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A Synthesis Study on Collecting, Managing, and Sharing Road Construction Asset Data

Hubo Cai, Chenxi Yuan, Timothy B. McClure, Phillip S. Dunston

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16. Abstract
Accurate and complete construction records and as-built data are the key prerequisites to the effective management of transportation infrastructure assets throughout their life cycle. The construction phase is the best time to collect such data. Assets such as underground drainage and culverts are visible and physically accessible only during construction. For assets such as guardrails, signals, and pavement, it is safer and more efficient to collect data during construction than after construction when the road segment is open to traffic.

The purpose of this project was to conduct a synthesis study to 1) assess the current status at INDOT regarding the collection of asset data during the construction phase and the use of such data in the operation and maintenance (O&M) phase, and 2) develop a framework for INDOT to leverage the construction inspection and documentation process to collect data for assets. Data needs during O&M were identified through rounds of meetings with relevant INDOT business units. The current practice in construction documentation was investigated in detail. A survey of state highway agencies (SHAs) was conducted to assess the state-of-the-practice.

A practical framework was developed to leverage the construction inspection and documentation practice to collect asset data that are needed in O&M. The framework uses specific pay items—construction activities that result in physical structures—as the bridge to connect plan assets (i.e. physical structures specified in the design documents) to their corresponding counterparts in the asset management systems. The framework is composed of 1) a data needs component for determining the information requirements from the O&M perspective, 2) a construction documentation module, and 3) a mapping mechanism to link data items to be collected during the construction documentation to data items in the asset management systems. The mapping mechanism was tested and validated using four priority asset classes—underdrains, guardrails, attenuators, and small culverts—from an INDOT construction project. The testing results show that the newly developed framework is viable and solid to collect asset data during the construction phase for O&M use in the future, without adding extra workload to construction crews. The framework can reduce/eliminate the duplicate data collection efforts at INDOT, leading to savings and efficiency gains in the long term.

17. Key Words

asset management, data needs, information management, life cycle data sharing

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EXECUTIVE SUMMARY

A SYNTHESIS STUDY ON COLLECTING, MANAGING, AND SHARING ROAD CONSTRUCTION ASSET DATA

INTRODUCTION

Transportation infrastructure asset management is a data-driven process. Accurate and complete in-place data of assets, i.e., the construction records and as-built data, are the key prerequisite to the effective management, operation, and maintenance of infrastructure assets. Many states, including Indiana, spend a decent portion of their ever-shrinking budget on asset inventory to obtain data regarding asset location, materials, dimensions, and condition.

The construction phase is the best time for collecting in-place data of infrastructure assets. Unfortunately, in the current practice, the construction data collection (for the purpose of construction inspection and documentation) and asset data collection (for asset management) are two separate processes. This isolated approach creates a blockage that prevents the flow of asset data collected during construction into asset management information systems, leading to duplicate efforts in data collection—a magnificent waste. To eliminate this waste, there is a need to create mechanisms to leverage the construction documentation process to collect asset data during the construction phase and to automate the flow of asset data into corresponding asset management information systems.

To eliminate duplicate asset data collection efforts, a framework was created in this study to leverage the construction inspection and documentation practice to collect asset data that are needed in operations and maintenance (O&M) during the construction phase. The framework uses specific pay items—construction activities that result in physical structures—as the bridge to connect plan assets (i.e., physical structures specified in the design documents) to their corresponding counterparts in the asset management systems. The framework is composed of (1) a data needs component for determining the information requirements from the O&M perspective, (2) a construction documentation module, and (3) a mapping mechanism to link data items to be collected during the construction documentation to data items in the asset management systems. The mapping mechanism was tested and validated using four priority asset classes—underdrains, guardrails, attenuators, and small culverts—from an INDOT construction project.

FINDINGS

Data needs at INDOT vary across types of assets and business units. A total of 91 assets/asset components were identified in this study. Despite the variance in data needs, essential data items remain the same: location, dimensions, materials, and condition. The examination of the construction documentation practice and process revealed that all these essential data items are being collected during the construction phase for the construction documentation purpose. This finding forms the prerequisite for the methodology in this study: to create a mechanism that links asset data collected in construction documentation to their counterparts in asset management systems.

A data needs assessment framework was created to assess the data needs for seven major assets: road pavement sections, underdrains, guardrails and attenuators, utilities crossings and relocations, culverts, ditches and outfalls, and signs. Rounds of meetings were conducted to determine the data needs for these assets from nine business units. Resulting data needs are graphically illustrated in Figures 5.4 to 5.14 and Appendix D in this report. Data items are organized under asset and asset component and their type is categorized as location, geometry, physical attributes, condition/performance, administrative, or construction and maintenance. For every data item, its current hosting database and suggested hosting database are spelled out. In addition, users (business units that expressed their need/interest for specific data items) are listed out for every data item.

A survey of state highway agencies (SHAs) regarding their practice on collecting, managing, and sharing construction asset data was conducted. The survey questions were organized into four groups: construction, asset management (during operation and maintenance), road inventory, and information technology. A total of 42 valid responses were received. The asset management group had the largest number of responses (15). The other three groups had roughly equal numbers of responses. Survey results show that the paper-based format is still the dominant format in data exchange, which causes severe data interoperability and exchangeability issues and major blocks to the flow of data from design into construction and operation and maintenance, and to the update of electronic files to reflect the as-designed, as-constructed, as-built, and as-maintained conditions throughout the infrastructure life cycle. Survey results also show that while many SHAs recognize the data blockage issue and some are taking initiative, there are no existing mechanisms in the current practice to leverage the construction documentation process to collect asset data for the asset management purpose in the future phase of O&M.

A framework was created to leverage the construction documentation for collecting and sharing road construction asset data. This framework follows the construction inspection process and, as illustrated in Figure 5.30 of the report, eliminates the need to manually link construction activity, pay item, and plan asset, thus allowing the flow of necessary information regarding the plan assets being inspected to construction engineers to enhance their work efficiency. The framework includes a mapping mechanism to link plan assets to assets in the asset management system based on matching pay items. Such a mechanism works because (1) every single plan asset is associated to pay items in the contract information book (CIB), (2) every asset in the asset management system is associated with a list of relevant pay items, (3) pay items have unique numbers that facilitate the matching process, (4) plan assets are connected to specific assets in the asset management system based on matching pay items, and (5) consequently, data collected in the construction documentation for plan assets automatically flow into the asset management system for the corresponding assets.

The framework was tested and illustrated for four priority assets—underdrains, guardrails, attenuators, and small culverts—using real INDOT construction project data. The testing results show that the newly developed framework is viable and solid for collecting asset data during the construction phase for O&M use without adding extra work for construction crews. The framework can reduce/eliminate INDOT's duplicate data collection efforts, leading to long-term savings and efficiency gains.

IMPLEMENTATION

The newly created framework and guideline are viable and solid for eliminating the data collection waste caused by the isolated approach in the current practice—separate processes for construction documentation and in-place data collection for assets—and the predominance of paper-based data exchange among applications. Recommendations for the implementation of the newly developed framework and guideline are listed as follows:

- Replace the paper-based format with electronic files—electronic design files are passed on to construction engineers; electronic files are marked, modified, and commented on during the construction phase to reflect the as-constructed and as-built condition; electronic construction records and as-built data automatically flow into asset management information systems for their usage during the O&M phase (and they are also continuously updated to reflect the as-maintained condition).
- Use the data needs assessment framework (Figure 5.1 in Section 5.1.2 of the report) to identify the data needs from INDOT business groups for all infrastructure assets to create a comprehensive view of what data items are needed by which business groups. The result forms the base for guiding the flow of asset data collected during construction into relevant asset management information systems and maintaining the data integrity across all INDOT information management systems.
- Retain the association between plan assets and pay items as a part of the design documents to be included in the contract documents. The one-to-one relationship between a plan asset and a pay item allows bringing relevant information to construction engineers in real time.
- Adopt the guideline, especially its mapping mechanism, in the mobile construction documentation app. As illustrated in Section 5.6.4 of the report, the mapping mechanism integrates the collection of asset data items into the construction documentation process and the guideline enables the flow of these asset data items collected during the construction documentation process into suitable places in the corresponding asset management information systems.
- The adoption needs to be gradual: starting with the four priority assets, expanding to the seven major assets, and eventually covering all assets.
- Conduct a pilot study with early involvement to test before rolling out the new approach to all construction projects.

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1. INTRODUCTION

Accurate and complete in-place data of assets (i.e., the construction records and as-built data), are the key prerequisite to the effective management, operation, and maintenance of infrastructure assets (AASHTO, 2011; Western European Road Directors, 2003). Such data reflect the nature of infrastructure assets: materials and assemblies that were used, construction means and methods that were deployed, location, quality, and performance measures (AASHTO-AGC-ARTBA Joint Committee, 2006; NCHRP, 2009). It provides reliable information for life cycle performance prediction and decision-making at strategic, network, and project levels (Flintsch & Bryant, 2006; NCHRP, 2005, 2010).

Recognizing the importance of accurate and complete in-place infrastructure information to the effective management of infrastructure assets, many states, including Indiana, spend decent portion of their ever-shrinking budgets on asset inventory. Asset inventory is the process of obtaining in-place data regarding assets' location, materials, dimensions, and condition. In the present practice, asset inventory is typically performed after construction is complete. Collecting accurate and complete in-place data for infrastructure assets, especially for those assets buried underground, is a grand challenge for state highway agencies (SHAs).

The construction phase is the best time for collecting in-place data of infrastructure assets. In the process of construction documentation, construction engineers collect many of the data items that are needed for operation and maintenance. But in the current practice, the construction documentation and the asset in-place data collection in SHAs, including the Indiana Department of Transportation (INDOT), are two separate processes. Very little, if any, of the asset data collected during construction is being passed on to asset management systems for life cycle management of infrastructure assets. Therefore, there is a missing opportunity in the current practice and there is a need to leverage the construction documentation practice to facilitate the flow of construction asset data to asset management information systems.

To eliminate the waste due to the duplicate asset data collection effort, INDOT initiated research (this research project) to channel the flow of asset data collected in the construction inspection and documentation process into asset management systems to facilitate life cycle sharing and management of infrastructure data. Literature review and surveys were conducted to identify gaps in the current knowledge and practice. A method was created to automate the flow of construction asset data into work management systems. This method was tested and validated by using a real INDOT construction project on four priority assets: underdrains, guardrails, attenuators, and small culverts. A framework and guideline were provided to assist the implementation of the newly recommended method.

2. PROBLEM STATEMENT

The construction phase is the best time for collecting as-built data for road infrastructure assets. Certain assets such as underground drainage and culverts are only visible and physically accessible during construction. Once construction is complete, these assets are at best partially accessible (i.e., field crews might access the ends of culverts). For other assets such as guardrails, crash cushions, signal and signage, and pavement, while collecting their data is possible after construction is complete and roads are open to traffic, it is very hazardous, inconvenient, time-consuming, and thus expensive. To fully explore the opportunity of asset data collection during construction, research is needed to determine answers to the following questions:

1. What data do INDOT's business units need?
2. When data are being collected in the construction documentation process?
3. What is the best time and method/technology for collecting asset data?
4. What is the data structure and how are the data organized in design documents, construction document database, and asset database?
5. How to match and link construction documentation data to asset management data?
6. How to channel the flow of construction asset data to asset management database?
7. How should the collected data be stored and managed?

3. RESEARCH OBJECTIVES AND STUDY SCOPE

INDOT has recognized the importance of having required data (in the right form) available when needed. To ensure that ultimate goal, initiatives such as the standardization of coordinate systems and CAD design files are underway. This study, through a synthesis of extant knowledge regarding practice and relevant technologies, aims at capturing a "big picture" view of the potential opportunities in data collection, management, and sharing; assessing the current status of INDOT's practice; and identifying a number of critical data items of major assets for a detailed investigation of best practices in aspects of timing, method, and responsibility for data collection.

A set of recommendations and a practical guidance will result from the synthesis study as tools to be used in implementation. The guidance, when followed, would facilitate the ideal data flow: (1) INDOT provides electronic design files in certain format(s) to contractors; (2) contractors take INDOT data and execute construction tasks; (3) INDOT construction engineers inspect and document construction work; and (4) resulting data automatically flow to asset management databases.

This study is arranged in such a way that first, the data needs of INDOT's business units (asset owning units) will be assessed. Then, a detailed investigation will be conducted for selected major assets. Specific objectives of this study are to accomplish the following:

1. Identify the data needs for operating and managing major assets;
2. Examine the construction process in aspects of data needs, data availability, and data gaps;
3. Identify the data collection opportunities in construction for major assets; and
4. Suggest best practices in aspects of collecting asset data during construction and channeling the flow of data into asset management databases.

The study scope for the detailed investigation is limited to major assets only, i.e., pavement (given its criticality), underground drainage and utilities (given the difficulties in after-construction data collection), and roadway safety assets including such items as guardrails, signs and signals, barriers, and crash cushions (given the difficulties in after-construction data collection).

4. WORKPLAN

The research approach is a synthesis study that consists of seven main tasks detailed below, including a pilot study on implementation.

- *Task 1:* INDOT Initial Interviews—Data Needs and Current Practice
- *Task 2:* Prioritization of Assets
- *Task 3:* Detailed Investigation on Timing and Methods in Data Collection for Priority Assets
- *Task 4:* Survey/Interviews of State Transportation Agencies
- *Task 5:* Assessment and Recommendations on Channeling the Flow of In-Place Asset Data Collected during Construction into Asset Management Databases
- *Task 6:* Pilot Implementation Study

Tasks 1 and 2 constitute Phase I. Task 1 aims at grabbing a "big picture" view. Task 2 aims at determining a list of selected critical items for detailed investigation via a prioritization procedure. Making up Phase II, Tasks 3 to 5 focus on the detailed investigation for selected major assets and Task 6 is a pilot study on implementation to test the suggested procedural changes and the implementation guidance.

5. FINDINGS AND DELIVERABLES

5.1 Data Needs and Assessment of the Current Practice

5.1.1 Literature Review: Data Needs in Asset Management for SHAs

An extensive literature review was conducted regarding the data needs in asset management for SHAs in aspects of asset classification and relevant data items, non-asset classification and data items, categorization of data requirements, data collection methods (i.e., manual, automated, semi-automated, and remote collection), device for data collection, data management mode, and criteria for selecting data. Findings are listed in Appendix A.

Table 5.1 summarizes the classification of assets and typical data items in asset management for SHAs based on the review of several studies (AASHTO, 2011; AASHTO-AGC-ARTBA Joint Committee, 2006; Flintsch & Bryant, 2006; NCHRP, 2005, 2009; Western European Directors, 2003). LRS refers to linear referencing system, a spatial referencing system that allows the determination of location by referring to a reference mark on a route/road and the distance along the road. Location is an essential data item that is needed by every asset and asset component. It is clear that for the asset management purpose, it is required to be able to (1) locate and find assets in the field, (2) measure assets, and (3) retrieve and update asset information. Table 5.2 lists the broadly categorized data requirements.

5.1.2 INDOT Data Needs: Road Inventory, Pavement Management, and Operation and Maintenance

INDOT had an organization wide interview regarding data needs from different business units. Kevin Munro from the Management Information System unit led the initiative. The result is a data needs matrix with a total of over 100 assets/asset data items. In this research project, the matrix was re-organized and grouped, resulting in 91 asset/asset data items. Details are included in Appendix B. Table 5.3 provides a sample of road section. ESRI's roads and highways has replaced EXOR as the database for Road Inventory.

Based on the findings from literature review and INDOT initial data needs assessment, a framework (see Figure 5.1) was proposed to identify data needs and cross-reference assets. Table 5.4 illustrates the use of the framework on road, guardrail, and underdrain assets as examples.

5.1.3 Construction Documentation at INDOT

A few rounds of meetings with INDOT construction engineers were conducted to examine the construction documentation practice at INDOT. Table 5.5 lists major activities in a typical road construction project and their associated pay items, data/information to be recorded, and construction documentation details. It is clear that many data items required in asset management are being recorded in the construction documentation process.

5.1.4 Limitations in INDOT's Practice Regarding Data Flow from Design to Construction and Operation and Maintenance

Figure 5.2 illustrates the limitations in the current practice of data flow from the design to construction and operation and maintenance phases, highlighting the data blockage issue: the lack of a mechanism to facilitate the flow of asset data collected during construction into asset management. This blockage issue is to a large extent caused by the use of the paper-based approach in the current practice: construction engineers receive paper-based design documents and redline them to document as-built. Figure 5.3 illustrates the suggested data

TABLE 5.1
Asset classification and relevant data items.

Asset	Data Items	Notes
Road (inventory)	Functional class(ification) Identification codes Location History of construction and rehabilitation Geometrical characteristics • Divided/undivided roadway • Number of lanes • Lane width • Shoulder type and width • Radius of curves/degree of curvature Pavement • Pavement type • Layer thickness • Materials • Overlays • Drainage • Condition ◦ Skid resistance ◦ Serviceability	LRS
Signal	Structural support • Type • Service life Signal head • Service life • Date of installation Bulbs Signal controller Construction and maintenance history Condition of the signal Location	Location shall be registered to road network via LRS
Sign	Structural support Sheeting and painting material • Type • Service life Font size Visibility Retroreflectivity Construction and maintenance history Location	Location shall be registered to road network via LRS
Lighting	Structural support • Type • Service life Lighting bulbs • Type • Service life • Level of illumination Spacing between lighting poles Construction and maintenance history Location	Location shall be registered to road network via LRS
Detection devices	Type Location False alarm rate Life of the detector components	Location shall be registered to road network via LRS
Pavement marking	Type and material Retro reflectivity Location Construction and maintenance history	Location shall be registered to road network via LRS
Guardrail	Type and material Location Condition Construction and maintenance history	Location shall be registered to road network via LRS
Tunnel		
Drainage	Can be further detailed down to cross pipes, box culverts, entrance pipes, curb and gutter, paved ditches, unpaved ditches, edge drains and underdrains, stormwater ponds, and drop inlets Some subtypes can be treated as a "Type" attribute while some such as ponds shall be treated as features in a separate data layer	
Other traffic assets	Attenuators, pavement striping, delineators, pavement markers	
Structure	Retaining wall Sound barrier	
Sidewalk		
Roadside	Vegetation and aesthetics Trees Shrub and bush Historic markers Right-of-way fence	
Facilities	Rest areas Weigh station Movable bridge	

flow, in which electronic files replace the paper-based approach. It represents an ideal data flow scenario: electronic design files enter the construction phase, contractors and INDOT updates the electronic files to reflect the progress and as-constructed, the electronic files automatically become as-built at the completion of construction and enter the operation and maintenance phase.

5.2 Prioritization of Assets for Detailed Investigation

Given the large number of assets INDOT is responsible for, a working session with the study advisory council

TABLE 5.2
Broadly categorized data requirements.

Group	Definition
Location	Actual location of the asset as denoted using a linear referencing system or geographic coordinates
Physical attributes	Description of the considered assets, which can include material type, size, length, etc.
Condition	Might be different from one asset to another. Examples: aggregated overall measure-pavement condition, bridge health indices, etc.; individual measure-pavement surface resistance, etc.

(SAC) was conducted to prioritize assets for detailed investigation. Criteria include the criticality of data items (e.g., the risk of not having these data items), the cost and quality difference between collecting them during construction and after construction, and the significance in project cost/duration/quality impacts. The SAC recommended six categories of assets for detailed investigation. The Maintenance Group suggested to include Signs, resulting in a total of seven categories of priority assets:

- Road pavement sections
- Underdrains
- Guardrails and attenuators
- Utilities crossings and relocations
- Culverts (large and small)
- Ditches and outfalls
- Signs

5.3 Data Needs of the Priority Assets

Given the list of the priority assets, an initial data needs matrix was developed, following the framework presented in Section 5.1.2. Starting with this draft data needs matrix, the research team had a number of working sessions and meetings with each of the following business units within INDOT to determine their data needs and suggested hosting databases: Road Inventory, Maintenance, Pavement Management, Design, Environment, Hydraulics, Right of Way, Traffic, and Utility. Appendix D contains the details for all seven priority assets. All data items are categorized into different data types and annotated with hosting databases and the business units expressed interest in them. Figure 5.4 shows the legend. Figure 5.5 illustrates the structure of asset components for Road/Pavement. Figures 5.6 to 5.14 provide detailed data needs for individual priority assets.

