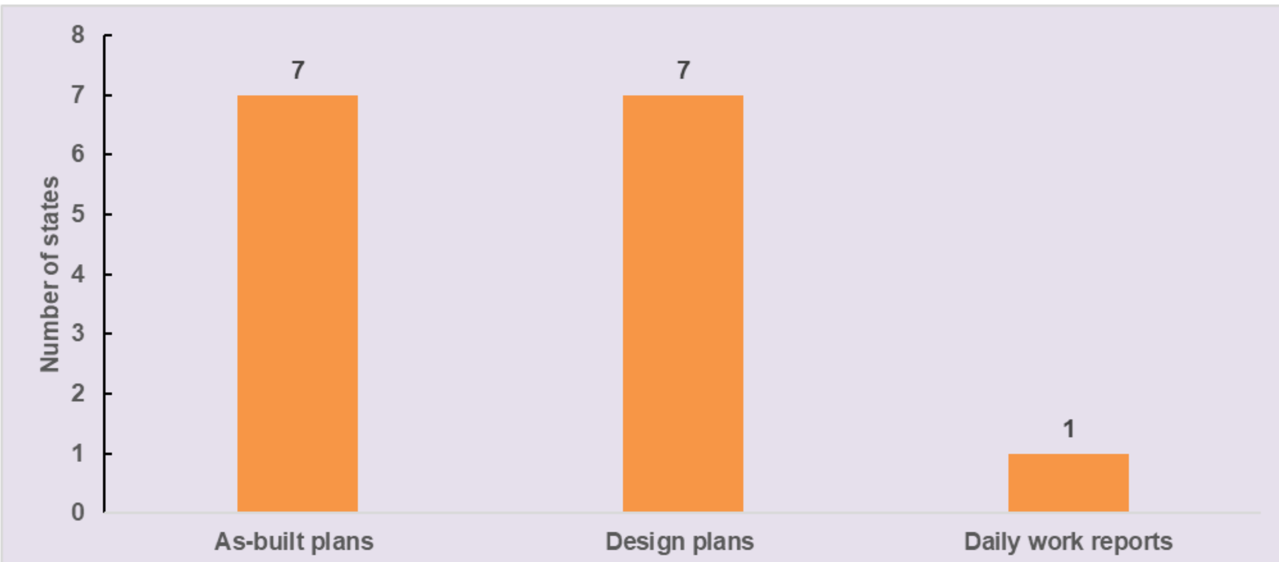

Figure 68. Construction Project Documents for Asset Inventory Data Extraction

Construction documents	States
As-built plans	New Mexico, Wyoming, California, Indiana, Vermont, Idaho, Oregon
Design plans	New Mexico, Wyoming, California, Indiana, Vermont, Oregon, Ohio
Daily work reports	New Mexico

c. Software applications of construction documents

Table 67. Name of software applications from construction documents

States	Software applications from construction documents
Vermont	Adobe Acrobat (PDF)
California	CADD files housed in ProjectWise As-Builts from in-house Project Database
Wyoming	iPDWeb
Indiana	Oracle Database, PDF
New Mexico	N/A

d. Data extraction methods

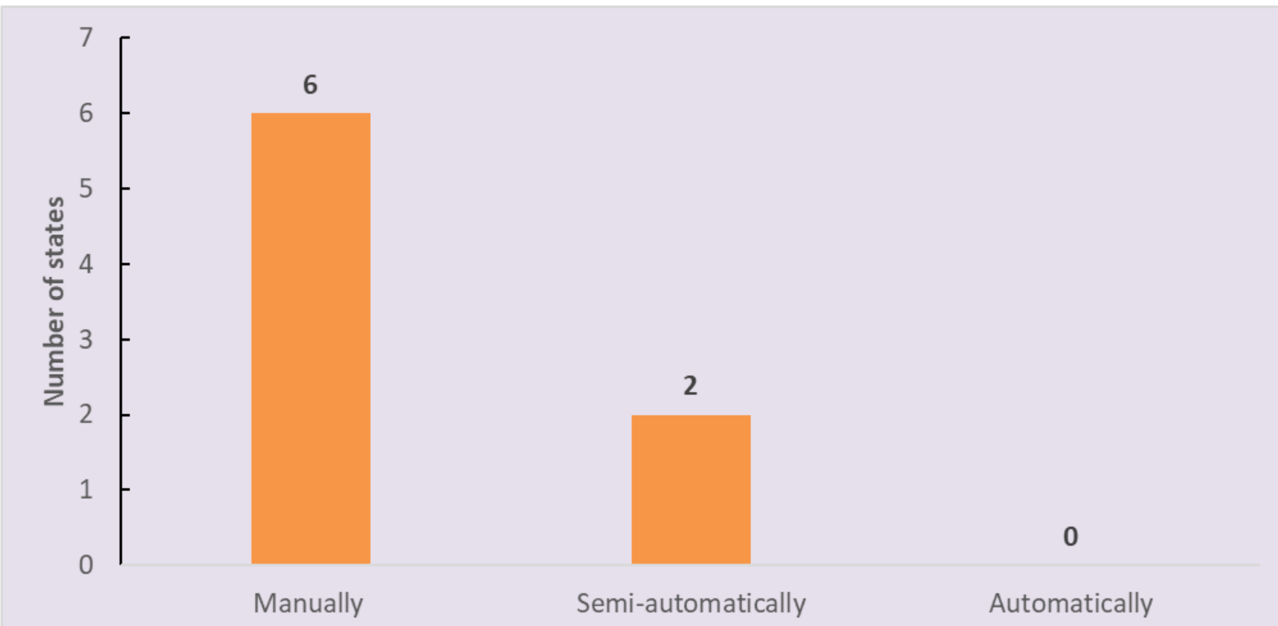

Figure 69. Data extraction methods from construction documents

Data extraction method	States
Manually	Wyoming, California, Indiana, Vermont, Idaho, Oregon
Semi-automatically	New Mexico, Ohio
Automatically	

e. Challenges

Table 68. Challenges in using construction documents for updating transportation asset inventories.