TABLE 5.3
Sample INDOT data needs—road section.

ID	Asset	Data Item	Data type	Owner (Steward)	User	Database	Notes
1	Road (section)	Location	Line (LRS)	Road Inventory		EXOR	Tech Svcs uses road section data AMS-Roadway is another system/ database that contains road section data
		Name and two alias	Attribute	Road Inventory		EXOR	
		Mainline ID	Attribute (linear events)				
		Functional class	Line (assumed to be linear events and thus, can be considered as attribute)	Road Inventory		EXOR	
		Rural/Urban	Attribute (linear events)	Road Inventory		EXOR	
		Contract#	Attribute (linear events)	SPMS business owner		EXOR inherited from SPMS	
		District	Attribute (linear events)	Road Inventory		EXOR	
		IRI	Attribute (linear events)	Road Inventory		EXOR	
		Speed limit	Attribute (linear events)	Road Inventory		EXOR	
		Jurisdiction system, county/ fed., municipal.; RTEL, Ramp code, and segment (including special segments)	Attributes of LRS (coded)	Road Inventory		EXOR	All coded in a single attribute, taking on different number of digits and locations
		Pavement friction	Attribute (linear events)	Traffic safety Pavement			
		#of lanes	Attribute (linear events)	Road Inventory			
		Lane width	Attribute (linear events)	Road Inventory			
		Surface material	Attribute (linear events)	Road Inventory			
		Base type	Attribute (linear events)	Road Inventory			
		Base depth	Attribute (linear events)	Road Inventory			
		Horizontal curvature	Attribute (linear events)	Road Inventory			
		Vertical curvature	Attribute (linear events)	Road Inventory			

Asset	
ID	*(Table B.1 in Appendix B)*
WMS Asset ID	*(Table B.2 in Appendix B)*
Component or subtype	
WMS Module	
Data	Location
	Geometry
	Physical attributes
	Condition/performance measure
	Administration
	Construction and maintenance
Owner/Steward	Data owner
	Asset accountability
	Data collector
	User/use
Database/software/interoperability	
Data collection	*(Method and timing for data collection)*

Figure 5.1 A framework for identifying data needs and cross-referencing assets.

5.4 Survey of State Highway Agencies Regarding Data Flow and Exchange

A survey was conducted to determine the state-of-the-practice at SHAs regarding collecting and sharing construction asset data. The survey was distributed through AASHTO's Standing Committee on Highways. The questionnaire contains four groups of questions: construction, road inventory, asset management, and information technology. Appendix E provides the survey questionnaire.

A total of 42 valid responses were received and analyzed. Figure 5.15 illustrates the distribution of the primary job functions of those responded. Asset management during O&M phase is the group with the largest number of responses. Examining the comments of that group reveals that the asset management of SHAs covers a wide range of assets, and pavement, bridge, guardrail and attenuator, culvert, signs, and signals are the ones mentioned most frequently.

1. Responses to the Construction Group Questions

A total of 18 responses were received for the construction group questions. Figure 5.16 counts the responses regarding the format of design files/drawings that are available for use in construction. Considering that PDF files are one type of paper-based, i.e., not a format of digital CADD files, the majority is still using non-intelligent, paper-based file format.

Figure 5.17 provides the counts regarding geospatial referencing systems being used in construction projects. As expected, project stationing and offseting is the dominating method. This indicates that the geospatial locations of project stationing shall be documented and georegistered to faciliate future reference to and locating of assets in the field.

Figure 5.18 illustrates the response summary regarding as-built. Redlining on paper drawings is still the dominating means. Among the 12 responses stating receiving CADD files (as indicated in Figure 5.15), only 3 appear to update the electronic CADD files and pass along the electronic files during and after construction.

Figure 5.19 summarizes the responses regarding the standard data format/medium for reporting and archiving construction records. The result aligns well with Figure 5.16: paper-based is the dominant format in construction documentation.

Figure 5.20 summarizes the data collection tools available to construction engineers in inspection. Wheel/distance measurement instruction, an easy-to-use distance measurement tool, plays a major role. Professional judgment is very important. Global positioning system (GPS) is making its way in construction inspection.

Figure 5.21 illustrates the perception of construction engineers regarding what business units are using construction records. The responses cover almost all infrastructure life cycle stages: planning, design, environmental permitting, and operation and management. The distribution is relatively even with design being the largest, which indicates the importance of having accurate existing condition data in design.

2. Responses to the Information Technology Group Questions

A total of 20 responses were received to the questions included in the information technology (IT) group. The first question is a free-text question, asking participants the IT infrastructure for data management throughout the infrastructure life cycle stages. It was found that (a) in the design phase, CAD systems, AASHOTO software packages, and project document management systems co-exist; (b) in the construction phase, typical construction project management tools such as Site Manager are assisting construction documentation and management; (c) in the operations phase, a variety of tools exist, leaning towards work management systems; and (d) in road inventory, geographical information system (GIS) dominates.

Figure 5.22 ranks the responses to the question regarding the capacity of the current software systems to facilitate data from between different phases. Compatibility is a blocking barrier that prevents the data flow from construction to downstream applications.

Figure 5.23 ranks the most significant barriers that prevent the continuous data flow. The top barrier is business process, followed by organizational structure and lack of human resources.

Another free-text questions was asked about the technical initiatives at SHAs to address the data flow limitations; 12 out of 20 respondents stated that they are aware of such initiatives at their organizations. A large number of SHAs have realized the data flow and information sharing issue and are taking actions towards a total data management system.

TABLE 5.4
Data needs of sample assets at INDOT.

Asset	ID (Table B. 1.)	WMS Asset ID (Table B. 2.)	Component or Subtype	WMS Module	Data						Owner/Steward				Database/ Software/ Interoperability	Data Collection
					Location	Geometry	Physical attributes	Condition/ performance measure	Administrative	Construction and maintenance	Data owner	Asset accountability	Data collector	User/use		
Road	1	25	Segment / section	Roadway	Starting and ending location	Line					Road Inventory		Road Inventory	HPMS reporting to FHWA on the extent and characteristics of state jurisdiction roadways	EXOR	
			Intersection			Horizontal curvature					Road Inventory		Road Inventory		WMS	
			Ramp / Interchange Y			Vertical curvature					Road Inventory		Road Inventory			
			Connector / Frontage Road						Functional class		Road Inventory		Road Inventory	Maintenance Operation		Roadway videolog for geometries
									Rural/Urban		WMS		WMS			
									District		WMS		WMS			
									Jurisdiction system, county/fed., municipal, RTEL, Ramp code, segment , and Met Code		Road Inventory		Road Inventory			
									National Truck Network NTN (0/1)		Road Inventory					
									LRS ID		Road Inventory					
									Federal Aid System		Road Inventory					
										Work Type						
										Finish Date						
							Name and two alias				Road Inventory					
							Access control (no, partial, full)				Road Inventory					
							# of through lanes				Road Inventory					
							Direction Parking				Road Inventory		Road Inventory			
							Mainline ID				WMS	Maintenance	WMS	Annual Highway Performance Monitoring System (HPMS) report	Deighton's Dtims	PathRunner XP Vehicle

TABLE 5.4
(Continued)

Asset	ID (Table B. 1.)	WMS Asset ID (Table B. 2.)	Component or Subtype	WMS Module	Data: Location	Data: Geometry	Data: Physical attributes	Data: Condition/ performance measure	Data: Administrative	Data: Construction and maintenance	Owner/Steward: Data owner	Owner/Steward: Asset accountability	Owner/Steward: Data collector	Owner/Steward: User/use	Database/ Software/ Interoperability	Data Collection
							Lane width				Road Inventory		Road Inventory		SPMS--> EXOR	
							Surface material			Pavement	Road Inventory		Road Inventory	Traffic safety	Microsoft Access	
							Base type				Road Inventory		Road Inventory	District-scoping maintenance, preservation, or restorative activities	WMS	
							Vertical pavement section				Road Inventory		Road Inventory	INDOT Office of Materials		
							IRI				WMS		Pathway Services (contractor) State Level INDOT Research Division	Office of Pavement Engineering	WMS	
							Pavement friction				Pavement		INDOT Research Division	Trafic Safety, District Scoping, Maintenance, Preservation or retroactive activities INDOT office of Materials Management		
							Thickness			Contractor#	WMS		INDOT Research Division	Office of Pavement Engineering, Office of Geotechnical Engineering		
	58						Toe of Slope				Survey / Aerial Engineering		Env. Svcs. Ecology & Waterway			
	70						Top of Bank				Survey / Aerial Engineering		Env. Svcs. Ecology & Waterway			
	1		Intersection		Point Location	Point										
Guardrail	25	21		Roadway	Starting and ending location	Line	Type				Tech Services		Operations		AMS - Roadway	
					Offset		Materials									
Underdrain	31	33		Roadway	Starting and ending location	Line	Size				Tech Services		Operations		AMS - Roadway	
					Offset											
						Point	Outlet									

TABLE 5.5
Construction documentation in typical road construction projects.

		Pay Item		Data/Information	Construction Documentation		
#	Construction Activity	Code	Description		Quality inspection	Quantity	Notes
1	Traffic control—set up						No permanent component
	Utility relocation	105.06 104.05	Cooperation with utilities Removal and disposal of structures and obstructions	Locations and attributes of utility relocations			Cooperation specs
2	Clearing site	201	Clearing & grubbing	Temporary Right of way		Area or lump sum (LS)	Natural
2a	Removal	202	Removal of structures and obstructions			Varies	Manmade
3	Stripping	201	Clearing & grubbing	Topo		Area or LS	Remove organic layer of soil
4	Installing soil erosion/ sediment control items	107.15 205	Erosion control plan and proof of publication Temporary erosion and sediment control	Unless it is permanent		Varies	
5	Excavation	203	Excavation & embankment	Topo		CY	Pay actual quantities
6	Blasting	107.13					Option for contractor not separate pay item
7	Handling/removal of regulated waste	104.06 202.08	Removal and disposal of regulated materials Removal of underground storage tanks containing petroleum Products or other hazardous chemicals			Varies	
8	Subgrade treatment	207	Subgrade	Topo		SY	Pay actual quantities
9	Aggregate base courses	301	Aggregate base	Topo		TON	Pay actual quantities
9a	Sub Base	302	Subbase			TON	Associated with PCCP
9b	Shoulders	303	Aggregate pavements & shoulders			TON	
10	Embankment	203 208	Excavation & embankment Finishing shoulders, ditches, and slopes	Topo		CY	Pay actual quantities
11	Drainage (under)	718	Underdrains	Location		LF, EACH	
12	Milling	306				SY	
13	Asphalt paving	304 400	Asphalt bases Asphalt pavements		Smoothness, compaction	TON	
14	Concrete paving	305 500	Concrete bases Concrete pavement		505 tests Flex tests, slump tests	SY	
15	Guardrail/cable rail	601	Guardrail				
16	Sidewalk	604	Sidewalks, curb ramps, steps, and handrails			SY	

TABLE 5.5
(Continued)

#	Construction Activity	Pay Item Code	Pay Item Description	Data/Information	Construction Documentation: Quality inspection	Construction Documentation: Quantity	Construction Documentation: Notes
18	Barrier curb	605	Curbing			LFT	Specific type defined in plans
19	Traffic stripes/traffic markings	808	Pavement traffic markings			LFT, EACH	
20	Fence	601 615(.03)	Fences Monuments, markers, and parking barriers	Right of way		LFT EACH	Concrete markers (define ROW) are a different pay item, but done at the same time with fence; typically fence follows ROW lines
21	ITS—fiber optic conduit and cable	809 805.07	Its controller cabinets and foundations Conduit and cable installations			EACH LF	
22	Highway lighting (foundations and poles)	807	Highway illumination			LF, EACH	
23	Traffic signals (foundations and poles)	805	Traffic signals			LF, EACH	
24	Overhead sign structures	802	Signs			EACH, SF Posts - LF	
25	Roadside signs	802	Signs			EACH, SF Posts - LF	
26	Landscape plantings	621 622	Seeding & sodding Planting trees, shrubs, and vines			SY EACH	
27	Pipe placement	211 714 thru 725	B-borrow & structure backfill Covers all drainage pipes & structures			CY LF, EACH	Any storm/sewer, but excluding underdrains
28	Sound wall post placement						
29	Sound wall panel placement						
30	Placement of lighting features						
31	Retaining walls	731	MSE walls				
32	Attenuator (crash barriers/cushions)	601.08	Impact attenuators				
33	Median	602	Concrete barrier				

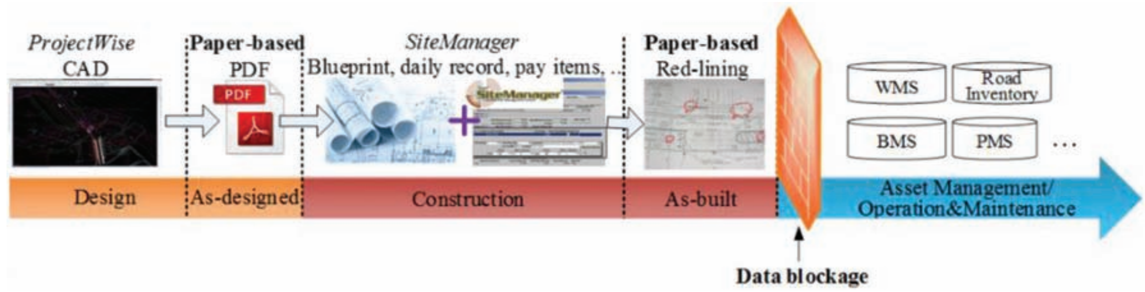


Figure 5.2 Asset data flow in the current practice at INDOT.

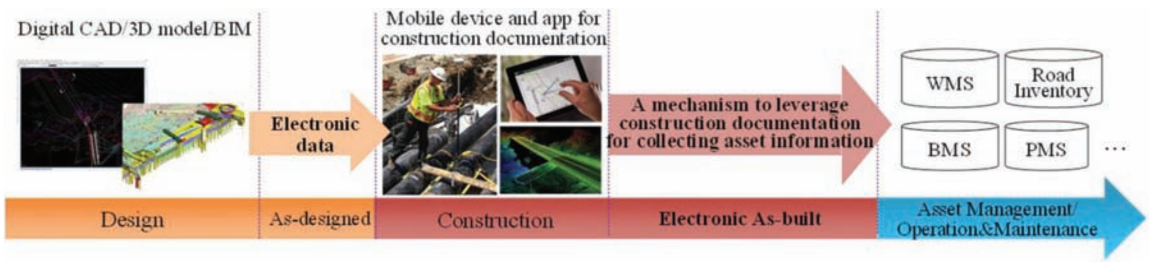


Figure 5.3 The suggested data flow.

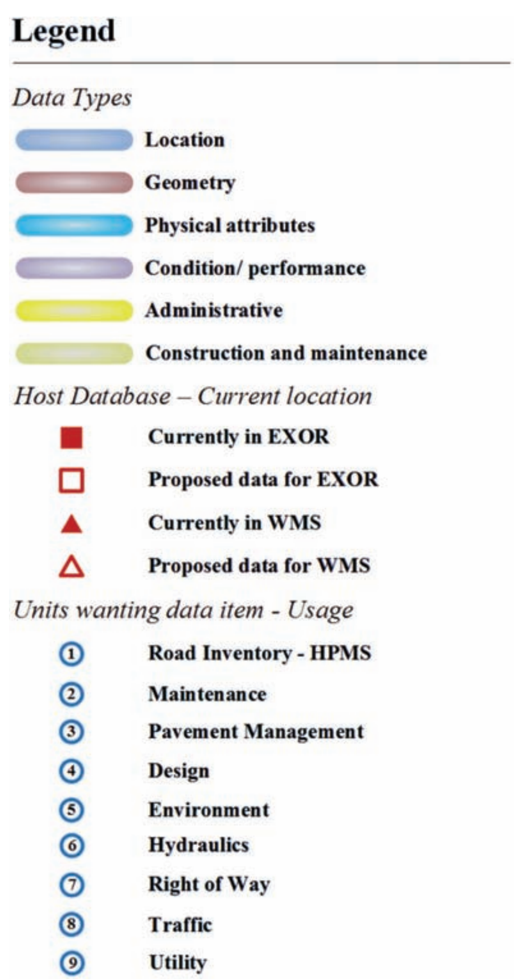


Figure 5.4 Legend used in detailed data needs assessment.

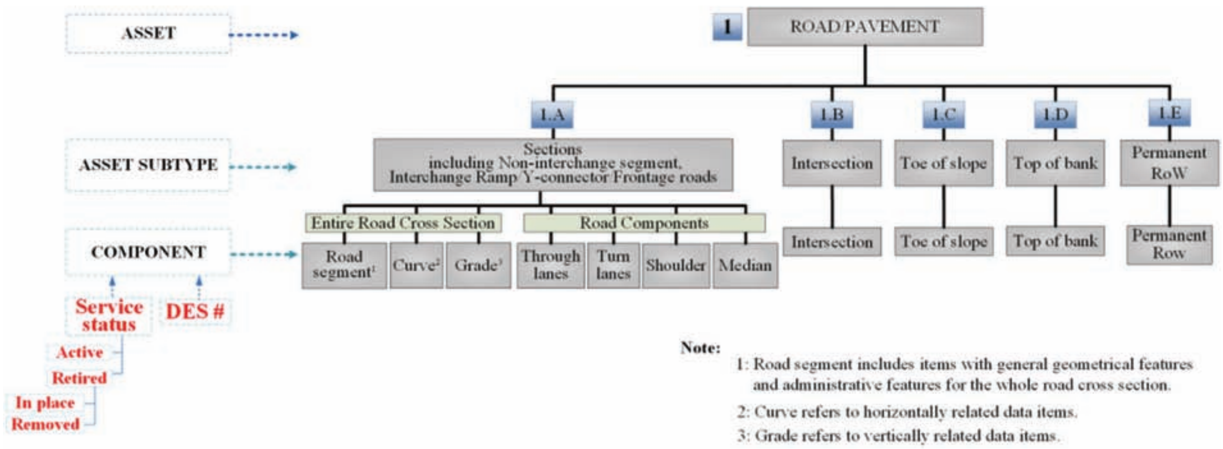


Figure 5.5 The overall structure of the road/pavement asset and its components.