States	Challenges
Wyoming	Accuracy of as-built plans and manual entry into Agile Assets
Vermont	CADD files are "flattened" to PDF, eliminating the possibility of direct data extraction. Even if CADD files were not flattened, no standards would ensure consistent location and data values.
New Mexico	Frequency and data processing
Indiana	The data source isn't always located in a consistent location. The data available isn't consistent and well-defined.
California	Time-consuming; Staff's ability to accurately read detailed plans
Idaho	The biggest challenges we currently have is a recent change to our LRS means it is sometimes difficult to determine which method of referencing in the construction documents.
Ohio	Currently we do not receive As-Built information, and are extracting from the design plans, so there could be a difference. As we advance BIM to higher levels (4D, 5D, etc.) I foresee our technology integration and data interchange issues with our current architecture & process that will need evaluated

Table 69. Summarizing Innovative practices among Pioneering states using Method c

States	Respondents	Method c: Asset inventory data extraction from construction documents (e.g., as-built plans/models and daily reports of work items)				
		Assets	Construction project documents	Software applications	Extraction methods	Challenges
Alaska	Jillian Nicolazzo	N/A	N/A	N/A	N/A	N/A
Indiana	Derek Fuller	-Drainage, -Smaller assets	-As-built plans, -Design plans	-Oracle Database, -PDF	-Manually	-The data source isn't always located in a consistent location. -The data available isn't consistent and well defined.
Minnesota	Trisha Stefanski	N/A	N/A	N/A	N/A	N/A
New Mexico	Hao Yin	-Bridges and Highways	-As-built plans, -Daily work reports, -Design plans	N/A	-Semi-automatically	-Frequency and data processing
New York	Mike Rossi	N/A	N/A	N/A	N/A	N/A
New York	Brett Dean	N/A	N/A	N/A	N/A	N/A
Wyoming	Wes Bybee	-Culverts, -Roadway Thicknesses, -Bridge Rehabilitation	-As-built plans, -Design plans	-iPDWeb	-Manually	-Accuracy of as-built plans and manual entry into Agile Assets.
Idaho	Dorothy Aydelotte	N/A	As-built plans,	Sharepoint	Manually	A recent change to LRS means
Ohio	Ian Kidner	N/A	Design plans	FME	Semi-automatically	Technology integration and data interchange issues with the current architecture & process

2.7. Method d: Asset inventory data extraction from maintenance work orders

a. Asset inventory data collection

Table 70. Asset inventory data collection using Method d

States	Asset inventory data collection
Delaware	All categories focused on previously installed devices before we began collection during construction and on devices not easily identified by lidar.
California	As much as we can. Generally, the work orders we see are for simple stand-alone work. Replacing guardrails, signs, etc
New Mexico	Drainage
Vermont	Small Culverts, Guardrails, Signs, Stencils

b. Maintenance work orders format

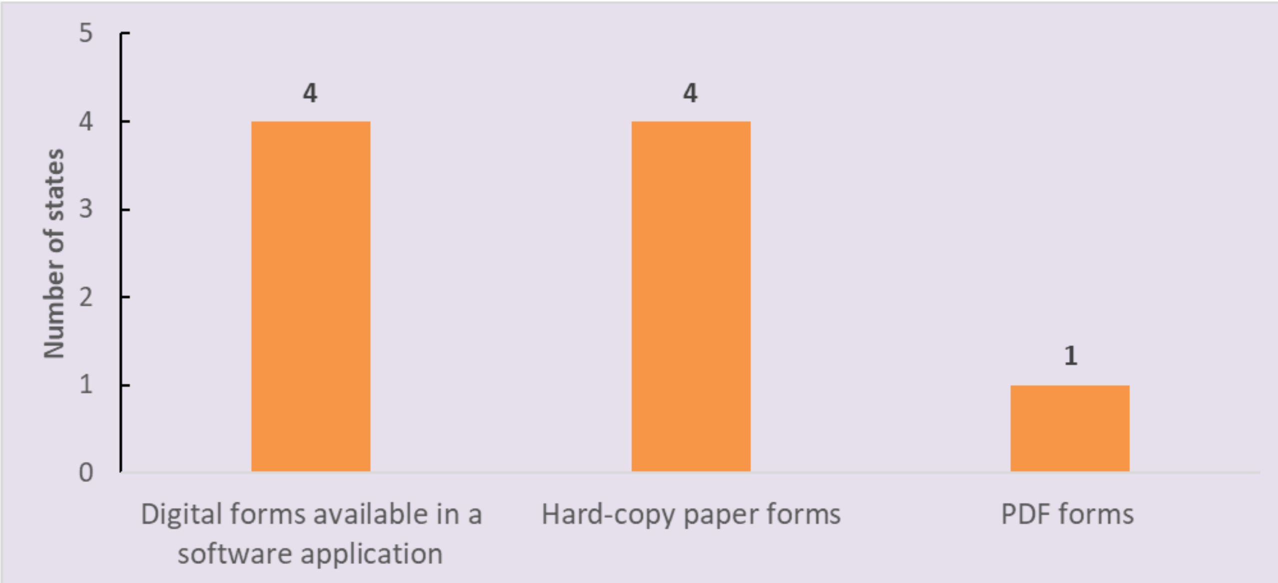

Figure 70. Format of Maintenance work orders

c. Software applications

Table 71. Software applications are obtained from maintenance work orders

States	Software applications
Delaware	IBM Maximo
California	In-house database
Vermont	MATS (In-House Application)
New Mexico	N/A
Ohio	Agile Assets

d. Data extraction methods

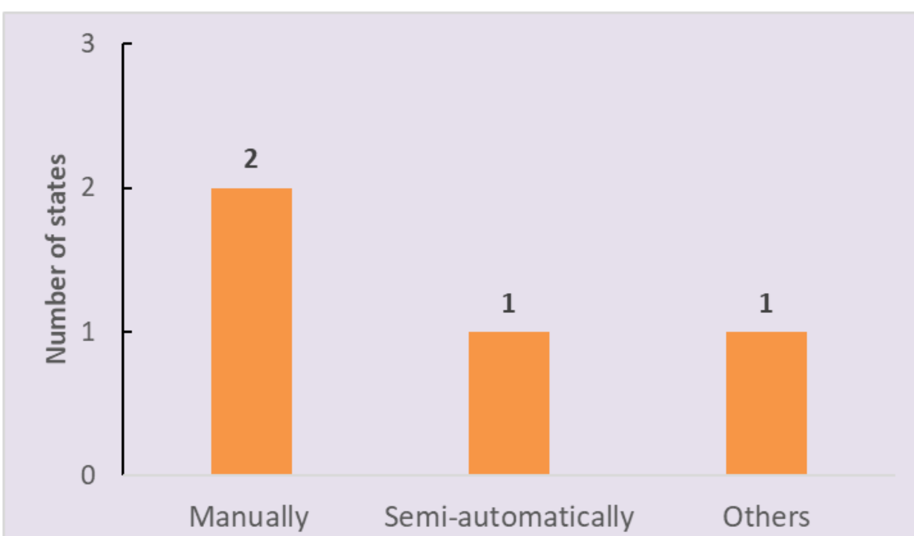

Figure 71. Data extraction methods from maintenance work orders

Table 72. Data extraction methods from maintenance work orders

Methods	States
Manually	California, Vermont
Semi-automatically	New Mexico
Others	Delaware

e. Challenges

Table 73. Challenges in using maintenance work orders for updating transportation asset inventories.

States	Challenges
Vermont	Data entry is not standardized, so data quality is suspect and sometimes makes the data unusable.
California	Time-consuming; Info in work orders is not very detailed.
New Mexico	Time effort
Delaware	Unsure
Ohio	Unsure

Table 74. Summarizing Innovative practices among Pioneering states using Method d

States	Respondents	Method d: Asset inventory data extraction from asset maintenance work orders				
		Asset inventory data extraction	Maintenance work orders format	Software applications	Extraction methods	Challenges
Alaska	Jillian Nicolazzo	N/A	N/A	N/A	N/A	N/A
Indiana	Derek Fuller	N/A	N/A	N/A	N/A	N/A
Minnesota	Trisha Stefanski	N/A	N/A	N/A	N/A	N/A
New Mexico	Hao Yin	Drainage	- Digital forms available in a software application, - Hard-copy paper forms, - PDF forms	N/A	Semi-automatically	Time effort
New York	Mike Rossi	N/A	N/A	N/A	N/A	N/A
New York	Brett Dean	N/A	N/A	N/A	N/A	N/A
Wyoming	Wes Bybee	N/A	N/A	N/A	N/A	N/A
Idaho	Dorothy Aydelotte	N/A	N/A	N/A	N/A	N/A
Ohio	Ian Kidner	N/A	Digital forms available in a software application, Hard-copy paper forms,	Agile Assets	N/A	N/A

2.8. Additional comments and suggestions

a. Annual budget spent for asset inventory data collection

Table 75. Estimation of the annual budget spent for asset inventory data collection

States	Annual budget
Wyoming	$800k for pavement surfaces; unsure of all other assets
New York	$90M per year (A vast majority of this is our bridge inspection contracts)
Kentucky	N/A
New Mexico	Unsure
Missouri	Unsure
California	Unsure
Indiana	Unsure
New York	Unsure
Delaware	Unsure
Vermont	Unsure
District of Columbia	Unsure
Michigan	Unsure
Alaska	Unsure $1 million, maybe
Minnesota	Unsure
Georgia	Unsure
Idaho	Unsure
Arizona	Unsure
Oregon	Unsure
Ohio	Unsure

b. Comments

Table 76. Additional comments regarding types and methods of asset inventory data collection.

States	Additional comments
Alaska	We are beginning to inventory things like signs, lights, culverts, and guardrails, but it has not been implemented statewide. We also have a partial inventory of rock slopes, soil slopes, and retaining walls.
California	We generally are trying to capture HPMS and MIRE-type data elements.
Delaware	We are looking to upgrade our processes into a more cohesive system that improves asset management, digital as-builts, and Construction QC.
Indiana	For use in determining life expectancy and condition of assets and predicting future maintenance costs.
Michigan	We are looking to leverage other workflows designers perform to move asset information from the CAD to the GIS environment. The goal is that field staff will only have to verify location and input specific asset information versus performing all data collected in the field.
Minnesota	MnDOT utilizes remote sensing technologies on above-ground assets and as-builts post-construction to collect asset inventory data. When Maintenance crews fix or add assets, those crews are also updating asset inventory.
Missouri	Each asset is a separate inventory connected to a centralized LRS. Different divisions maintain different assets. Many are updated during required annual inspections; others are updated during installation. Additionally, we collect yearly ROW videos of every route while collecting pavement data.
New York	Photolog, consultant data collection projects (handicapped sidewalk ramps, signalized or un-signalized crosswalks, etc.), exploring mobile LiDAR options
Vermont	Some asset data currently collected is not specific to building an asset inventory. It may be more about getting a rough order of magnitude.
Wyoming	Pavement surfacing data is collected through consultants. Bridge data is compiled utilizing inspection data. Culverts and other items are tracked via as-builts.
Idaho	Construction information is collected from the as-built plans. Current condition information and curvature is collected by our profile van. Other asset information is collected by various means including field inventory, LIDAR, and reference to video footage from the profile van among other methods. In the past we have attempted to gather data from maintenance work orders, but uneven entry of those forms proved to make the data unreliable at best.
Arizona	The data is currently collected In House, using GPS devices.
Ohio	As mentioned in an earlier question, we are starting to collect mobile LiDAR. We plan to create entirely new inventories like pavement markings, and seek opportunities to augment the inventories manually maintained by field staff with iPads (ESRI). We are also looking into crowd-sourced data from OEM vehicles as another potential data source.

c. Suggestions

Table 77. Recommendations for reducing field asset inventory data collection

States	Recommendation 1	Recommendation 2	Recommendation 3
Alaska	Fugro collects pavement data annually. In 2018 we had them also do a data extraction to count and locate signs, lights, and guardrails.	We could extract installation dates and locations of signs, lights, guardrails, etc., from construction as-builts, but it would be a huge task.	We could better use the data collected by the QA/QC program conducted by the maintenance & operations section.
California	Easy access to CADD files and plans or proposals when available.	Permit-type work is hard to track as we are not notified when major work is performed.	Local Entities could provide better data on off-system routes.
Delaware	Collect information at the point of installation.		
District of Columbia	collection of relevant data after construction	use of as-built drawings	
Indiana	Automated methods to utilize the as-designed CAD data in construction for as-built asset collection.	Consistent data requirements.	Software that is easily compatible with data from other software.
Minnesota	Building Information Modeling: utilize existing asset data, add survey data, add/modify at the design stage, review attributes at construction phase, add as-built locations, and push back into the asset database.	Generate a baseline of asset data by innovative remote sensing technology: aerial or Mobile lidar and imagery.	Maintenance crews create work orders and update/add asset data directly on mobile hardware devices with user-friendly software.
New York	Mobile LiDAR of transportation system	Photolog of transportation system	extract data from construction As-Builts
Vermont	Full electronic process and files, from design through construction completion.	Standardized processes and data.	Communication - all the agency staff know the big picture regarding data, their part in creating and maintaining data, and the uses and needs for the consistent data they produce.
Wyoming	Utilizing GPS modeling to integrate as-built data into Agile Assets		