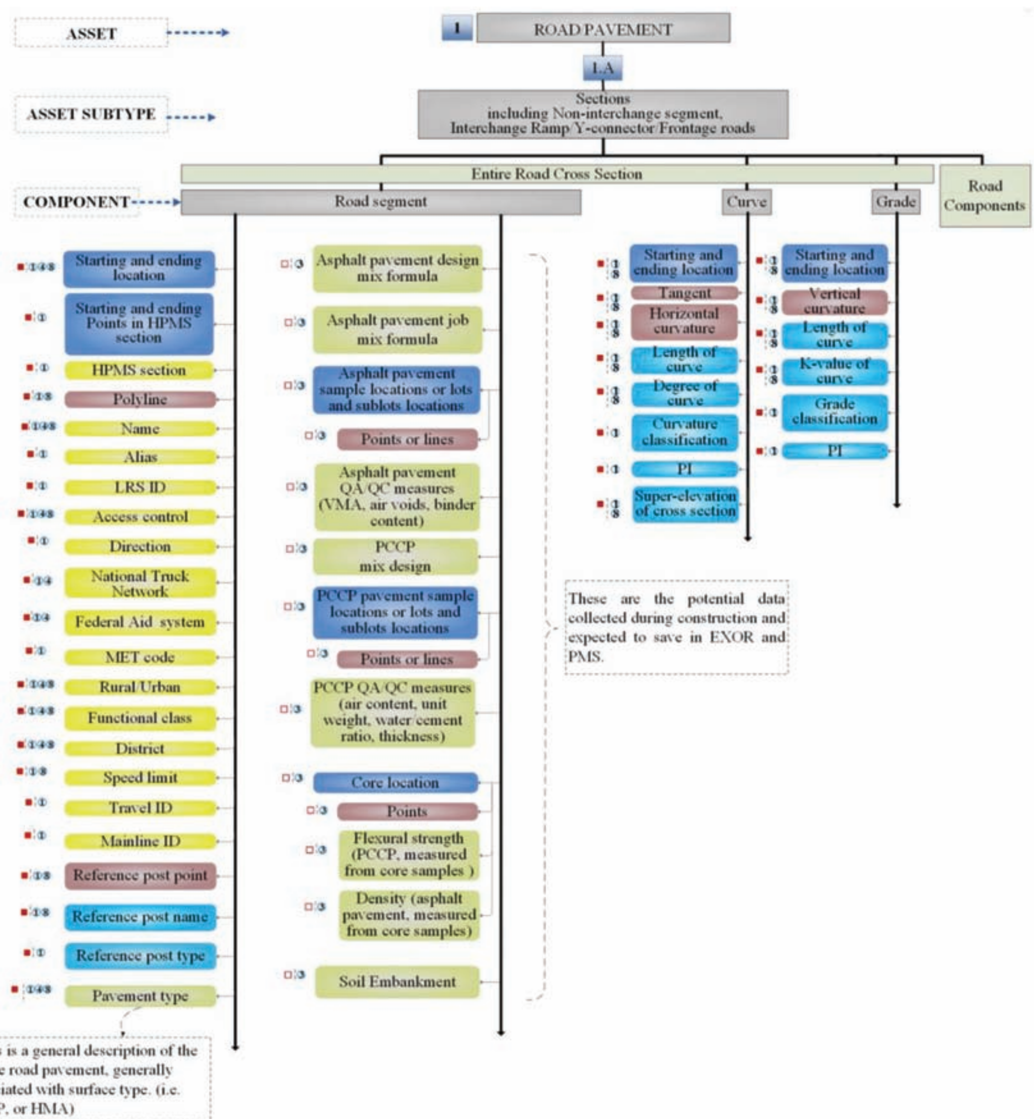


Figure 5.6 Data needs of the entire road cross section.

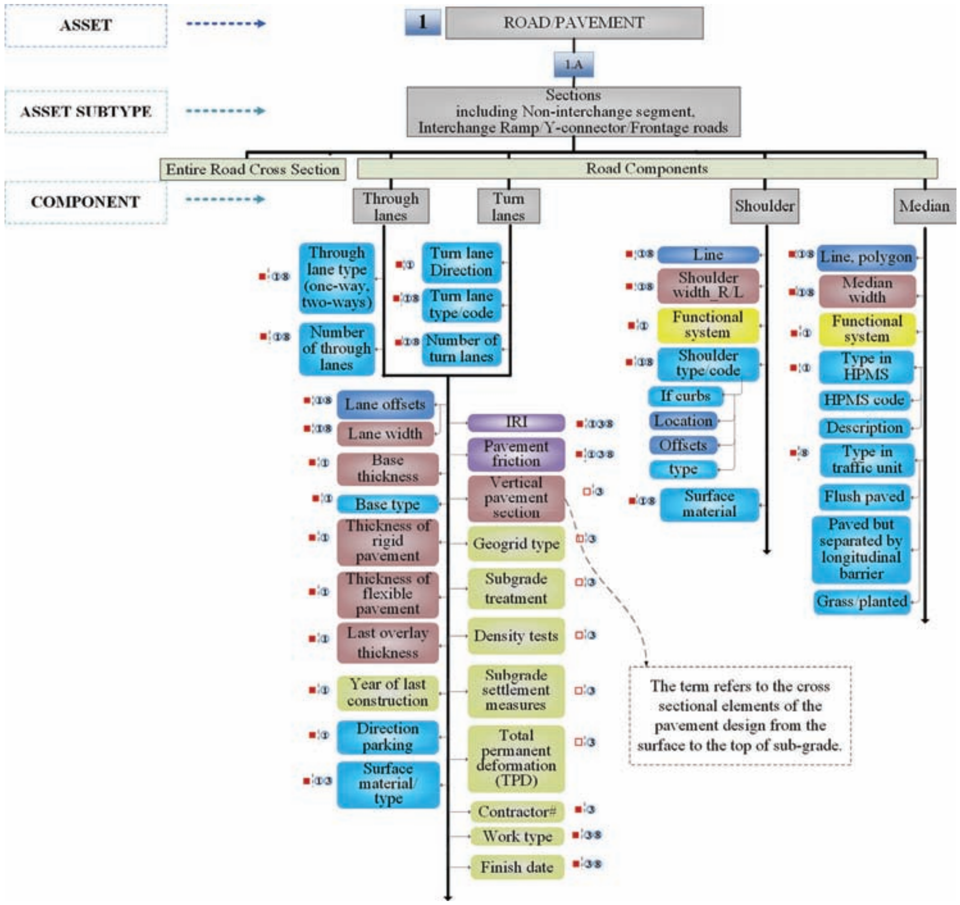


Figure 5.7 Data needs of the individual road components.

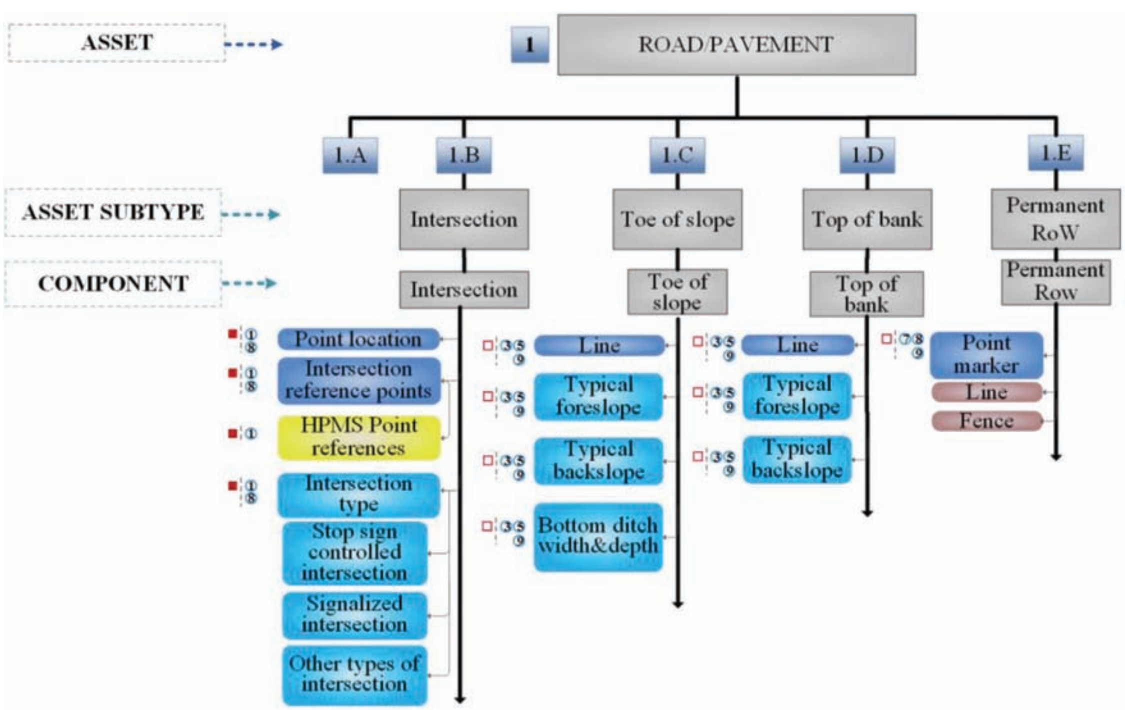


Figure 5.8 Data needs of other road components.

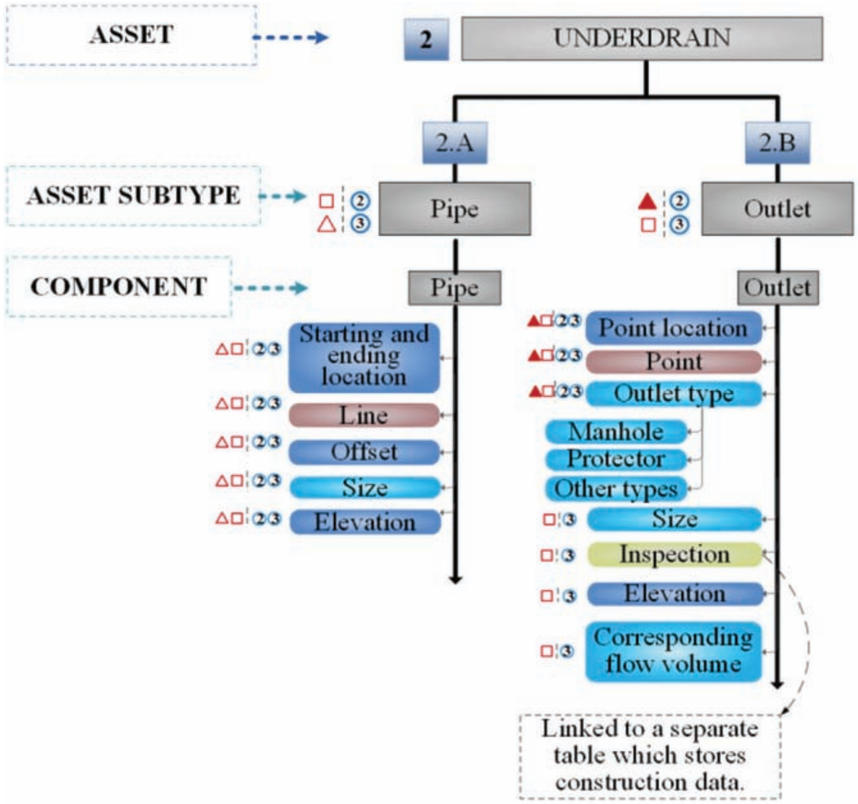


Figure 5.9 Data needs of underdrains.

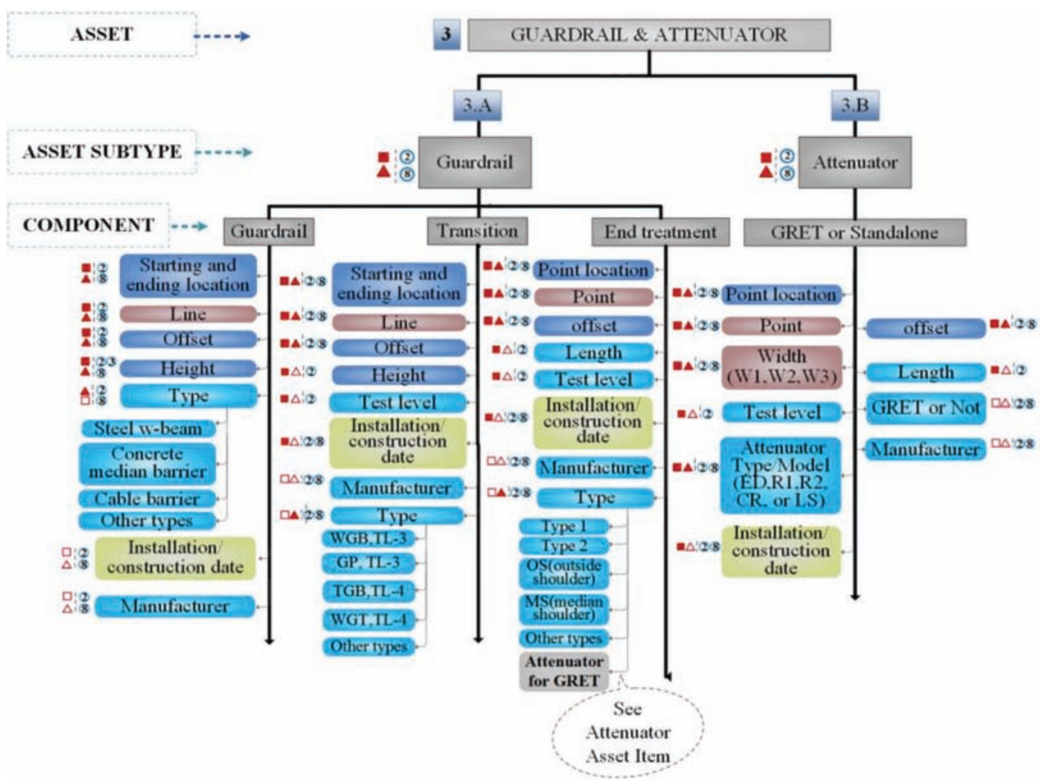


Figure 5.10 Data needs of guardrails and attenuators.

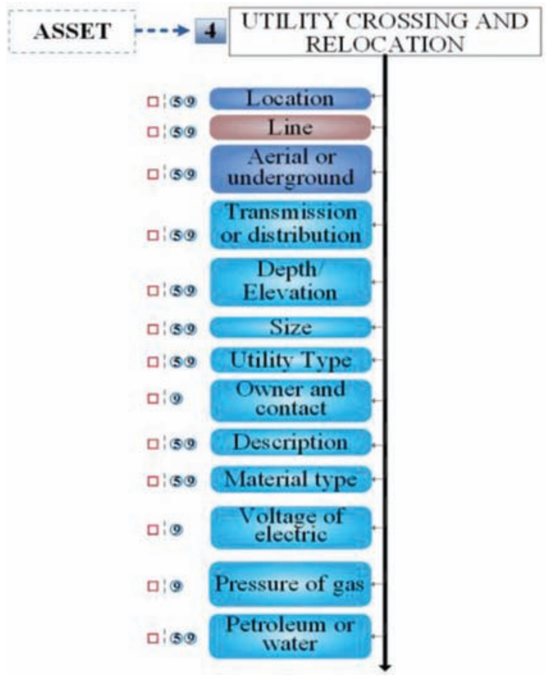


Figure 5.11 Data needs of utility crossing and relocation.

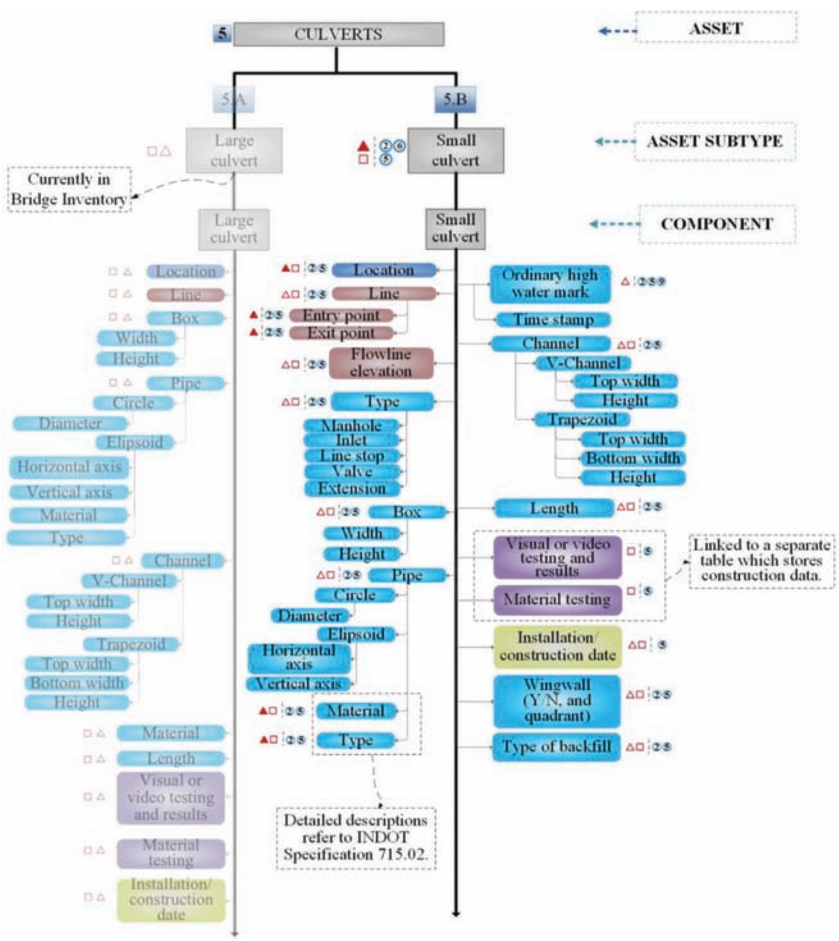


Figure 5.12 Data needs of (small) culverts.

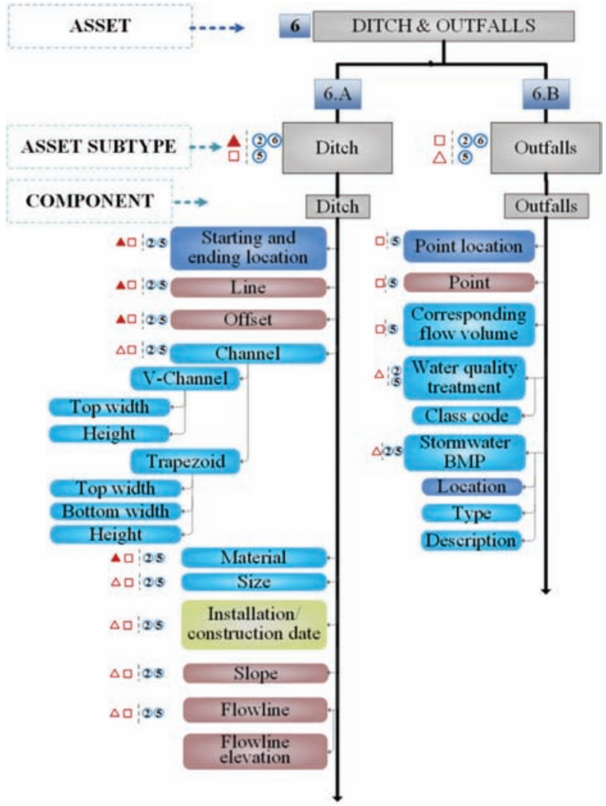


Figure 5.13 Data needs of ditches and outfalls.

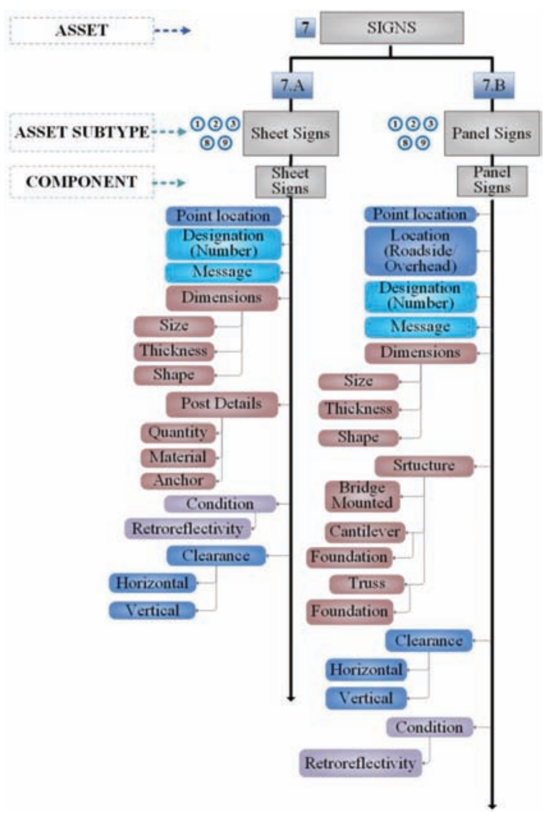


Figure 5.14 Data needs of signs.

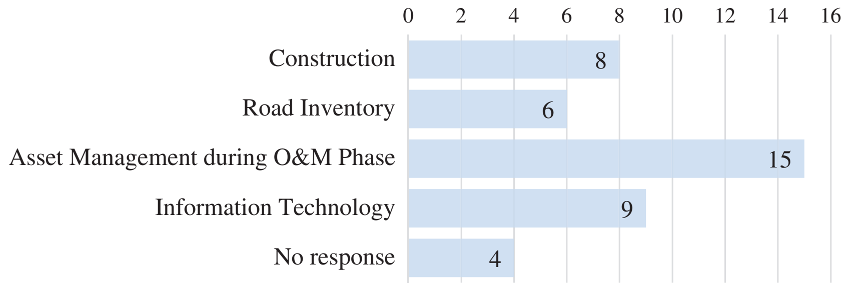


Figure 5.15 Distribution of survey responses based on the primary job function.