3. Section B: Construction Project Data Collection and Management

3.1. Project data collection

Table 78. Project data are collected during the construction stage of project delivery

States	Construction project data collection
Maine	All Item or material quantity and locations, along with installation and acceptance notes. The elevation will be picked up on some items and materials. Depending upon the item, the location may be station and offset, beginning and ending station, or GPS location.
New York	Asset locations (above and below ground), alignment info, elevations, surface info, bridge clearances, ROW verification, contractor layout and location verification, quantity calculations for work items (earthwork/topsoil, etc.), and any other info deemed important. Items installed per day, quantities, material acceptances, contractor(s) on-site, location.
Wyoming	Locations & Depths
California	Most data relating to inventory is not collected until the end of the project or after it is open to traffic.
Arkansas	Site Manager Daily Work Reports include work completed, weather, measurement and payment, time charges, traffic conditions, contractors working, etc.
Delaware	Storm Water Management Facilities, Storm Sewer Structures
Kentucky	None

There are vast construction project data collected during the construction stage, such as asset locations, quantities, measurements, payment, and all project conditions.

3.2. Types of As-built drawings

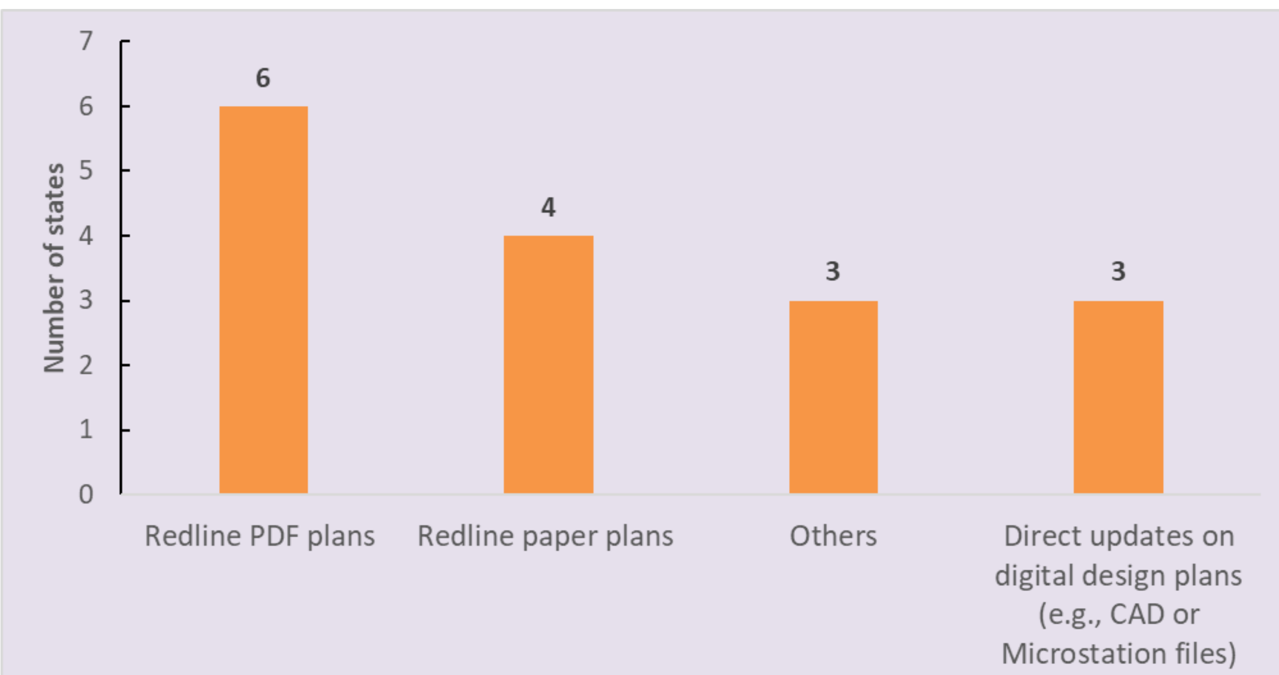

Figure 72. Types of as-built drawings

Table 79. As-built drawing types

As-buil drawing types	States
Redline PDF plans	Wyoming, California, New York, Maine, Delaware, Ohio
Redline paper plans	New York, Maine, Delaware, Ohio
Others	New York, Arkansas, Kentucky
Direct updates on digital design plans (e.g., CAD or Microstation files)	California, New York, Ohio