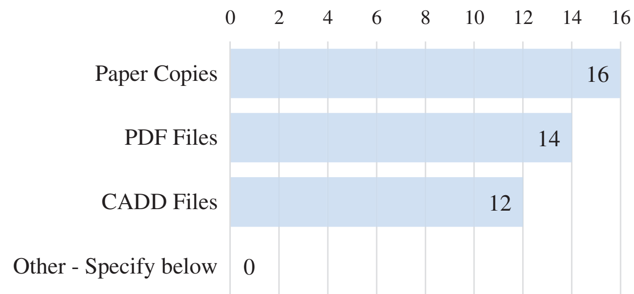


Figure 5.16 Format of design files/drawings for use in construction.

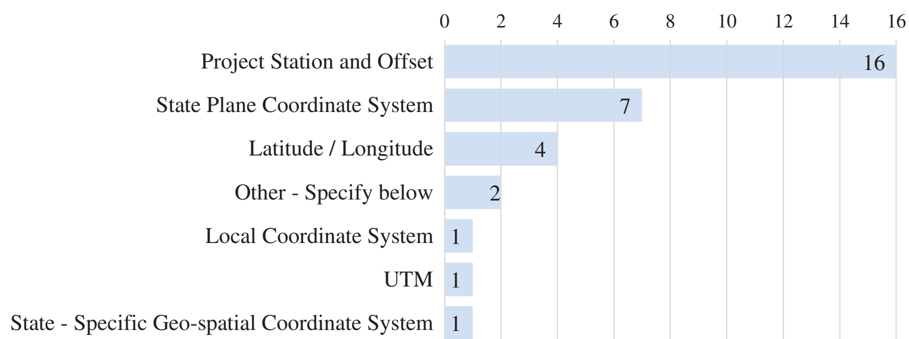


Figure 5.17 Use of geospatial referencing systems in construction projects.

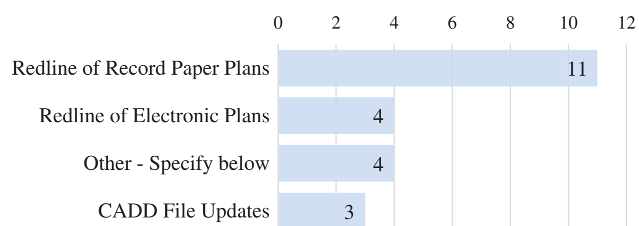


Figure 5.18 Methods for recording as-built.

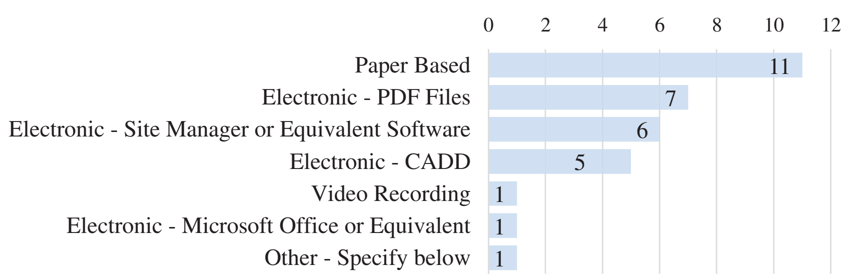


Figure 5.19 Means/format of reporting and archiving construction records.

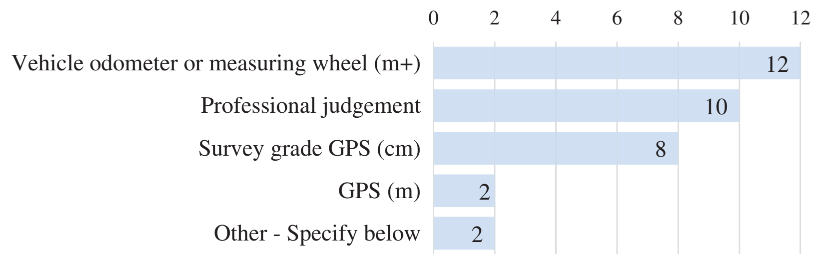


Figure 5.20 Available tools in construction inspection.

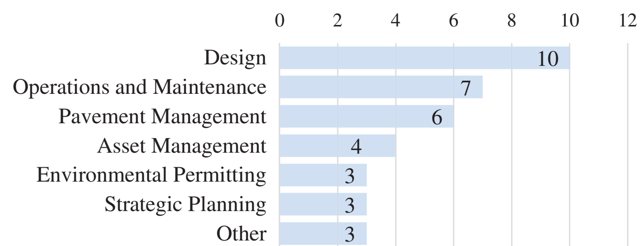


Figure 5.21 Use of construction records.

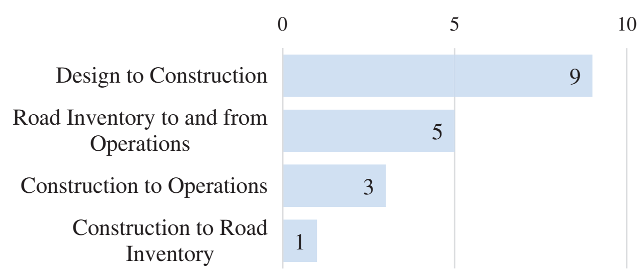


Figure 5.22 Capacity of existing software systems to facilitate data flow between applications.

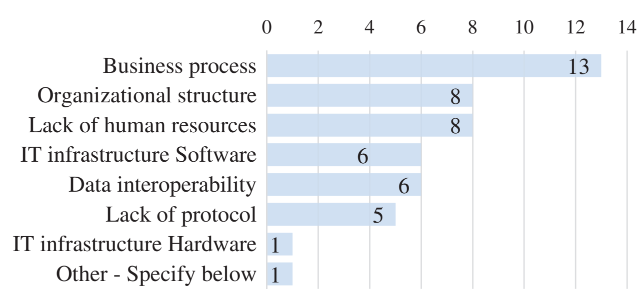


Figure 5.23 Barriers to the continuous data flow.

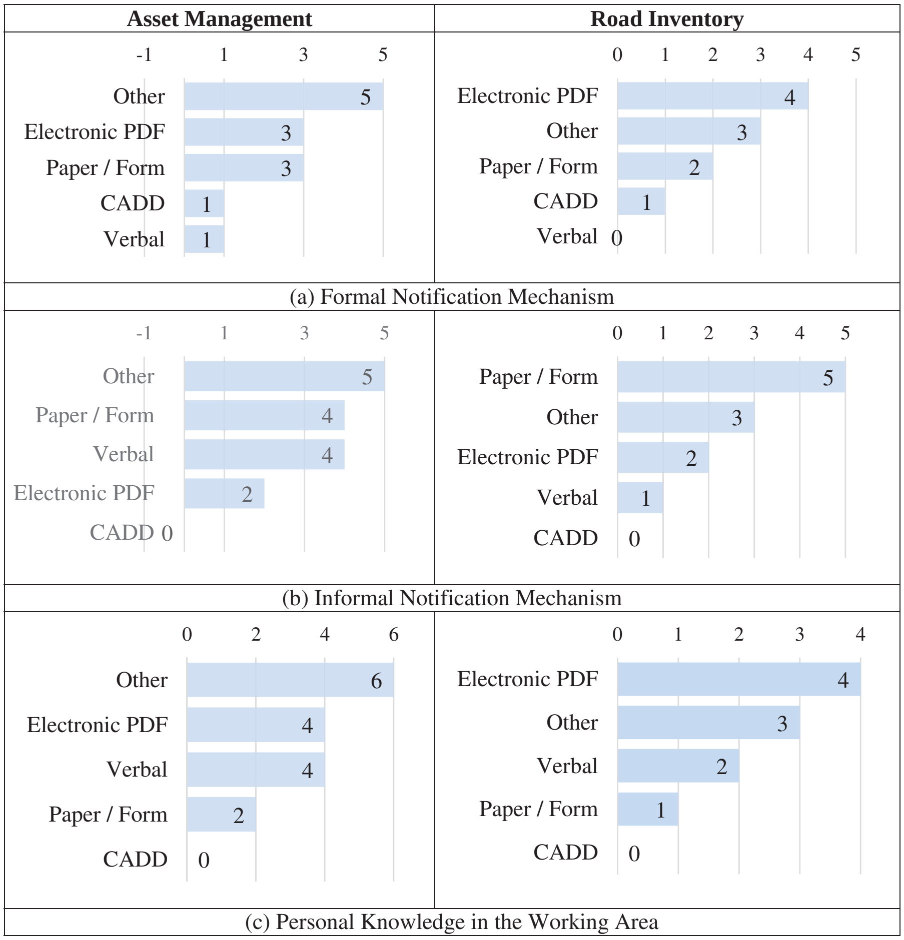


Figure 5.24 Notification mechanisms and data formats for newly constructed assets.

3. Responses to the Asset Management Group and Road Inventory Group Questions

The same set of questions was included in the asset management group (during the operation & maintenance phase) and the road inventory group. A total of 22 responses were received for the asset management group questions and a total of 19 responses were received for the road inventory group questions. This section contains summary results for both groups to facilitate the side-by-side comparison.

The first question is about the notification mechanism for newly constructed assets. For asset management, 13 out of 22 responses stated the existence of a formal notification mechanism; 15 stated the use of informal notification mechanisms; and 16 stated the reliance on personal knowledge in the area. Responses for road inventory are similar. Asset management groups and road inventory groups at many SHAs are relying on informal means and personal knowledge to know the completion of new assets so that they can start their documentation process. Figure 5.24 lists the data forms under various notification mechanisms. Non-intelligent PDF and paper-based format are the dominant ones.

The second question is about the notification mechanism for existing assets. For asset management, 14 out of 22 responses stated the existence of a formal notification mechanism; 15 stated the use of informal notification mechanisms; and 15 stated the reliance on personal knowledge in the area. Responses for road inventory are similar. Asset management groups and road inventory groups at many SHAs are relying on informal means and personal knowledge to know the completion of new assets so that they can start their documentation process. Figure 5.25 lists the data forms under various notification mechanisms. Similar to observations on new assets, non-intelligent PDF and paper-based format are the dominant one.

Figure 5.26 summarizes the responses to available technologies for field data collection. GPS and wheel are the mains ones for both asset management and road inventory. Professional judgment is being used a lot in asset management. Road inventory uses paper maps a lot.

Figure 5.27 illustrates the accuracy requirements in the aspect of corresponding technologies that can achieve the required accuracy. For the purpose of locating assets, accuracy at the level of several meters is common and accuracy at sub-meter level is desired. It is

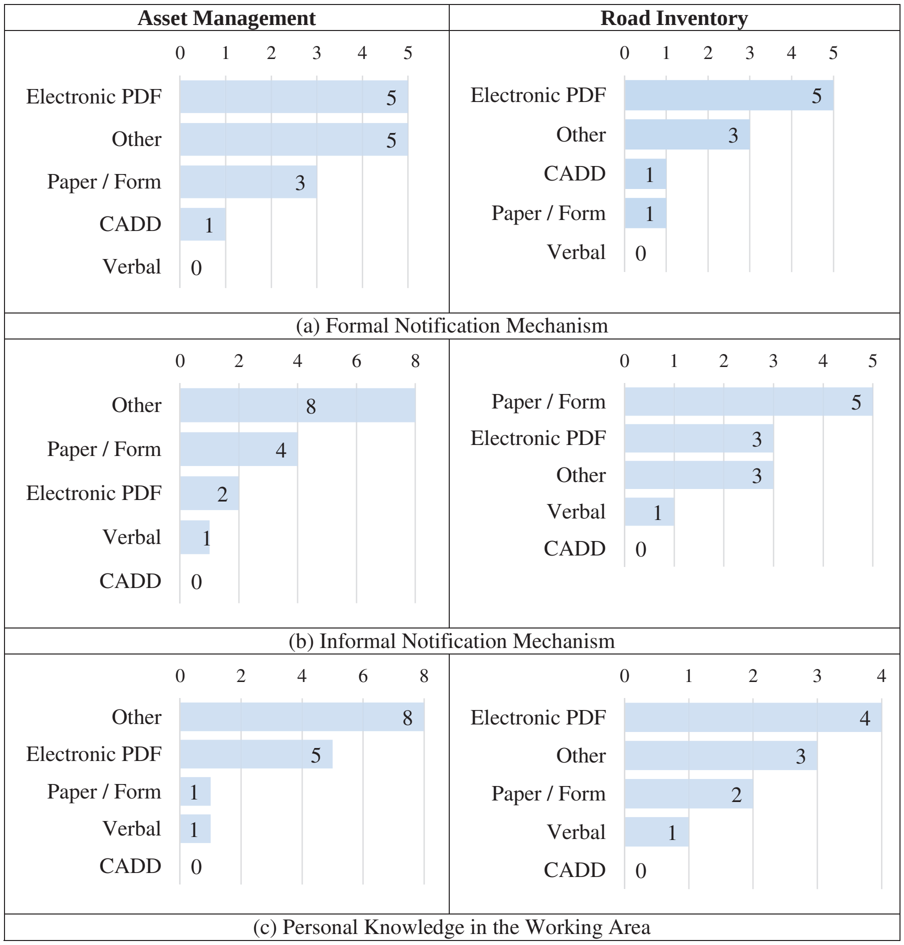


Figure 5.25 Notification mechanisms and data formats for existing assets.

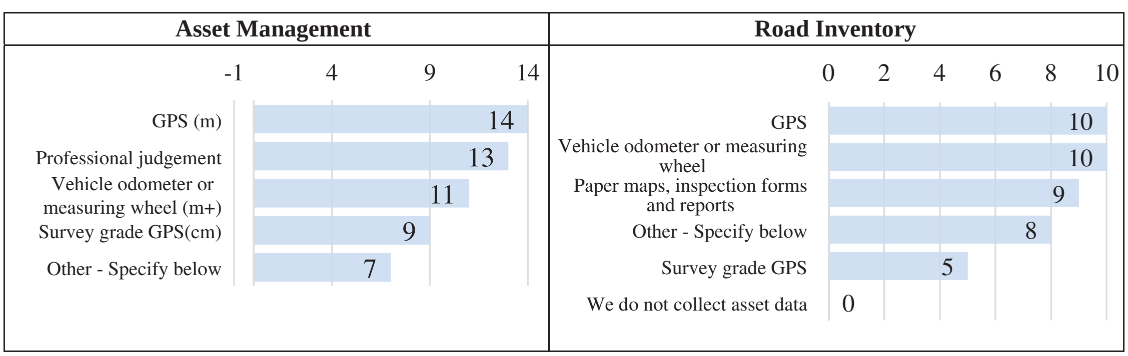


Figure 5.26 Technologies available to field personnel for data collection.

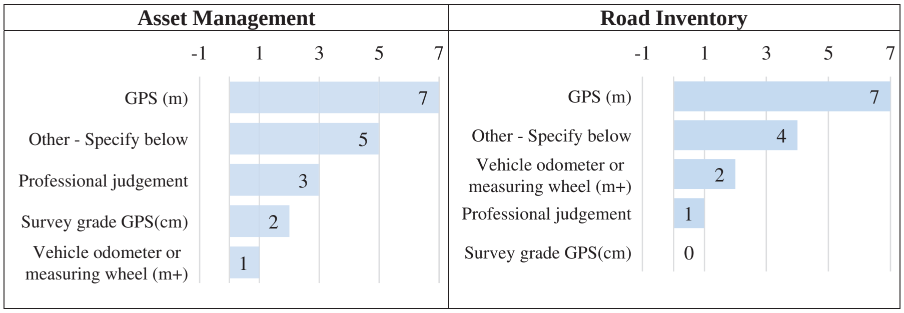


Figure 5.27 Accuracy requirement.

not necessary for the accuracy to be at the level of centimeters. A follow-up question was asked about quantitative standards for asset locating accuracy. It appears that most SHAs are still at the stage of defining accuracy standards in addition to the achievable precision by different technologies.

5.5 Leveraging Construction Documentation Process for Collecting Asset Data

The construction inspection process shall guide the field implementation of construction documentation. Table 5.6 illustrates the construction inspection process with examples for a concrete pipe installation. Figure 5.28 graphically illustrates the process. In the current practice at INDOT, construction engineers have to mentally linking construction activity (received notification), plan asset (physical structures), and pay items (for documentation) and record quantities for identified pay items.

INDOT has developed a mobile field app for recording quantities of pay items. Figure 5.29 illustrates a couple of screenshots. With this app, the starting point for construction documentation is pay items; that is, construction engineers must have completed the mental linking process before they can start documentation. This approach places pressure on construction engineers. It does not align with the construction inspection process.

Both the field app and the construction documentation process need to be modified to align with the construction inspection process. A method was created to automate the mental linking process and the flow of data items from construction documentation to asset management systems. Figure 5.30 illustrates the user interface as well as the steps of the newly created construction inspection model. The process starts with picking a plan activity—Step 1, which aligns with Step 1 in Figure 5.28. Step 2 in Figure 5.30 aligns with Step 2 in Figure 5.28, in which all the mental linking processes are automated; that is, upon the selection of the plan activity, relevant plan asset information is automatically retried and associated pay items are automatically determined. This new arrangement allows construction engineers to verify the link among construction activity, plan assets, and pay items rather than to mentally link them. Moreover, relevant plan asset information (from drawings and specs.) is available to construction engineers, shifting the entire field inspection and construction documentation practice into a "check-and-verify" mode.

Behind the scene, a mechanism was established to match data items in construction documentation to data items required by asset management systems (e.g., work management system, or WMS). In the example illustrated in Figure 5.30, the plan asset is Structure 25 (pipe); the corresponding asset is Ditch in the asset management system. Any WMS data items not directly recorded in the current construction documentation practice will have to be collected by construction engineers ([2.3] in Step 2).

The mechanism that links/matches plan assets to assets in asset management systems such as WMS is the key to implementing the construction inspection model for construction documentation and leveraging this documentation practice for collecting asset data during construction. Figure 5.31 illustrates the framework for this linking mechanism. It contains four modules and uses pay items as the bridge to connect to plan assets and assets in WMS.

Module 1: Associating Pay Items in the Contract Information Book (CIB) to Plan Assets

The goal of Module 1 is to associate pay item(s) in the CIB to every plan asset—physical structure prescribed in design documents (plans/drawings). This goal was achieved by interviewing INDOT construction engineers and examining four INDOT standards—INDOT 2014 CAD Standards Manual, INDOT 2013 Design Manual, INDOT 2014 Standard Specifications, and INDOT 2014 Standard Drawings. INDOT standards prescribe how and where in the plans physical structures (plan assets) are specified. For instance, the schedule/table of underdrains contains relevant information for all underdrain plan assets including various types of pipes, outlets, and outlet protectors. Knowledge and experience of INDOT construction engineers help determine the construction process and association between plan assets and pay items. Together, they enable the retrieval of plan asset information for every pay item and the retrieval of pay item information for every plan asset.

TABLE 5.6
An example of construction inspection process and corresponding documentation.

Steps in a construction inspection process	Corresponding examples
1. Schedule of activity from contractor	1. Install concrete pipe by Main Street, Structure 25
2. Review plans/specs for construction components and process	2. Pipe 18″ RCP, placement method, and backfill requirements per spec section 715
3. Inspect activity to insure requirements are met	3. Pipe excavated, bedded, installed, and backfilled. Quantities measured.
4. Record pay item quantities in SiteManager based on associated plan asset(s)	4. Structure 47 on plan—2 pay items: 149′ 18″ Type 1 pipe and 95cy Structure Backfill Type 1.