3.3. Collection tools, technologies, and methods

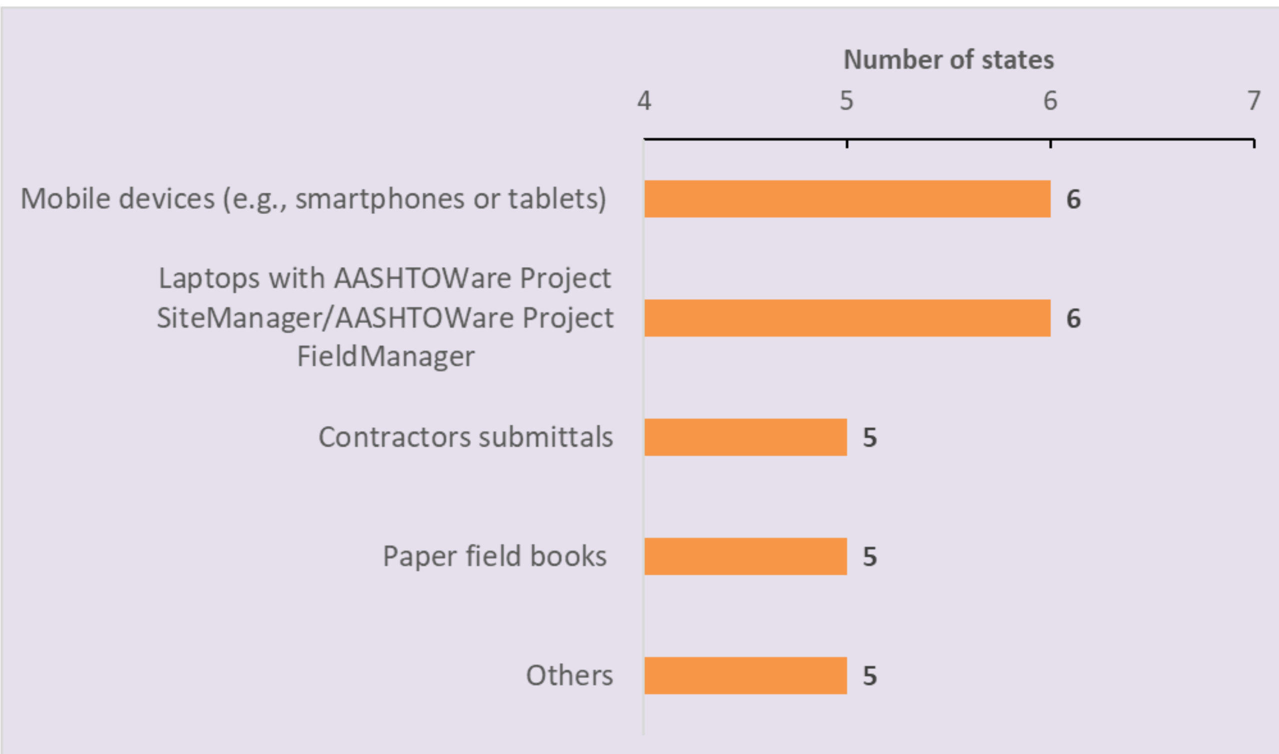

Figure 73. Technology, Tools, and Methods Used for Collecting Construction Project Data

Table 80. Data collection tools, technologies, and methods

Tools, technologies, methods	States
Mobile devices (e.g., smartphones or tablets)	Wyoming, New York, Maine, Delaware, Arkansas, Georgia
Contractors submittals	California, New York, Maine, Arkansas, Georgia, Ohio
Laptops with AASHTOWare Project SiteManager/AASHTOWare Project FieldManager	California, New York, Delaware, Arkansas, Georgia
Paper field books	California, New York, Maine, Arkansas, Georgia
Others	Wyoming, New York, Arkansas, Kentucky, Oregon

Table 81. Other tools, technologies, and methods used for construction project data collection

States	Other tools, technologies, and methods
Wyoming	iPDWeb
Kentucky	None
New York	Survey equipment, piloting various software and products to see what would be beneficial to our field staff
Arkansas	Tablets
Ohio	GoForms

3.4. Mobile applications

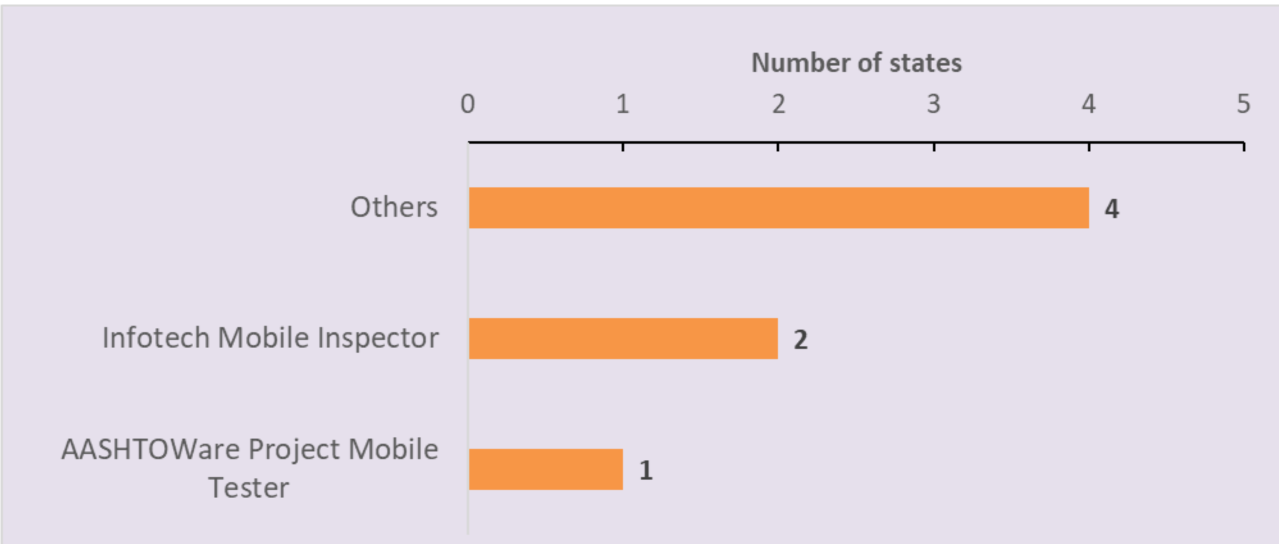

Figure 74. Mobile applications used for field collection of construction project data

Table 82. Mobile applications used for field collection of construction data

Mobile applications	States
Others	Wyoming, New York, Delaware, Arkansas
Infotech Mobile Inspector	New York, Maine
AASHTOWare Project Mobile Tester	Georgia
Agile Materials Manager	
Agile Structures Inspector	
Agile Work Manager	

Table 83. Other mobile applications used for construction project data collection

States	Other mobile applications
New York	Agile Assets, piloting Reconstruct software,3D/4D/5D BIM on large Design/Build projects
Arkansas	Doc Express
Wyoming	iPDWeb Fieldbook application
Delaware	Oracle Primavera Unifier