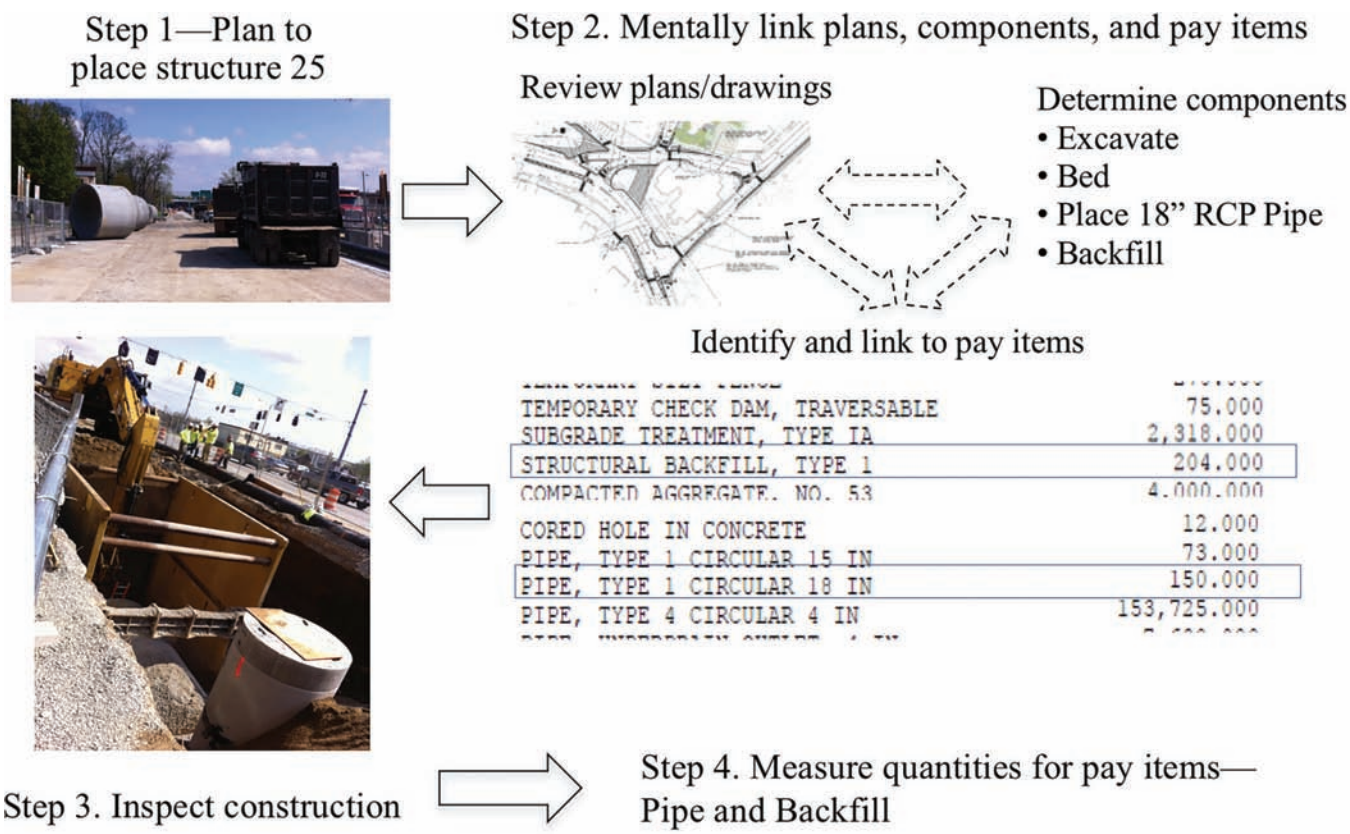


Figure 5.28 Inspection model.

If the plans/design drawings are in an intelligent, digital form, the retrievals can be automated because for every pay item, it is known what plan asset to look for and where to find relevant information. Consequently, detailed drawings and specifications regarding a plan asset or pay item can be retrieved and presented to construction engineers (similar to part [2.2] in Figure 5.30) to assist them in verifying that physical structures have been constructed correctly.

In the current practice at INDOT, pay items are generated after design is complete and before project letting. Plan assets determine pay items and their quantities. Resulting pay items are part of the construction contract. This means that the association between pay items and plan assets has already been established; however, the information is not being passed into construction. In future implementation, it is recommended to save the association information when generating pay items based on design (plan assets) and use that association information in construction documentation and field data collection.

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

Module 2 aims at pre-compiling a list of relevant pay items for every WMS asset. Some pay items are relevant to more than one asset; therefore, they can appear in many lists. INDOT standard specification and knowledge

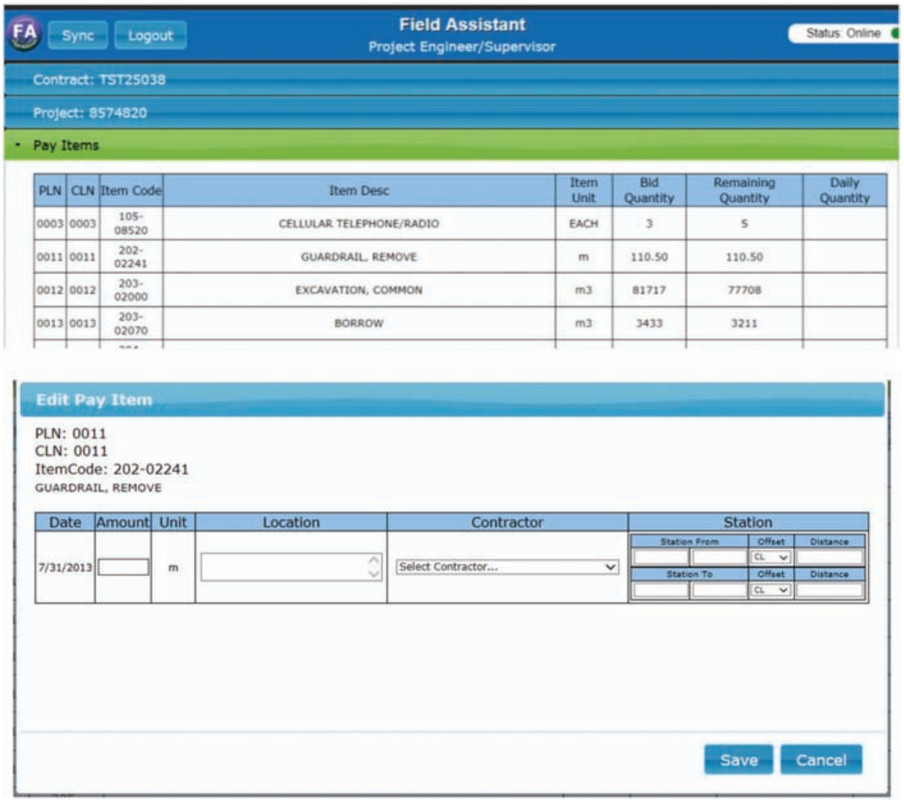


Figure 5.29 Screenshots of INDOT's field app.

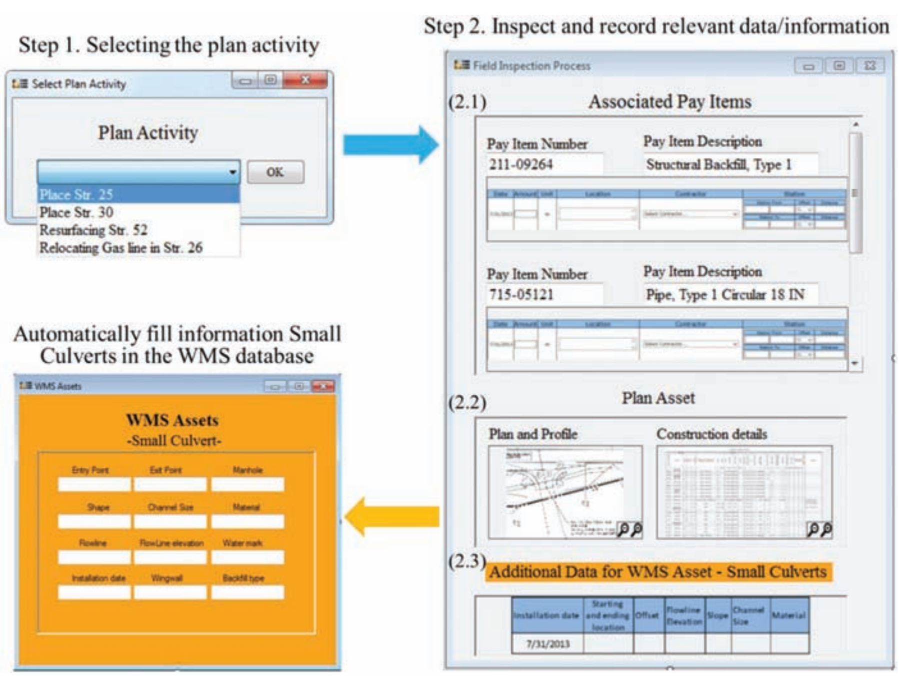


Figure 5.30 The conceptual user interface and workflow of the construction inspection model.

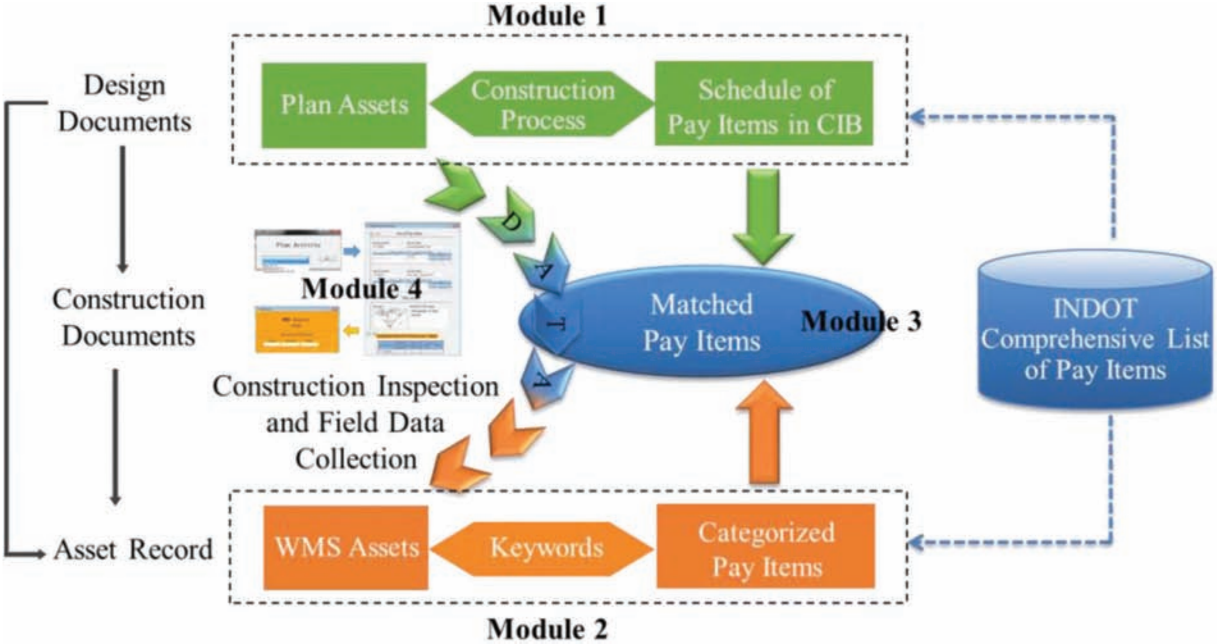


Figure 5.31 The framework for linking plan assets and assets in WMS via pay items.

on construction were first consulted to identify a list of keywords. These keywords were then used to search through the comprehensive list of pay items to retrieve relevant pay items. Resulting list was then examined to remove irrelevant pay items to reach 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 quite straightforward because every pay item in CIB and in the pre-compiled lists has a unique identifier/number. *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*. These matched pay items function as the bridge that connects plan assets to WMS assets such that when data items about plan assets flow into WMS.

Module 4: Construction Inspection and Field Data Collection

Module 4 is the field data collection and the channeling of construction documentation data items to WMS, described in Figure 5.30. Construction engineers use the field app to document relevant information for specific 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; certain data items, while they can come from design documents, they must be verified by construction engineers in the field; data items that are not covered in the current construction documentation practice must be collected by construction engineers. In this Module, every data item is labeled as either “Field collected,” “Field verified,” or “Field not involved/Information passing through.”

The result of carrying out Module 4 is asset data items collected during the construction documentation practice.

The framework is valid because (1) matched pay items are sets of common pay items that appear in CIB and in the pre-compiled lists belonging to specific WMS assets, (2) every pay item in CIB is associated with plan asset(s), and (3) every pay item in a pre-compiled list is associated with the corresponding WMS asset. Consequently, plan assets are connected to specific WMS assets; relevant data items collected by construction documentation practice for the construction of plan assets are automatically channeled into WMS to the corresponding WMS assets.

5.6 Case Illustration

The recommended framework was tested using data from an INDOT construction project. The project (contract number: IR-30143-A) includes both rehabilitation and new construction of roadways on US-31. The case illustration used the new construction part (about 18 miles long), with a total of 445 pay items in CIB.

The framework was tested for four classes/types of assets: underdrains, guardrail, attenuator, and small culverts. These four were chosen based on their construction costs and maintenance costs in the past three years. Table 5.7 lists the top 13 pay item classes based on their construction expenditure at INDOT. Table 5.8 lists the top 13 WMS assets based on their total cost of maintenance and rehabilitation for fiscal year 2012, 2013, and 2014.

5.6.1 Associating CIB Pay Items to Plan Assets

As mentioned before, in the current practice at INDOT, plan assets are designed and documented first, and then relevant pay items are identified for the plan assets before project letting. This indicates that plan assets and CIB pay items are already linked to each other, but the association/linking is neither saved, nor passed from design/generation of the bidding package to construction. As a result, in the case illustration, the starting point was two separate sets: plan assets and CIB pay items, and we have to establish the association between them. *It is recommended that INDOT keeps the association between plan assets and CIB pay items and passes that association into construction documentation and field data collection app.*

INDOT standards specify that for each of the four priority assets, there are schedules/tables in plans. These schedules/tables were the starting point to find pay items for selective groups of plan assets. Table 5.9 lists where relevant plan asset information might be found for each of the four priority assets.

Figure 5.32 illustrates the typical construction processes for the four priority assets and the association between plan assets and pay items. Construction steps such as "Excavate trench" for underdrains installation or "Backfill" for small culverts installation do not have a direct connection related to plan assets; therefore, their associated pay items are not listed in Table 5.10. Also, depending on the level of detail for the construction process, a plan asset might have more than one associated pay items. For instance, "install underdrain pipe" can be further detailed down into "place aggregate for underdrains," "place geotextiles for underdrains," and "place pipe of type 4 circular 4 inch." Consequently, there are three pay items that are associated with the plan asset of "underdrain pipe." Under that scenario, only data items documented for the main pay item—"715-05203 PIPE, TYPE 4 CIRCULAR 4 IN" will flow into WMS. The other two pay items, while still associated with the plan asset and can appear as part of the field data collection screen for the plan asset, will not send in their data to WMS. To reduce the size of Figure 5.32, this many-to-one association is only detailed out for the "install underdrain pipe" case. Only the main pay item is listed for all other cases. For certain plan assets such as guardrail end treatment, many different types can be used in a project. Each type corresponds to a specific pay item and therefore, these associations are identified individually and are all listed in Figure 5.32.

5.6.2 Pre-Compiling Pay Items for WMS Assets

Table 5.10 lists the key words used to search for relevant pay items from INDOT's full list for the four priority assets. The pre-compiled list of relevant pay items for underdrains has 17 pay items; for guardrails, 235; for attenuators, 55; and for culverts, 1222 (due to a wide variety of pipe types). Table 5.11 lists all the 17 pay items relevant to underdrains.

5.6.3 Matching Pay Items

Matching the pre-compiled lists of pay items to pay items in CIB results in 7 matched pay items for underdrains, 8 matched pay items for guardrails, 2 matched pay items for attenuators, and 66 matched pay items for small culverts. All of them are listed in Table 5.12. The large number of matched pay items for small culverts is attributed to many types of pipe and pipe terminations in this project. Line

TABLE 5.7
Top 13 pay item classes based on construction expenditure at INDOT.

Rank	Pay Item Class	WMS Asset	Pay Item Class $	Pay Item Class %
1	*CULVERT, STORM & SANITARY SEWERS*	Small culverts	$248,317,865	3.8
2	*SPECIAL FILL & BACKFILL ("B" BORROW)*	Small culverts	$173,092,702	2.7
3	TRAFFIC SIGNALS	Signals	$105,036,767	1.6
4	*MANHOLES, INLETS AND CATCH BASINS*	Small culverts	$91,363,741	1.4
5	*CONCRETE BOX CULVERTS & RETAINING WALLS*	Small culverts	$71,285,000	1.1
6	SIDEWALKS, CURB RAMPS, AND STEPS	ADA	$66,949,700	1
7	SEEDING AND SODDING	Mowables	$64,575,807	1
8	RIPRAP AND SLOPEWALL	Ditch	$63,802,962	1
9	GUARD RAIL	Guardrail	$63,241,514	1
10	GROUND MOUNTED SIGNS	Sign	$56,921,631	0.9
11	CURBING	Curbs	$56,240,654	0.9
12	PAVEMENT TRAFFIC MARKING	Special Markings	$52,694,877	0.8
13	UNDERDRAINS	Underdrains	$50,301,034	0.8

TABLE 5.8
Top 13 assets based on their maintenance and rehabilitation expenditure at INDOT.

Asset Type	Total Cost ($1,000)
Signals	6,202
Small Culverts	1,873
Attenuators	453
Special Markings	354
Underdrains	181
Sign	154
Ditch	146
Guardrail	102
Shoulders	100
Overhead Structures	20
Fences	12
Fixtures	8

TABLE 5.9
Schedules/tables in plans for the four priority assets.

Priority Asset	Information Source in Plans
Underdrains	Underdrains table
Small culverts	Structure data table and pipe material table
Guardrails	Guardrail table and cable barrier system table
Attenuators	Guardrail table*

*Attenuators not attached to guardrail do not show up in this table, but are included in pay items in CIB. Examine drawings.

number and approximate quantity came from the CIB book, and they are project-specific.

5.6.4 Mockup of Construction Inspection and Field Data Collection

Table 5.13 illustrates the data collection method for every data item required by asset management for the four priority assets. “Field collected” means the data item is collected by construction engineers in the field. For instance, the “Standing and ending location” for component “Pipe” under “Underdrain” is collected by construction engineers. “Field verified” means the data item is obtained from design and presented to construction engineers for them to verify in the field. For instance, the “Size” of the “Pipe” only needs to be verified in the field. “Field not involved/Information passing through” means that the data item comes directly from the design documents and construction engineers are not involved. For instance, for the “Elevation” of the “Pipe”, although the construction engineers must ensure the elevation of the pipe is set correctly to enable the gravity flow, they neither verify, nor collect the actual value of the elevation in the current practice.

1. Underdrains. The inspection scenario for underdrains is the installation of underdrains (pipes, outlets, and protectors) for northbound from station 39+00.00 to 49+00.00. Figure 5.33 illustrates a portion of the information regarding relevant plan assets. Figures 5.34, 5.35, 5.36, 5.37, and 5.38 illustrate how the data collection will work for main pipe, outlet pipe, and outlet protector. IPad style user interface is used to illustrate the data items currently being collected in the construction documentation process. The user interface has ten compartments. Compartment 1 and 2 show the contract number and project number, respectively. These two are filled when the construction engineer logs in and selects a project. Using Figure 5.34 as the example, when the construction engineer selects the activity of “Install Underdrains” in Compartment 3, Compartment 4 is automatically filled with all pay items associated with plan assets covered under the activity, i.e., underdrain pipes, outlets, and outlet protectors. The construction engineer then selects “PIPE, TYPE 4, CIRCULAR 4 IN,” and Compartment 5 is updated to show the interface for construction documentation—data collection for the chosen pay item, Compartment 6 shows construction records that have been collected and highlights the current record. Compartment 7, which is optional, shows information in the plans/drawings of the plan asset, and Compartment 8 lists all data items that will flow into WMS.

2. Guardrails. The inspection scenario for guardrails is the installation of guardrails (guardrail beam, transition, and end treatment) for US 31 Line A-NB, LT from station 446 to station 449. Figure 5.37 illustrates a portion of the information regarding relevant plan assets. Figures 5.38 to Figure 5.40 illustrate how the data collection and documentation will work for guardrails, guardrail transitions, and guardrail end treatments following the same procedure as described in Figure 5.34.