3.5. Data management software applications

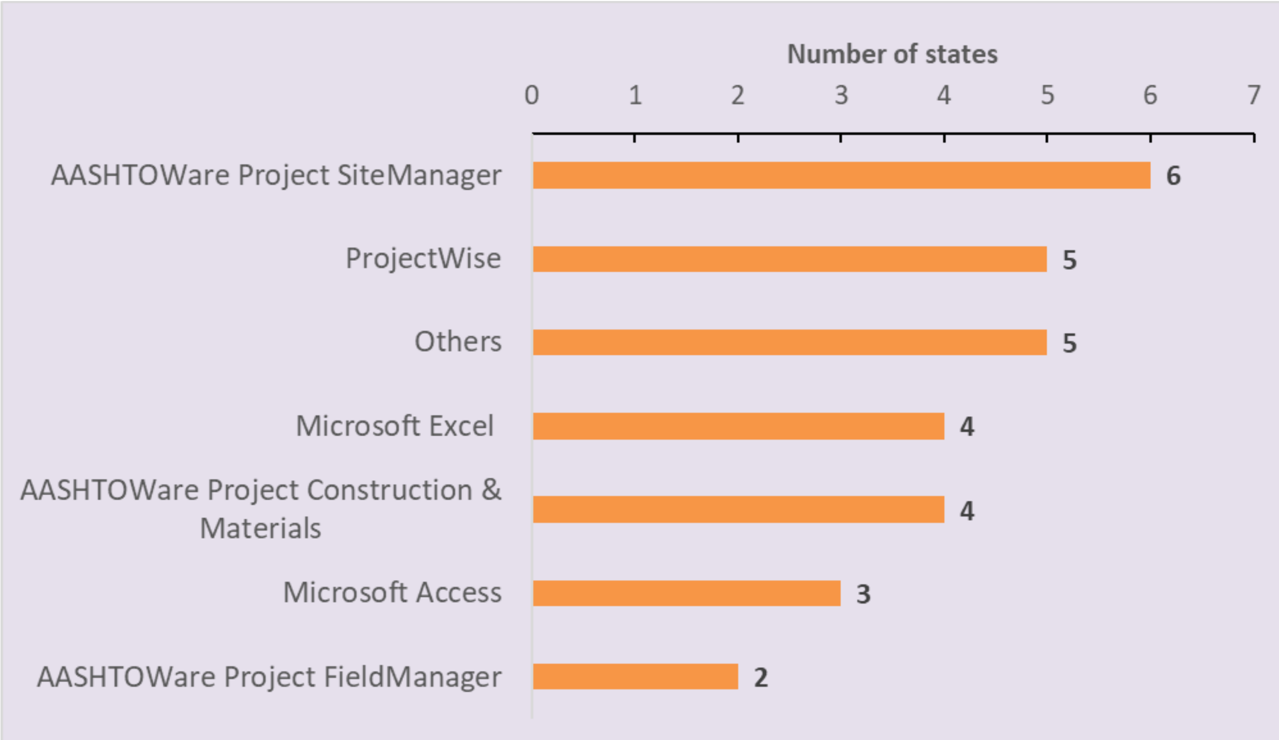

Figure 75. Software applications used for managing construction data

Table 84. Software applications applied for construction project data collection

Software applications	States
Others	Wyoming, New York, Maine, Delaware, Arkansas
AASHTOWare Project SiteManager	California, New York, Arkansas, Kentucky, Georgia, Ohio
Microsoft Excel	New York, Maine, Arkansas, Kentucky
ProjectWise	California, New York, Delaware, Kentucky, Oregon
AASHTOWare Project Construction & Materials	New York, Arkansas, Kentucky, Georgia
Microsoft Access	New York, Maine, Arkansas
AASHTOWare Project FieldManager	Maine, Georgia

Table 85. Other software applications used for construction project data collection

States	Other software applications
Arkansas	AASHTOWare Project - pending
Wyoming	iPDWeb
Delaware	Oracle Primavera Unifier
New York	Piloting Reconstruct
Maine	Working on the implementation of AASHTOWare Project Construction and Materials for the upcoming season - will not be using the Materials portion of the software.

3.6. Construction documents

Table 86. Collected construction documents

States	Construction documents
New York	All survey data, MicroStation files, electronic As-Built data, and maybe Daily Work Reports, if they contain enough detail.
California	As-Builts/ CADD
Kentucky	Digital Plans
Arkansas	Plans and Contract
Delaware	Primarily plans, at the moment. Looking increase access to GPS Rovers for Construction inspection and move the data directly to Esri.
Wyoming	Survey data.
Maine	We are hoping to eventually be able to extract some asset data from AASHTOWare Project Construction and Materials.

Table 87. Summarizing Innovative practices among Pioneering states in Construction Project Data Collection and Management

States	Respondents	Construction Project Data Collection					
		Project data collection	Type of As-built drawings	Technologies, tools, and methods	Mobile applications	Software applications	Construction documents can be used for extracting asset inventory data.
Alaska	Jillian Nicolazzo	N/A	N/A	N/A	N/A	N/A	N/A
Indiana	Derek Fuller	N/A	N/A	N/A	N/A	N/A	N/A
Minnesota	Trisha Stefanski	N/A	N/A	N/A	N/A	N/A	N/A
New Mexico	Hao Yin	N/A	N/A	N/A	N/A	N/A	N/A
New York	Mike Rossi	N/A	N/A	N/A	N/A	N/A	N/A
New York	Brett Dean	- Asset locations (above and below ground), alignment info, elevations, surface info, bridge clearances, ROW verification, contractor layout and location verification, quantity calculations for work items (earthwork/topsoil, etc.), any other info deemed important	Direct updates on digital design plans (e.g., CAD or Microstation files), Redline paper plans, Redline PDF plans, Bluebeam	Contractors submittals, Mobile devices (e.g., smartphones or tablets), Laptops with AASHTOWare Project SiteManager/AASHTOWare Project FieldManager, Paper field books, Survey equipment, Piloting various software and products to see what would be beneficial to our field staff	Infotech Mobile Inspector, Agile Assets, Piloting Reconstruct software, 3D/4D/5D BIM on large Design/Build projects	AASHTOWare Project Construction & Materials, AASHTOWare Project SiteManager, Microsoft Access, Microsoft Excel, ProjectWise, Piloting Reconstruct	All survey data, MicroStation files, electronic As-Built data
Wyoming	Wes Bybee	Locations & Depths	Redline PDF plans	Mobile devices (e.g., smartphones or tablets), iPDWeb	iPDWeb Fieldbook application	iPDWeb	Survey data
Idaho	Dorothy Aydelotte	N/A	Direct updates on digital design plans (e.g., CAD or Microstation files), Redline paper plans, Redline PDF plans,	Laptops with AASHTOWare Project SiteManager/AASHTOWare Project FieldManager GoForms	N/A	AASHTOWare Project SiteManager	N/A

4. Minnesota DOT practices

Table 88. A sample data attributes of Traffic barriers collected in MnDOT

No	Column ID	Column Label	View Type	Data Type
1	AUD_DATE_CREATE	Edit Date Create	D-Date	
2	AUD_DATE_UPDATE	Edit Date Update	D-Date	
3	AUD_USER_CREATE	Edit User Create	S-String	
4	AUD_USER_UPDATE	Edit User Update	S-String	
5	CC_SPATIAL	Geometry	G-Geometry	Geometry
6	CC_XY_SOURCE	X-Y Source	T-List	Integer
7	COMMENT_ID	Att.	R-Number	Integer
8	COMMENT_STR	Comments	S-String	String
9	DATE_ACTIVE	Date Activated	D-Date	Date
10	DATE_RETIRE	Retire Date	D-Date	Date
11	DATE_UPDATE	Date Update	D-Date	Date
12	DISP_METHOD_ID	Disposal Method	T-List	Integer
13	EXT_ASSET_ID	External Asset ID	S-String	String
14	GLOBALID	Global ID	S-String	
15	INSTALL_DATE	Installed Date	D-Date	Date
16	LENGTH	Length	R-Number	Number
17	MMS_ACC_HORIZ	Horizontal Accuracy	R-Number	Number
18	MOB_LRS_CALC	LRS recalculate	S-String	
19	MOB_ROUTE_GLOBALID	Route Link	S-String	
20	OBJECTID	ArcGis ID	R-Number	
21	OWNER_ID	Administrative Unit	T-List	Integer
22	PERIODIC_MAINT_ID	Periodic maint id	R-Number	Integer
23	RETIRE_REASON_ID	Retired Reason	T-List	Integer
24	TB_ANCHOR_POST_DN_ID	Downstream Anchor Post Type	T-List	Integer
25	TB_ANCHOR_POST_UP_ID	Upstream Anchor Post Type	T-List	Integer
26	TB_BARRIER_HEIGHT	Height of Barrier	R-Number	Number
27	TB_BARRIER_OFFSET	Barrier Offset	R-Number	Number
28	TB_BLOCK_OUT_DEPTH_ID	Blockout Depth	T-List	Integer
29	TB_BLOCK_OUT_TYPE_ID	Blockout Type	T-List	Integer
30	TB_CABLE_NUM	# of Cables	R-Number	Number
31	TB_CURB_HEIGHT_ID	Curb Height	T-List	Integer
32	TB_INSTALLED_BY	Installed By	S-String	String
33	TB_INSTALL_LOC_ID	Installed Location	T-List	Integer
34	TB_LBCAT_TYPE_ID	Category Type	T-List	Integer
35	TB_LBSUBCAT_TYPE_ID	Subcategory Type	T-List	Integer
36	TB_LINE_POST_ID	Line Post Type	T-List	Integer
37	TB_POST_SPACING	Nominal Post Spacing	R-Number	Number
38	TB_POST_TYPE_ID	Post Type	T-List	Integer
39	TB_QC	QC	C-CheckBox	Integer
40	TRAF_BARRIER_CLASS_CODE_ID	Linear Barriers Class Code	T-List	Integer
41	TRAF_BARRIER_ID	Linear Barriers	T-List	Integer
42	TRAF_BARRIER_NAME	Linear Barriers	S-String	String
43	TRAF_BARRIER_STATUS_ID	Linear Barriers Status	T-List	Integer
44	USER_UPDATE	User Update	S-String	String

Table 89. A sample data attributes of ITS Devices collected in MnDOT

No	Column ID	Column Label	View Type	Data Type
1	ACCOUNTCODE	Account Code	S-String	String
2	AUDIT_LINK	Record History	T-List	Integer
3	COMMENT_ID	Att.	R-Number	Integer
4	COMMENT_STR	Comments	S-String	String
5	DATE_ACTIVE	Date Activated	D-Date	Date
6	DATE_RETIRE	Retire Date	D-Date	Date
7	DATE_UPDATE	Date Update	D-Date	Date
8	EXT_ASSET_ID	External Asset ID	S-String	String
9	GEOM	Geometry	G-Geometry	Geometry
10	HEIGHT	Height	R-Number	Integer
11	IFAMS_COMMENT	IFAMS Comments	S-String	String
12	INSTALLATIONDATE	Installation Date	D-Date	Date
13	ITS_ALIAS	Alias	S-String	String
14	ITS_DEVICE_CLASS_CODE_ID	Device Class Code	T-List	Integer
15	ITS_DEVICE_ID	ITS Device	T-List	Integer
16	ITS_DEVICE_NAME	ITS Device	S-String	String
17	ITS_DEVICE_STATUS_ID	Asset Status	T-List	Integer
18	ITS_STRUCTURE_ID	ITS Structure	T-List	Integer
19	ITS_SUBOWNER	Secondary Owner	S-String	String
20	MAINT_HIST_LINK	Maint. History	T-List	Integer
21	MANUFACTURER	Manufacturer	S-String	String
22	MISC_SYSTEM_ID	Miscellaneous Systems	T-List	
23	MODELNUMBER	Model #	S-String	String
24	OWNER_ID	Administrative Unit	T-List	Integer
25	PARTNUMBER	Part #	S-String	String
26	PERIODIC_MAINT_ID	Periodic maint id	R-Number	Integer
27	PROJECT_NUMBER	State Project Number	S-String	String
28	RACK_POSITION	Rack Position	R-Number	Integer
29	SERIALNUMBER	Serial #	S-String	String
30	SGL_ESS_ZONE_ID	Maintenance Zone	T-List	Integer
31	SGL_ITS_DEVTYPE_ID	Device Type	T-List	Integer
32	SGL_ITS_GEOMSRC_ID	Geom. Source	T-List	Integer
33	SGL_ITS_MNTTYPE_ID	Mount Type	T-List	Integer
34	SGL_ITS_OWNER_ID	Responsible Owner	T-List	Integer
35	SGL_MAINT_AREA_ID	District Maintenance Area	T-List	Integer
36	SGL_THRU_LOCATION	Location (Cross-Street)	S-String	String
37	SGL_THRU_ROUTE_ID	Thru Route	T-List	Integer
38	SIGNAL_SYSTEM_ID	Signal System	T-List	Integer
39	USER_UPDATE	User Update	S-String	String