3. Impact Attenuators. The inspection scenario for impact attenuators is the installation of two GRET impact attenuators at US 31 Line “B”, Station 1,049+58.61; and two non-GRET impact attenuators at US 31 Line “B”, Station 252+91.83. For GRET impact attenuators, the information can be found from the guardrail table shown in Figure 5.41. For the other two impact attenuators that are not attached to guardrail do not show up in this guardrail table, the relevant information can be found from plan drawings. The relevant data collection and documentation procedures of GRET impact attenuators and non-GRET impact attenuators are shown in Figure 5.42 and Figure 5.43 respectively.

4. Small Culverts. The inspection scenario for small culverts is the installation of small culvert at section 202 Line “B,” 242+25.00, Left. Figure 5.44 shows the structure data table related to the segment of the small culverts. Figures 5.45, 5.46, and 5.47 illustrate how the data collection will work for culvert pipelines, pipe end sections, and inlets.

Figure 5.48 illustrates all the data items collected for WMS assets using the framework for all four inspection scenarios.

TABLE 5.10
Relevant pay items for underdrains.

Priority Asset	Keywords	Items Manually Removed / *Added*
Underdrains	Underdrain; outlet; protector; pipe, type 4	Removal: Pipe, type 4 circular more than 6 inch (used for culverts); Outlet box, electrical, weatherproof.
Guardrail	Post, guardrail, W beam, delineator, cable, transition, end treatment, terminal, barrel, timber	Removal: Pay items related to traffic control, temporary right of way, pavement and bases, and signs and signals
Attenuator	Impact attenuator, attenuating terminal, energy absorbing terminal, barrel, timber	Removal: Combination attenuating terminal, repair, labor only; guardrail attenuating terminal, nose assembly, mkn; and guardrail attenuating terminal, side plate, mksd
Culverts	Excavation, waterway; pipeline—pipe; pipe connectors—stop, valve, cap, casting, pump, plug, blind frange, butterfly debris screen, dripline, ductible iron fitting, gate, riser, connection, join; pipe terminator—manhole, hatch, monitoring well, catch basin, inlet, drain(age), end section, flushing, head(er), protection; structural plate pipe and concrete box structure—structure plate, box; side ditch, riprap, backfill, grout, slope wall, trench, sewer, stormwater	Removal: A large number of irrelevant items were removed *Adding: Items of "Best management practice," "force main," "life station," "maintenance," and "trash rack" were added*

TABLE 5.11
Seventeen relevant pay items for underdrains.

Section	Item	Description	Unit
718	718-52610	AGGREGATE FOR UNDERDRAINS	CYS
619	619-91969	CLEAN UNDERDRAIN OUTLET	EACH
718	718-99153	GEOTEXTILES FOR UNDERDRAIN	SYS
718	718-06526	HMA FOR UNDERDRAINS	TON
718	718-06528	OUTLET PROTECTOR, 1	EACH
718	718-06529	OUTLET PROTECTOR, 2	EACH
718	718-06531	OUTLET PROTECTOR, 3	EACH
715	715-05203	PIPE, TYPE 4 CIRCULAR 4 IN	LFT
715	715-05048	PIPE, TYPE 4 CIRCULAR 6 IN	LFT
715	715-05435	PIPE, UNDERDRAIN OUTLET, 4 IN.	LFT
715	715-05053	PIPE, UNDERDRAIN, OUTLET 6 IN	LFT
718	718-09980	RETROFIT DRAIN	EACH
718	718-11685	UNDERDRAIN CLEANOUT PORT	EACH
718	718-09979	UNDERDRAIN OUTLET CLEANING	EACH
718	718-09978	UNDERDRAIN OUTLET INSPECTION	EACH
718	718-08308	UNDERDRAIN, PATCHING	LFT
718	718-06532	VIDEO INSPECTION FOR UNDERDRAINS	LFT

TABLE 5.12
Matched pay items for the four priority assets.

Asset	Pay Item	Description	Unit	Quantity
Underdrains	718-52610	AGGREGATE FOR UNDERDRAINS	CYS	3,791
	718-99153	GEOTEXTILES FOR UNDERDRAIN	SYS	27,346
	718-06528	OUTLET PROTECTOR, 1	EACH	113
	718-06529	OUTLET PROTECTOR, 2	EACH	4
	715-05203	PIPE, TYPE 4 CIRCULAR 4 IN	LFT	30,447
	715-05053	PIPE, UNDERDRAIN, OUTLET 6 IN	LFT	3,842
	718-06532	VIDEO INSPECTION FOR UNDERDRAINS	LFT	9,500
Guardrails	601-01522	GUARDRAIL, TRANSITION TYPE TGB	EACH	25
	601-94689	GUARDRAIL END TREATMENT, OS	EACH	16
	601-94690	GUARDRAIL END TREATMENT, MS	EACH	4
	601-99108	GUARDRAIL, W-BEAM, DOUBLE FACED, 6 FT 3 IN SPACING	LFT	900
	602-06729	BARRIER DELINEATOR	EACH	56
	627-09327	CABLE BARRIER SYSTEM, TYPE TL-4	LFT	21959
	627-09331	SAFETY TERMINAL, TYPE TL-4	EACH	20
	601-99105	GUARDRAIL, W-BEAM, 6 FT 3 IN SPACING	LFT	3707
Attenuators	601-06233	IMPACT ATTENUATOR, ED, W1, TL-3	EACH	2
	601-06246	IMPACT ATTENUATOR, R2, W1, TL-3	EACH	2
Small culverts	616-05688	RIPRAP, CLASS 1	TON	8
	616-06405	RIPRAP, REVETMENT	TON	4219
	714-11173	STRUCTURE, REINFORCED CONCRETE BOX SECTIONS, 6 FT X 3 FT	LFT	580
	715-01336	GATE VALVE, 12 IN	EACH	4
	715-04995	LINE STOP 12"	EACH	3
	715-05024	PIPE, TYPE 2 CIRCULAR 36 IN	LFT	341
	715-05048	PIPE, TYPE 4 CIRCULAR 6 IN	LFT	26450
	715-05125	PIPE, TYPE 1 CIRCULAR 30 IN	LFT	165
	715-05169	PIPE, TYPE 3 CIRCULAR 15 IN	LFT	582
	715-05203	PIPE, TYPE 4 CIRCULAR 4 IN	LFT	30447
	715-09064	VIDEO INSPECTION FOR PIPE	LFT	8263
	715-10238	PIPE ROADWAY DRAIN CASTING EXTENSION	EACH	4
	715-46005	PIPE END SECTION, DIA 15"	EACH	27
	715-98961	FORCE MAIN SANITARY SEWER, 2.5"	LFT	225
	716-07633	PIPE INSTALLATION, TRENCHLESS, 24 IN	LFT	210
	719-05438	PIPE, DRAIN TILE TERMINAL SECTION, 4 IN	LFT	40
	...	...	...	...

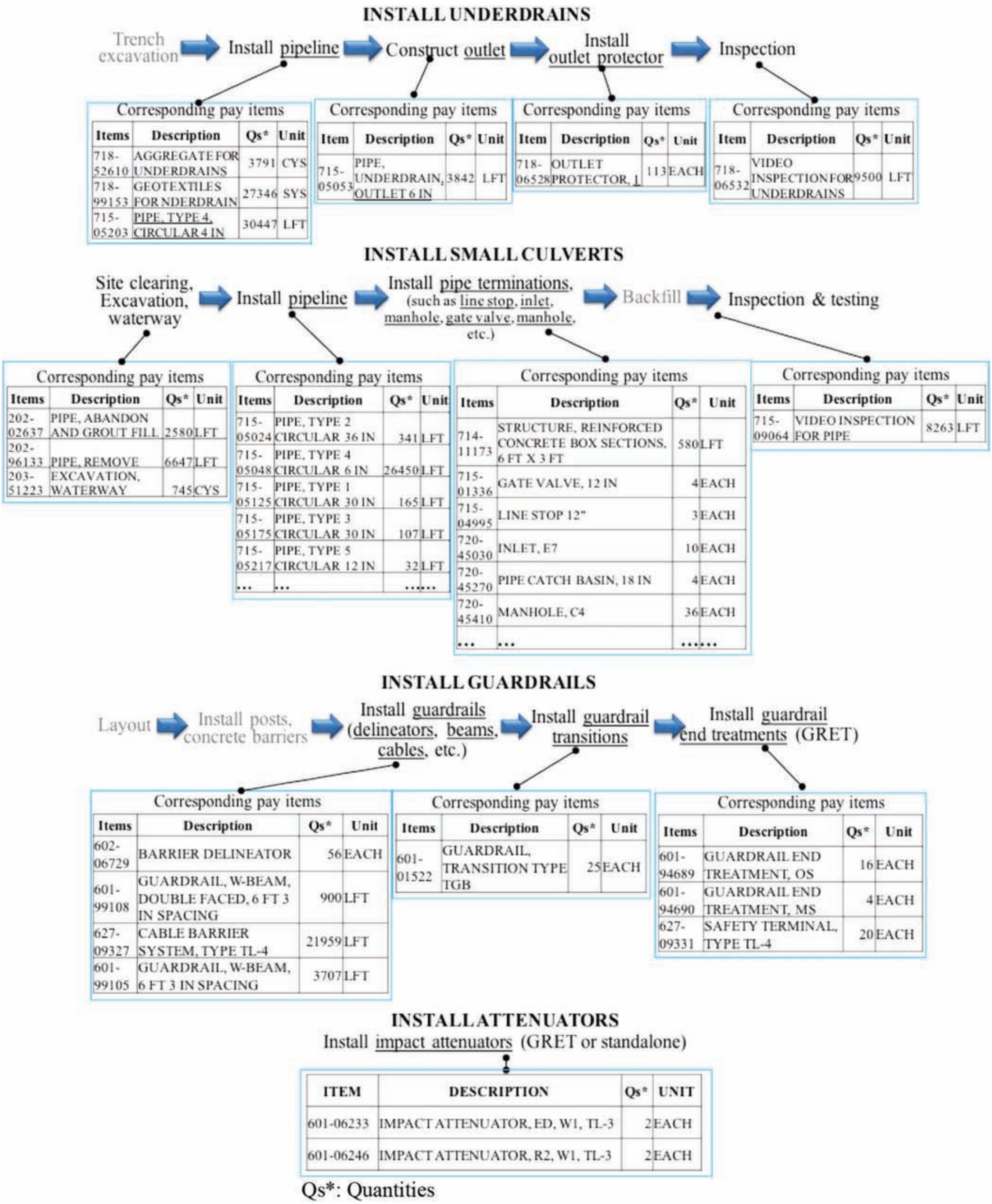


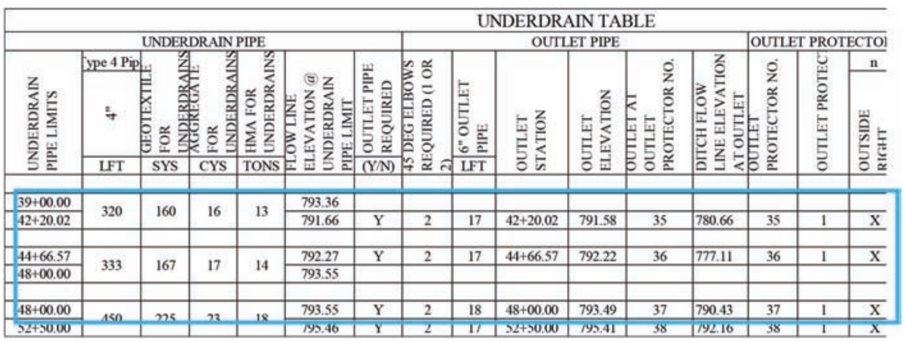
Figure 5.32 Associated pay items in CIB to the four priority plan assets.

TABLE 5.13
Three data flow types for individual data items of the four priority assets.

WMS Assets	Asset Subtype or Component	Data items	Data Flow Types from Plan to WMS Assets
Underdrain	Pipe	Starting and ending location	Field collected
		Line	Field collected
		Offset	Field collected
		Size	Field verified
		Elevation	Field not involved/information passing through
	Outlet	Point location	Field collected
		Point	Field collected
		Outlet type (manhole, protector, other)	Field verified
		Size	Field verified
		Inspection	Field collected
		Elevation	Field not involved/information passing through
		Corresponding flow volume	Field not involved/information passing through
Guardrail	Guardrail	Starting and ending location	Field collected
		Line	Field collected
		Offset	Field collected
		Height	Field verified
		Type	Field verified
		Installation/construction date	Field collected
		Manufacturer	Field verified
	Transition	Starting and ending location	Field collected
		Line	Field collected
		Offset	Field collected
		Height	Field verified
		Test level	Field verified
		Installation/construction date	Field collected
		Manufacturer	Field verified
		Type (steel w-beam, concrete median barrier, cable barrier, other)	Field verified
	End treatment	Point location	Field collected
		Point	Field collected
		Offset	Field collected
		Length	Field collected
		Test level	Field verified
		Installation/construction date	Field collected
		Manufacturer	Field verified
		Type (Type1,2, OS,MS, other)	Field verified
Attenuator	GRET or Standalone	Point location	Field collected
		Point	Field collected
		Width (W1,W2,W3)	Field verified
		Offset	Field collected
		Length	Field collected
		Test level (ED,R1,R2,CR,LS)	Field verified
		Installation/construction date	Field collected
		Manufacturer	Field verified
		Attenuator type/model	Field verified
		GRET or not	Field verified
Small culverts	Small culvert	Location	Field collected
		Line (entry point, exit point)	Field collected
		Flowline elevation	Field not involved/information passing through
		Type (manhole, inlet, line stop, valve, extension, etc.)	Field verified
		Box (width, height)	Field verified
		Pipe (circle/ellipsoid, material, type)	Field verified

TABLE 5.13
(Continued)

WMS Assets	Asset Subtype or Component	Data items	Data Flow Types from Plan to WMS Assets
		Ordinary high water mark	Field not involved/information passing through
		Channel (V-channel, trapezoid)	Field verified
		Length	Field collected
		Visual or video testing and results	Field collected
		Material testing	Field collected
		Installation/construction date	Field collected
		Wingwall (Y/N, and quadrant)	Field verified
		Type of backfill	Field verified



UNDERDRAIN TABLE

UNDERDRAIN PIPE: UNDERDRAIN PIPE LIMITS	UNDERDRAIN PIPE: Type 4 Pip... 4" (LFT)	UNDERDRAIN PIPE: GEOTEXTILE FOR UNDERDRAINS (SYS)	UNDERDRAIN PIPE: AGGREGATE FOR UNDERDRAINS (CYS)	UNDERDRAIN PIPE: HMA FOR UNDERDRAINS (TONS)	UNDERDRAIN PIPE: FLOW LINE ELEVATION @ UNDERDRAIN PIPE LIMIT	OUTLET PIPE: OUTLET PIPE REQUIRED (Y/N)	OUTLET PIPE: 45 DEG ELBOWS REQUIRED (1 OR 2)	OUTLET PIPE: 6" OUTLET PIPE (LFT)	OUTLET PIPE: OUTLET STATION	OUTLET PIPE: OUTLET ELEVATION	OUTLET PIPE: OUTLET AT OUTLET PROTECTOR NO.	OUTLET PIPE: DITCH FLOW LINE ELEVATION AT OUTLET	OUTLET PROTECTOI: OUTLET PROTECTOR NO.	OUTLET PROTECTOI: OUTLET PROTEC	OUTLET PROTECTOI: n OUTSIDE RIGHT
39+00.00	320	160	16	13	793.36										
42+20.02					791.66	Y	2	17	42+20.02	791.58	35	780.66	35	1	X
44+66.57	333	167	17	14	792.27	Y	2	17	44+66.57	792.22	36	777.11	36	1	X
48+00.00					793.55										
48+00.00	450	225	23	18	793.55	Y	2	18	48+00.00	793.49	37	790.43	37	1	X
52+50.00					795.46	Y	2	17	52+50.00	795.41	38	792.16	38	1	X

Figure 5.33 Plan asset information for underdrains.

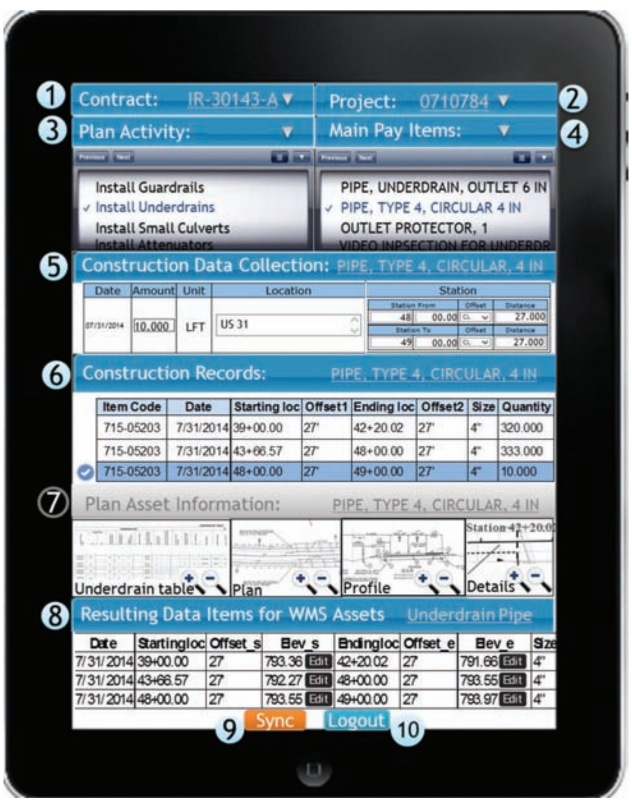


Figure 5.34 Data collection for underdrain pipe.

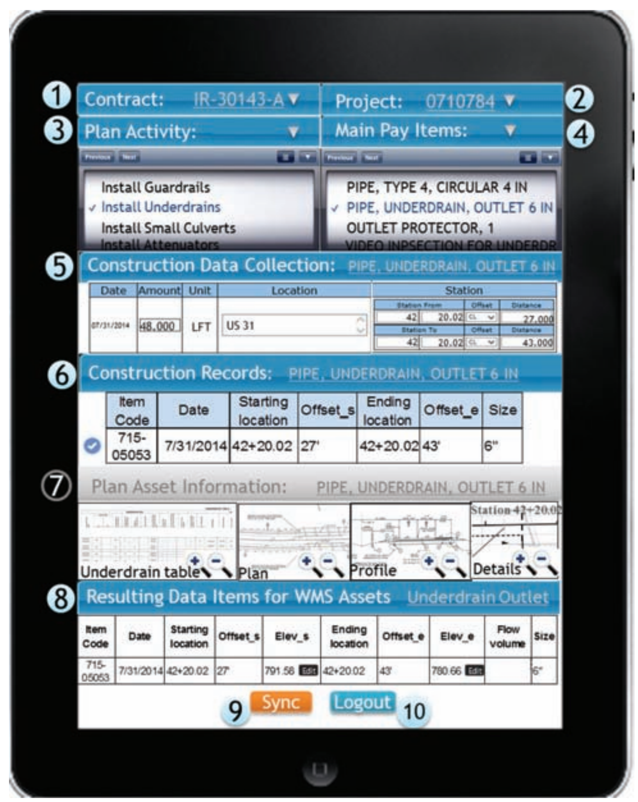


Figure 5.35 Data collection for underdrain outlet (pipe).

Figure 5.36 Data collection for underdrain outlet protector.

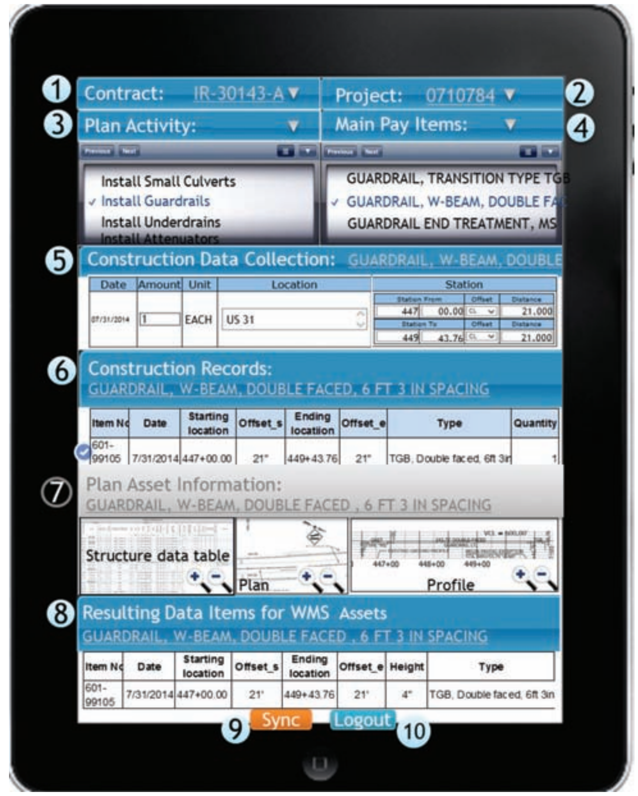


Figure 5.38 Data collection for guardrail beam.

GUARDRAIL SUMMARY TABLE									
ROAD	LINE	DIRECTION	STATION		W BEAM SINGLE FACE	W BEAM DOUBLE FACED	TRANSITION TYPE TGB	END TREATMENT OS	END TREATMENT MS
			FROM	TO	LFT	LFT	EACH	EACH	EACH
US 31	PR-A-R	LT	43+55.66	47+61.91	331.25		1		
US 31	PR-A-R	LT	41+30.11	40+36.36	18.75		1		
US 31	PR-A-R	RT	43+66.51	48+16.51		381.25	1		1
US 31	PR-B-R	RT	44+61.45	48+98.95	362.5		1	1	
US 31	PR-B-R	LT	42+25.12	38+31.37		18.75	1		1
US 31	PR-B-R	RT	42+35.90	41+29.65	31.25		1		
US 31	A-NB	LT	446+33.00	449+70.50		268.75	1		1
US 31	A-NB	RT	447+04.95	449+54.95	175		1	1	

Figure 5.37 Plan asset information for guardrails.

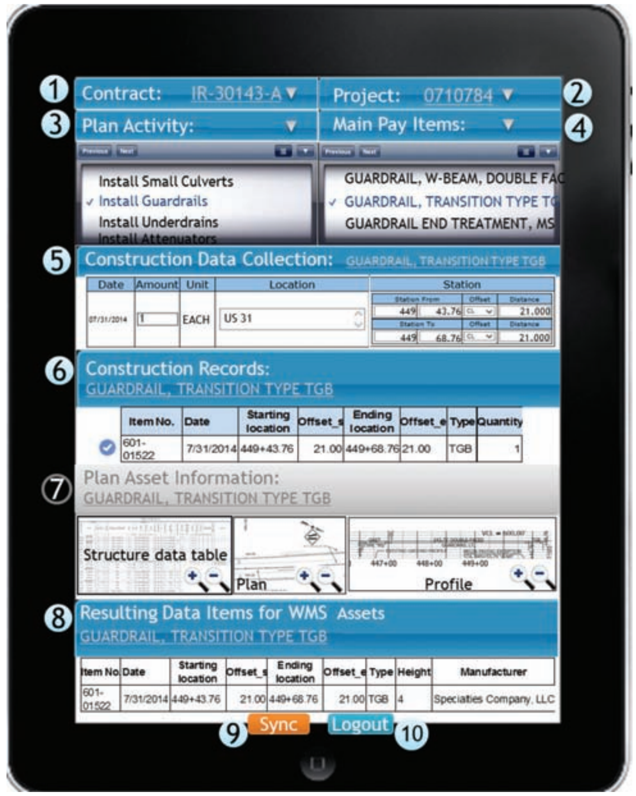


Figure 5.39 Data collection for guardrail transition.

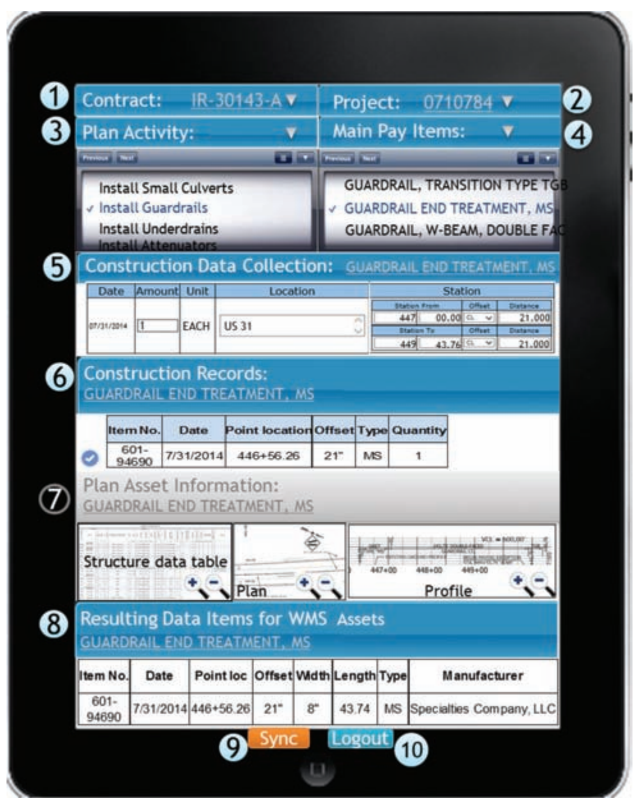


Figure 5.40 Data collection for guardrail end treatment (GRET).

FROM STATION	TO STATION	LOCATION LEFT	LOCATION LT. MEDIAN	LOCATION RT. MEDIAN	LOCATION RIGHT	GUARDRAIL, W BEAM, 6'-3" SPA.	RAILING, CONC., FT. W/AESTHETIC TREATMENT	RAILING, CONCRETE FC, MODIFIED	GUARDRAIL END TREATMENT OS	RAILING TRANSITION, TTX	GUARDRAIL TRANSITION TYPE TGB	RAILING, CONCRETE TYPE TX	IMPACT ATTENUATOR R2, W1, TL-3	CONC. BRIDGE RAILING TRANSITION TYPE TFT, MODIFIED	GUARDRAIL TERMINAL SYSTEM, W-BEAM, 6
						Lft.	Lft.	Lft.	Each	Each	Each	Lft.	Each	Each	Each
Line "B"															
1037+39.43	1037+89.43				X				1						
1037+89.43	1038+45.68				X	56.25									
1038+45.68	1038+70.68				X						1				
1038+70.68	1038+90.68				X									1	
1038+90.68	1044+54.71				X		564.03								
1044+54.71	1044+74.71				X									1	
1044+74.71	1044+99.71				X						1				
1044+99.71	1050+43.46				X	543.75									
1042+00.00	1046+18.75	X				418.75									
1046+18.75	1046+68.75	X							1						
1049+00.18	1049+36.68		X										1		
1049+80.53	1050+17.03		X										1		
1053+26.00	1059+68.00	X					642.00								

Figure 5.41 Plan asset information for impact attenuators.

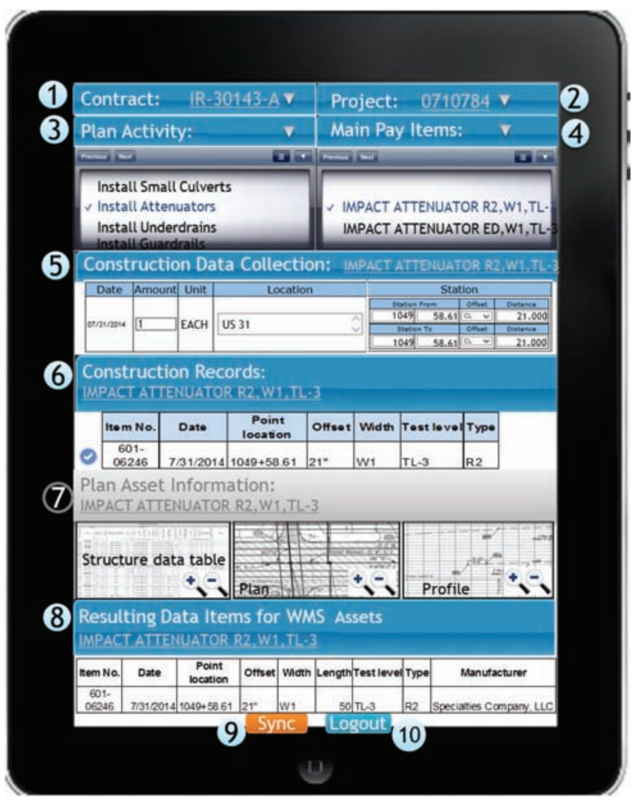


Figure 5.42 Data collection for impact attenuators as GRET.

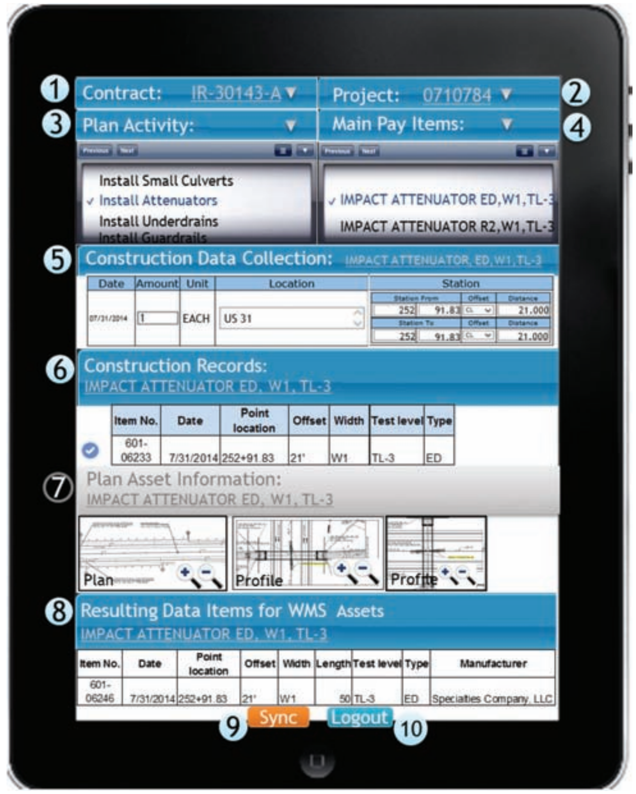


Figure 5.43 Data collection for standalone impact attenuators.

	LOCATION										FLOWLINE										
STRUCTURE NUMBER	STATION	LEFT	RIGHT	CROSS	SIZE	PIPE TYPE	MANHOLE, CATCH BASIN, INLET, OR SPECIALTY STRUCTURE	LENGTH	SKEW	COVER	UP STREAM	DOWN STREAM	CASTING	SERVICE LIFE	SITE DESIGNATION	pH	BACKFILL METHOD	STRUCTURAL BACKFILL, TYPE 1	REVETMENT RIPRAP*	CLASS 1 RIPRAP	CONCRETE CLASS A, FOR STRUCTURES
					in			ft	DEG.	ft	ELEV.	ELEV.	ELEV.	yr				yd³	Ton	Ton	yd³
	LINE "A-SB"																				
200G	437+15.00		X		18	2	INLET, TYPE N-12	81		1.6	833.78	832.75		75	NA	7.0	1/3	18.46/6.04		1.0	
200F	441+00.00		X		15	2	INLET, TYPE N-12	91		2.8	825.74	824.90		75	NA	7.0	1/3	15.77/9.28	1.6		
	LINE "A-NB"																				
200E	445+25.00	X			18	2	INLET, TYPE N-12	97		2.8	817.15	816.82		75	NA	7.0	1/3	18.89/14.53	2.3		
200	454+75.00		X		12	2	INLET, TYPE N-12	108		5.0	814.32	812.46		75	NA	7.0	1/3	13.26/12.92		0.7	
200A	457+75.00		X		12	2	INLET, TYPE N-12	111		5.8	816.25	814.00		75	NA	7.0	1/3	13.26/12.92		0.7	
201	461+00.00		X		18	2	INLET, TYPE N-12	109		5.1	817.62	816.50		75	NA	7.0	1/3	19.07/16.38		1.5	
	LINE "R"																				
202	242+25.00	X			18	2	INLET, TYPE N-12	104		2.9	821.02	820.00		75	NA	7.0	1/3	19.07/16.38		1.5	
203	249+00.00		X		18	2	INLET, TYPE N-12	106		4.2	824.17	823.00		75	NA	7.0	1/3	19.07/16.38		1.5	
302	240+07.00	X			12	2	INLET, TYPE E7 MODIFIED	17		5.9	814.89	814.46	820.60	75	NA	7.0	1	5.28	52.3/1.4		

Figure 5.44 Plan asset information for small culverts.

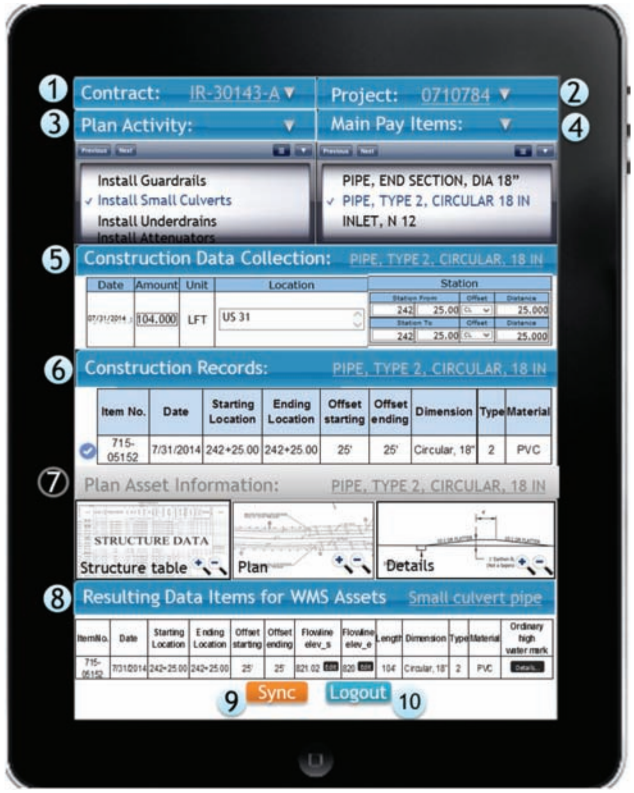


Figure 5.45 Data collection for small culverts pipelines.

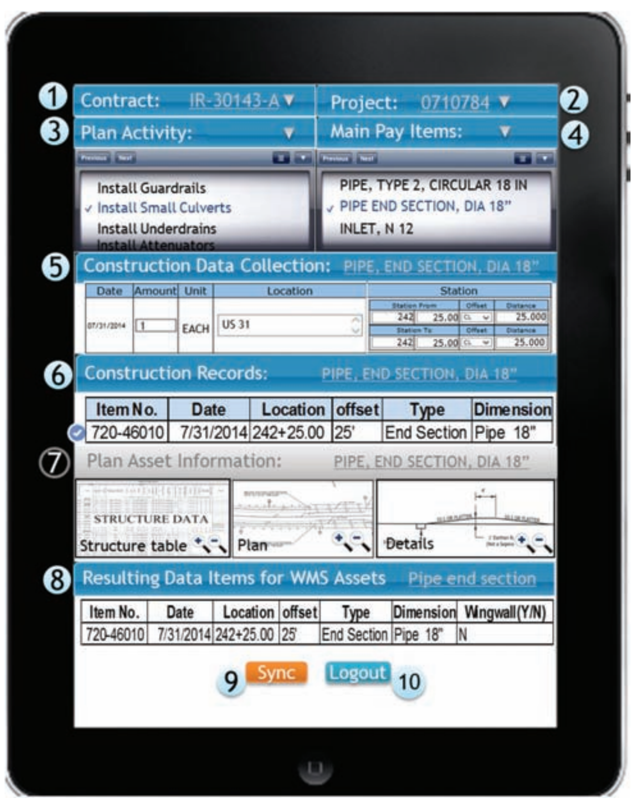


Figure 5.46 Data collection for small culverts pipe end section.

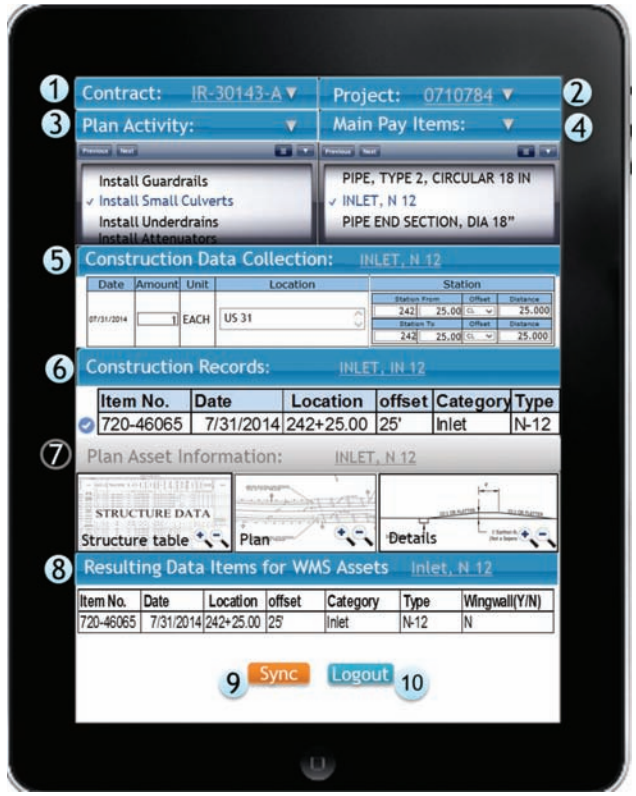


Figure 5.47 Data collection for small culverts inlets.

Item Code	Date	Starting loc	Offset_s	Elev_s	Ending loc	Offset_e	Elev_e	Size
715-05203	7/31/2014	39+00.00	27'	793.36	42+20.02	27'	791.66	4"
715-05203	7/31/2014	43+66.57	27'	792.27	48+00.00	27'	793.55	4"
715-05203	7/31/2014	48+00.00	27'	793.55	49+00.00	27'	793.97	4"

Item Code	Date	Starting location	Offset_s	Elev_s	Ending location	Offset_e	Elev_e	Flow volume	Size
715-05053	7/31/2014	42+20.02	27'	791.58	42+20.02	43'	780.66		6"

Item Code	No.	Date	Location	Offset	Elev_s	Elev_e	Type
715-06528	35	7/31/2014	42+20.02	43'	791.58	780.66	1

Item No.	Date	Starting location	Offset_s	Ending location	Offset_e	Height	Type
601-99105	7/31/2014	447+00.00	21'	449+43.76	21'	4"	TGB, Double faced, 6ft 3in

Item No.	Date	Starting location	Offset_s	Ending location	Offset_e	Type	Height	Manufacturer
601-01522	7/31/2014	449+43.76	21.00	449+68.76	21.00	TGB	4	Specialties Company, LLC

Item No.	Date	Point loc	Offset	Width	Length	Type	Manufacturer
601-94690	7/31/2014	446+56.26	21"	8"	43.74	MS	Specialties Company, LLC

Item No.	Date	Point location	Offset	Width	Length	Test level	Type	Manufacturer
601-06246	7/31/2014	1049+58.61	21"	W1	50	TL-3	R2	Specialties Company, LLC

Item No.	Date	Point location	Offset	Width	Length	Test level	Type	Manufacturer
601-06246	7/31/2014	252+91.83	21'	W1	50	TL-3	ED	Specialties Company, LLC

Item No.	Date	Starting Location	Ending Location	Offset starting	Offset ending	Flowline elev_s	Flowline elev_e	Length	Dimension	Type	Material	Ordinary high water mark
715-05152	7/31/2014	242+25.00	242+25.00	25'	25'	821.02	820	104'	Circular, 18"	2	PVC	

Item No.	Date	Location	offset	Type	Dimension	Wingwall(Y/N)
720-46010	7/31/2014	242+25.00	25'	End Section	Pipe 18"	N

Item No.	Date	Location	offset	Category	Type	Wingwall(Y/N)
720-46065	7/31/2014	242+25.00	25'	Inlet	N-12	N

Figure 5.48 WMS asset data collected through construction documentation.