Table 90. A sample data attributes of Hydraulic Pipes collected in MnDOT

No	Column ID	Column Label	View Type	Data Type
1	AUD_DATE_CREATE	Edit Date Create	D-Date	Date
2	AUD_DATE_UPDATE	Edit Date Update	D-Date	Date
3	AUD_USER_CREATE	Edit User Create	S-String	String
4	AUD_USER_UPDATE	Edit User Update	S-String	String
5	CC_SPATIAL	Geometry	G-Geometry	Geometry

6	COMMENT_ID	Att.	R-Number	Integer
7	COMMENT_STR	Comments	S-String	String
8	COUNTY_ID	County	T-List	Integer
9	DATE_ACTIVE	Date Activated	D-Date	Date
10	DATE_RETIRE	Retire Date	D-Date	Date
11	DATE_UPDATE	Date Update	D-Date	Date
12	EXT_ASSET_ID	External Asset ID	S-String	String
13	FROM_RP_OFFSET	Reference Post Offset	S-String	String
14	GLOBALID	Global ID	S-String	String
15	HYD_CURR_HEIGHT	Current Inside Height (In)	R-Number	Number
16	HYD_CURR_WIDTH	Current Inside Width (In)	R-Number	Number
17	HYD_DN_ELEV	Downstream Elevation (Ft)	R-Number	Number
18	HYD_DN_ELEV_SOURCE	Downstream Z Source	T-List	Integer
19	HYD_DN_H_ACC	Downstream Horizontal Accuracy	R-Number	Number
20	HYD_DN_V_ACC	Downstream Vertical Accuracy	R-Number	Number
21	HYD_DN_XY_SOURCE	Downstream X-Y Source	T-List	Integer
22	HYD_GEOM_LENGTH	Geom Length (ft)	R-Number	Number
23	HYD_LATITUDE_DN	Downstream Latitude	R-Number	Number
24	HYD_LATITUDE_UP	Upstream Latitude	R-Number	Number
25	HYD_LINER_YEAR	Year Lined	T-List	Integer
26	HYD_LONGITUDE_DN	Downstream Longitude	R-Number	Number
27	HYD_LONGITUDE_UP	Upstream Longitude	R-Number	Number
28	HYD_MATERIAL_CURR_ID	Current Inside Material	T-List	Integer
29	HYD_MATERIAL_ORIG_ID	Original Material Type	T-List	Integer
30	HYD_MS4_AREA	MS4 Area	T-List	Integer
31	HYD_OUTFALL	Outfall?	T-List	Integer
32	HYD_PIPESHAPE_ID	Current Pipe Shape	T-List	Integer
33	HYD_PIPESHAPE_ORIG_ID	Original Pipe Shape	T-List	Integer
34	HYD_PIPE_CLASSGAGE_ID	Pipe Class/Gage	T-List	Integer
35	HYD_PIPE_CLASS_CODE_ID	Pipe Class Code	T-List	Integer
36	HYD_PIPE_HEIGHT	Original Pipe Height (In)	R-Number	Number
37	HYD_PIPE_ID	Pipe	T-List	Integer
38	HYD_PIPE_LENGTH	Total Length (Ft)	R-Number	Number
39	HYD_PIPE_LINER	Lined	T-List	Integer
40	HYD_PIPE_NAME	Pipe	S-String	String
41	HYD_PIPE_STATUS_ID	Pipe Status	T-List	Integer
42	HYD_PIPE_TIES	Pipe Ties	T-List	Integer
43	HYD_PIPE_TYPE_ID	Pipe Type	T-List	Integer
44	HYD_PIPE_WIDTH	Original Pipe Width (In)	R-Number	Number
45	HYD_REG_NOTES	Regulatory Notes	S-String	String
46	HYD_REP_NOTES	Repair Notes	S-String	String
47	HYD_REP_PRIORITY_ID	Repair Priority	T-List	Integer

Table 91. A sample data attributes of Hydraulic Pipes collected in MnDOT *(continue)*

No	Column ID	Column Label	View Type	Data Type
48	HYD_REP_PROJORG_ID	Repair Project Type/Org	T-List	Integer
49	HYD_UPSTREAM_COVER	Cover at Upstream Road Edge (Ft)	R-Number	Integer
50	HYD_UP_ELEV	Upstream Elevation (Ft)	R-Number	Number
51	HYD_UP_ELEV_SOURCE	Upstream Z Source	T-List	Integer

52	HYD_UP_H_ACC	Upstream Horizontal Accuracy	R-Number	Number
53	HYD_UP_V_ACC	Upstream Vertical Accuracy	R-Number	Number
54	HYD_UP_XY_SOURCE	Upstream X-Y Source	T-List	Integer
55	HYD_YEAR_BUILT	Year Built	T-List	Integer
56	LOCAL_NAME	Local Name	S-String	String
57	LOC_IDENT	Location record identifier	R-Number	Integer
58	MMS_AGREEMENT_NUM	Maint. Agreement #	S-String	String
59	MMS_CONST_DIST_OWNER_ID	Construction District	T-List	Integer
60	MMS_JUR_OWNER_ID	Third Party Owner	T-List	Integer
61	MMS_JUR_OWNER_TYPE_ID	Owner Type	T-List	Integer
62	MMS_MAINT_DIST_OWNER_ID	Maintenance District	T-List	Integer
63	MMS_OFFSET_LR_ID	Left/Right of Centerline	T-List	Integer
64	MMS_ROADWAY_TYPE_ID	Roadway Type	T-List	Integer
65	MMS_SP_NUMBER	Built SP Number	S-String	String
66	MMS_STATE_OWNER_ID	State Owner	T-List	Integer
67	MMS_STATION	Station	S-String	String
68	MMS_TRAFFIC_DIR_ID	Traffic Direction	T-List	Integer
69	MMS_YEAR_TO_FIX	Year to Fix	T-List	Integer
70	MOB_LRS_CALC	LRS recalculate	S-String	String
71	MOB_ROUTE_GLOBALID	Route Link	S-String	String
72	OBJECTID	ArcGis ID	R-Number	Integer
73	OWNER_ID	Administrative Unit	T-List	Integer
74	PERIODIC_MAINT_ID	Periodic maint id	R-Number	Integer
75	REV_ID	REV ID	R-Number	Integer
76	SE_ANNO_CAD_DATA	SE ANNO CAD DATA	B-Color	Blob
77	USER_UPDATE	User Update	S-String	String