6. DELIVERABLES

Primary deliverables from this study are listed as follows:

- The framework for identifying data needs by the asset management in the operation and maintenance phase and cross-referencing assets in various information management systems (Figure 5.1 in Section 5.1.2);
- Data needs identified for seven major asset types (Figures 5.5 to 5.14 in Section 5.3);
- The knowledge on the state-of-the-practice at SHAs acquired through a survey (Section 5.4);
- The framework that follows the construction inspection process to enhance the construction documentation practice and integrate the collection of asset data into the construction documentation process (Figure 5.30 in Section 5.5);
- The implementation guideline that includes a mapping mechanism to channel the flow of asset data collected during construction into asset management information systems (Figure 5.31 in Section 5.5); and
- The illustration of the guideline for four priority assets using real construction project data.

7. RECOMMENDATIONS FOR IMPLEMANTATION

Recommendations for the implementation of newly developed framework and guideline are listed as follows:

- Replace paper-based format with electronic files—electronic design files are passed on to construction engineers; electronic files are marked, modified, and commented during the construction phase to reflect the as-constructed and as-built condition; electronic construction records and as-built data automatically flow into asset management information systems for their usage during the operation and maintenance phase (they are also continuously updated to reflect the as-maintained condition).
- Use the data needs assessment framework (Figure 5.1 in Section 5.1.2) to identify the data needs from INDOT business groups for all infrastructure assets to create a comprehensive view of what data items are needed by which business groups. The result forms the base for guiding the flow of asset data collected during construction into relevant asset management information systems and maintaining the data integrity across all information management systems in INDOT.
- Retain the association between plan assets and pay items as a part of the design documents to be included in the contract documents. The one-to-one relationship between a plan asset and a pay item allows bringing relevant information to construction engineers in real-time.
- Adopt the guideline, especially its mapping mechanism, in the mobile construction documentation app. As illustrated in Section 5.6.4, the mapping mechanism integrates the collection of asset data items into the construction documentation process and the guideline enables the flow of these asset data items collected during the construction documentation process into suitable places in the corresponding asset management information systems.
- The adoption needs to be gradual: starting from the four priority assets, expanding into the seven major assets, and eventually covering all assets.
- Conduct a pilot study with early involvement to test before rolling out the new approach to all construction projects.
- Provide training to construction engineers and allocating resources for real-time technical support—any technical glitches must be solved right away, modern construction is fast pacing and cannot afford nonessential waiting.

8. SUMMARY AND CONCLUSIONS

Transportation asset management is a data-driven process. Having accurate and complete in-place data, i.e., the construction records and as-built data, of transpiration infrastructure assets is the key prerequisite to their effective management, operation and maintenance. The construction phase is the best time to collect such data. Unfortunately, in the current practice, the construction data collection (for the construction inspection and documentation purpose) and asset data collection (for the asset management purpose) are two separate processes. This isolated approach creates the blockage issue that prevents the flow of asset data collected during construction into asset management information systems, leading to the duplicate effort on data collection—a magnificent waste. To eliminate this waste, there is a need to create mechanisms to leverage the construction documentation process to collect asset data during the construction phase and to automate the flow of asset data into corresponding asset management information systems.

A framework was created to leverage the construction inspection and documentation practice to collect asset data that are needed in O&M during the construction phase. The framework uses specific pay items—construction activities that result in physical structures—as the bridge to connect plan assets (i.e., physical structures specified in the design documents) to their corresponding counterparts in the asset management systems. The framework is composed of (1) a data needs component for determining the information requirements from the O&M perspective, (2) a construction documentation module, and (3) a mapping mechanism to link data items to be collected during the construction documentation to data items in the asset management systems. The mapping mechanism was tested and validated using four priority asset classes—underdrains, guardrails, attenuators, and small culverts—from an INDOT construction project. The testing results show that the newly developed framework is viable and solid to collect asset data during the construction phase for O&M use, without adding extra workload to construction crews. The framework can reduce/eliminate the duplicate data collection efforts at INDOT, leading to savings and efficiency gains in the long term.

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APPENDICES

APPENDIX A: LITERATURE REVIEW: ASSET CLASSIFICATION AND RELEVANT DATA ITEMS

TABLE A.1
Asset classification and data needs.

Asset	Data Items	Notes
Road (inventory)	Functional class(ification) Identification codes Location History of construction and rehabilitation Geometrical characteristics • Divided/undivided roadway • Number of lanes • Lane width • Shoulder type and width • Radius of curves/degree of curvature Pavement • Pavement type • Layer thickness • Materials • Overlays • Drainage • Condition ◦ Skid resistance ◦ Serviceability	LRS (Location)
Signal	Structural support • Type • Service life Signal head • Service life • Date of installation Bulbs Signal controller Construction and maintenance history Condition of the signal Location	Location shall be registered to road network via LRS
Sign	Structural support Sheeting and painting material • Type • Service life Font size Visibility Retroreflectivity Construction and maintenance history Location	Location shall be registered to road network via LRS
Lighting	Structural support • Type • Service life Lighting bulbs • Type • Service life • Level of illumination Spacing between lighting poles Construction and maintenance history Location	Location shall be registered to road network via LRS
Detection devices	Type Location False alarm rate Life of the detector components	Location shall be registered to road network via LRS

TABLE A.1
(Continued)

Asset	Data Items	Notes
Pavement marking	Type and material Retro reflectivity Location Construction and maintenance history	Location shall be registered to road network via LRS
Guardrail	Type and material Location Condition Construction and maintenance history	Location shall be registered to road network via LRS
Tunnel		
Drainage	Can be further detailed down to cross pipes, box culverts, entrance pipes, curb and gutter, paved ditches, unpaved ditches, edge drains and underdrains, stormwater ponds, and drop inlets Some subtypes can be treated as a "Type" attribute while some such as ponds shall be treated as features in a separate data layer	
Other traffic assets	Attenuators, pavement striping, delineators, pavement markers	
Structure	Retaining wall Sound barrier	
Sidewalk		
Roadside	Vegetation and aesthetics Trees Shrub and bush Historic markers Right-of-way fence	
Facilities	Rest areas Weigh station Movable bridge	

TABLE A.2
Non-asset classification and data items.

Non-asset	Data Items	Notes
Traffic	Average Annual Daily Traffic (AADT) Traffic composition of different vehicle types Lane distribution of different vehicles Directional distribution of different vehicles Weigh-in-Motion (WIM) • Axle load distributions of the axle groups of different vehicle types	Such data shall all have location, i.e., registered to the road network via LRS
Accident	Causes of accidents Severity Location	Accident location shall be registered to the road network via LRS to facilitate future analysis, e.g., road geometry-safety.
Climatic and environmental data	Precipitation Temperature variation Freeze-thaw cycles	Data normally in separate databases, but geo-registered for future overlay analysis
Construction productivity	Manpower requirement (size and profession) Material requirement (type and quantity) Equipment requirement (type and number) Time requirement Money requirement	For standard activities only

TABLE A.3
Broadly categorized data requirements.

Group	Definition
Location	Actual location of the asset as denoted using a linear referencing system or geographic coordinates
Physical attributes	Description of the considered assets, which can include material type, size, length, etc.
Condition	Might be different from one asset to another. Examples: aggregated overall measure-pavement condition, bridge health indices, etc.; individual measure-pavement surface resistance, etc.

TABLE A.4
Data collection methods.

Mode	Characteristics
Manual	Data collectors + distance-measuring devices GPS handheld or PDA/iPad or hand-written (pen and paper) Walking or driving (windshield survey)
Automated	Multi-purpose vehicle equipped with distance-measuring device, digital video cameras, gyroscope, laser sensors, computer hardware, and potentially GPS Hardware configuration and customization Specific software for data collection, processing, storage, and reporting
Semi-automated	Somewhere in between manual and automated methods
Remote collection	Satellite imagery and remote sensing applications, photogrammetry, laser, depth camera; another way of categorization: photolog, videolog, and digital images

TABLE A.5
Device for collecting signs and markers retroreflectivity.

Method	Reference	Applicable Asset
RetroView Digital Imaging RetroChecker RC 2000 Line-Inspector	www.mandli.com/systems/retro.php www.mandli.com/systems/retro.php www.mechatronic.de/01firma/en/index_firma_en.html	Signal and pavement marking
RoadVista Model 922 RoadVista Model 1200F StripeMaster II Model 930C Laserlux CEN 30 Mobile Retroreflectometer	www.roadvista.com/products/model922.shtml http://www.roadvista.com/1200f-handheld-retroreflectometer/ http://www.roadvista.com/stripemaster-2-touch-retroreflectometer http://www.roadvista.com/laserlux-cen-30-mobile-retroreflectometer/ http://www.lasertech.com/Impulse-Rangefinders.aspx	Retro reflectivity
Impulse RM for Signs HISLAT	www.odyssey.co.nz/ http://www.lightinglab.fi/facilities/Spectroradiometer/index.html	Signs
Spectroradiometer ProMetric 1400 Luminancephotometer		Streetlight

TABLE A.6
Data management modes.*

Model	Definition
A fused (warehouse) database	Channels/mechanisms of integration are established to bring data from various databases into a single, federated database server
Many interoperable databases	Data not brought into a single database server, but rather, interoperable channels/mechanisms are established to integrate data to support particular applications

*Keys for integration: Location and commonly accepted data definitions and consistent data formats across systems.

TABLE A.7
Criteria for selecting data.

Source	Model	Definition
(Deighton 1991)	Integrity	Whenever two data elements represent the same piece of information, they should be equal
	Accuracy	The data values represent as closely as possible the considered piece of information
	Validity	The given data values are correct in terms of their possible and potential ranges of values
	Security	Restricting access and properly ensuring systematic and frequent backups in other storage media protect sensitive, confidential, and important data
(WERD 2003)	Relevance	Every data item collected and stored should support an explicitly defined decision need
	Appropriateness	The amount of collected and stored data and the frequency of their updating should be based on the needs and resources of the agency or organization
	Reliability	The data should exhibit the required accuracy, spatial coverage, completeness, and currency
	Affordability	The collected data are in accordance with the agency's financial and staff resources

APPENDIX B: INDOT DATA NEEDS

TABLE B.1
INDOT data needs analysis (based on Kevin Munro's matrix).

ID*	Asset†	Data Item	Data Type	Owner (Steward)	User	Database	Notes
1	Road (section)	Location	Line (LRS)	Road Inventory		EXOR	Tech Svcs uses road section data. AMS-Roadway is another system/database that contains road section data.
		Name and two alias	Attribute	Road Inventory		EXOR	
		Mainline ID	Attribute (linear events)				
		Functional class	Line (assumed to be linear events and thus, can be considered as attribute)‡	Road Inventory		EXOR	
		Rural/Urban	Attribute (linear events)	Road Inventory		EXOR	
		Contract#	Attribute (linear events)	SPMS business owner		EXOR inherited from SPMS	
		District	Attribute (linear events)	Road Inventory		EXOR	
		IRI	Attribute (linear events)	Road Inventory		EXOR	
		Met Code					
		Speed limit	Attribute (linear events)	Road Inventory		EXOR	
		Jurisdiction system, county/fed., municipal.; RTEL, Ramp code, and segment (including special segments)	Attributes of LRS (coded)	Road Inventory		EXOR	All coded in a single attribute, taking on different number of digits and locations
		Pavement friction	Attribute (linear events)	Traffic safety Pavement			
		# of lanes	Attribute (linear events)	Road Inventory			
		Lane width	Attribute (linear events)	Road Inventory			
		Surface material	Attribute (linear events)	Road Inventory			
		Base type	Attribute (linear events)	Road Inventory			
		Base depth	Attribute (linear events)	Road Inventory			
		Horizontal curvature	Attribute (linear events)	Road Inventory			
		Vertical curvature	Attribute (linear events)	Road Inventory			
2	Snow route		Line	Tech Svcs		AMS-Roadway	
3	Turn lane		Line	Tech Svcs		AMS-Roadway	
4	Overhead structure		Point	Tech Svcs		AMS-Roadway	
5	Special marking		Point	Tech Svcs		AMS-Roadway	
6	Striping		Line	Tech Svcs		AMS-Roadway	
7	Fence		Line	Tech Svcs		AMS-Roadway	
8	Divider		Line	Tech Svcs		AMS-Roadway	
9	National truck routes		Line	Road Inventory		EXOR	
10	Federal aid		Line	Road Inventory		EXOR	
11	Reference post		Point	Road Inventory		EXOR	
12	HPMS section		Line	Road Inventory		EXOR	
13	Median		Line	Road Inventory Maintenance Operations		EXOR WMS	Supplementary to each other
14	Parking		Line	Road Inventory		EXOR	

TABLE B.1
(Continued)

ID*	Asset†	Data Item	Data Type	Owner (Steward)	User	Database	Notes
15	Rutting		Line	Road Inventory		EXOR	
16	Shoulder		Line	Road Inventory Maintenance Operations		EXOR WMS	Supplementary to each other
17	Traffic section		Line	Road Inventory		EXOR	
18	Traffic station		Point	Road Inventory		EXOR	
19	Bridge	Location	Point and Line	Road Inventory			Prefer to dis-inherit Is there a bridge management unit to take over the ownership?
		Bridge center	Point	Bridge Inspection	Road Inventory	R&H (proposed)	
		Deck length	Attribute	Bridge Inspection	Road Inventory	BIAS	
		Deck width	Attribute	Bridge Inspection		BIAS	
		Work type	Attribute	Bridge Inspection		SPMS	
		Structure #	Attribute	Bridge Inspection		BIAS	
		Features intersected	Attribute	Bridge Inspection		BIAS	
		Overhead clearance	Attribute	Bridge Inspection		BIAS	
20	Vegetation (invasive species)			Maintenance management			
		Herbicide treatment		Maintenance operations			
21	Erosion						
22	*RWIS sensors*			Maintenance operations			
23	*RWIS buried cable*			Maintenance operations			
24	Attenuator		Point	Tech Svcs		AMS-Roadway	
25	Guardrail		Line	Tech Svcs		AMS-Roadway	
26	Sign		Point	Tech Svcs		AMS-Roadway	
27	Curb		Line	Tech Svcs		AMS-Roadway	
28	Ditch		Line	Tech Svcs Survey Aerial Engineering	Utility/PM/Env. Svcs	AMS-Roadway New inventory	
29	Culvert	Small culvert	Point	Tech Svcs		AMS-Roadway	
		Culvert		Survey/Aerial Engineering	Env. Svcs/EWPO/PM	New Inventory	
30	Mowable		Line	Tech Svcs		AMS-Roadway	
31	Underdrain	Outlets and pipes	Point	Tech Svcs		AMS-Roadway	
32	Fixtures (lighting)		Point				Empty at this moment
33	Signal		Point	Traffic Operation		AMS-Signal	
34		Controller	Attribute				
35		Head	Attribute				
36		Maint History	Attribute				
37		Interconnect	Attribute				
		Preemption	Attribute				
		Utilities	Attribute				
38		Detectors	Attribute				
39		Poles	Attribute				
40		Arms	Attribute				

TABLE B.1
(Continued)

ID*	Asset†	Data Item	Data Type	Owner (Steward)	User	Database	Notes
41	ITS Site	Sites	Attribute (lat./long.)	Traffic Operation		AMS-ITS Site	
42		Cabinet	Empty				
43		Detectors	Empty				
44		WIM	Empty				
45		CCTV	Empty				
46		ATR	Empty				
47		HAR	Empty				
48		PDMS	Empty				
49		TOWER	Empty				
50		DMS	Empty				
51	Right of Way (permanent)		Line	Survey/Aerial Engineering	Env. Svcs/EWPO/PM	New inventory	
52	Right of Way (proposed)		Line	Designer/Real Estate, PLS	Env. Svcs/EWPO/PM	New inventory	
53	Right of Way (temporary)		Line	Designer/Real Estate, PLS	Env. Svcs/EWPO/PM	New inventory	
54	Right of Way (App Existing)		Line	Survey/Aerial Engineering	Env. Svcs/EWPO/PM	New inventory	
55	Swamp-marsh-wetland		Line	Survey/Aerial Engineering	Env. Svcs Ecology & Waterway	New inventory	
56	Water flow line		Line	Survey/Aerial Engineering	Env. Svcs Ecology & Waterway	New inventory	
57	Historically significant bridge		Point?	Env. Svcs			
58	Toe of slope	This could be an attribute of road section	Line	Survey/Aerial Engineering	Utility/Env. Svcs	New inventory	
59	Ordinary high water		Line	Survey/Aerial Engineering	Utility/Env. Svcs	New inventory	
60	*Catch basin (proposed)*		Point	Design	Env. Svcs - stormwater	New inventory	
61	*Culvert (proposed)*		Point	Design	Env. Svcs - stormwater	New inventory	
62	*Inlet (*proposed*)*		Point	Design	Env. Svcs - stormwater	New inventory	
63	*Storm sewer (proposed)*		Line	Design	Env. Svcs - stormwater	New inventory	
64	*Flow line (proposed)*		Line	Design	Env. Svcs/EWPO	New inventory	
65	Catch basin		Point	Survey/Aerial Engineering	Env. Svcs - stormwater	New inventory	
66	Inlet and manhole		Point	Survey/Aerial Engineering	Env. Svcs - stormwater	New inventory	
67	Sanitary sewer		Line	Survey/Aerial Engineering	Env. Svcs - stormwater	New inventory	
68	Storm sewer		Line	Survey/Aerial Engineering	Env. Svcs - stormwater	New inventory	
69	Waters edge						
70	Top of bank	Treated the same way as toe of slope					
71	Riprap		Point				
72	Intermittent stream						
73	*Control sensor*		Point	Traffic Operation			
74	*Fiber runs*		Point	Traffic Operation			
75	*Power supply runs*		Point	Traffic Operation			
76	*Communication runs*		Point	Traffic Operation			
77	*Cable barrier*		Line	Road Inventory	Traffic Operation		
78	*Rumble strips*		Line				
79	*Grant programs (history)*						

TABLE B.1
(Continued)

ID*	Asset†	Data Item	Data Type	Owner (Steward)	User	Database	Notes
80	*Project stationing alignment*		Line	Survey/Arial Engineering	Road Inventory Geotech Maintenance		
81	*Soil compaction*			Construction			
82	*Pile driving*						
83	*Planting quantity*		Point	Env. Svcs-ecol/permit			
84	*Monumentation (project control)*	Project control is different from monument		Survey/Arial Engineering			
85	*Sensitive subsurface materials*	Polypyrene, foundary sand, coal ash, etc. Maybe geo-grid?	Line	Geotech	Permit		
86	*Bore holes*		Point	Geotech	Pavement Construction		
87	*Above ground facility pt relocated*	Poles, down guys, communication pedestals, vaults, cabinets, switches, fire hydrants, etc.	Point	Utility	ITS Environmental		
88	*Above ground facility line relocated*	Guy wire, power/under build power or communication cables	Line	Utility	Environmental		
89	*Above ground facility polygon relocated*	Sub-station, climate control facilities (RWIS), cell towers	Polygon	Utility	Environmental		
90	*Surface facility relocated*	Manhole, hand holes, boxes, valves	Point	Utility	Environmental		
91	*Underground facility line relocated*	Fiber optics, communication cables, power cables, gas distribution lines, gas transmission lines, petroleum lines, water, sewer, (extentions: conduits, encasements)	Line	Utility	ITS Environmental		

* x = included in data needs matrix; y = not included in data needs matrix yet.
† Physical assets vs. *proposed assets* vs. *desired assets and asset data items*.
‡ Text in red reflects the team's thoughts/additions/modifications to the original data table.

TABLE B.2
Work management system (WMS) assets.

Asset Type	WMS Module	WMS Asset ID	Asset Type	WMS Module	WMS Asset ID
De-icing system	Facilities	1	Small culverts	Roadway	28
DWTS	Facilities	2	Snow routes	Roadway	29
Electrical	Facilities	3	Special markings	Roadway	30
HVAC	Facilities	4	Striping	Roadway	31
Mechanical	Facilities	5	Turn lanes	Roadway	32
Plumbing	Facilities	6	Underdrains	Roadway	33
Pumps	Facilities	7	ADA State*	Roadway	41
Roofs	Facilities	8	ADA	Roadway	42
Safety	Facilities	9	Arms	Signals	34
Site	Facilities	10	Controller	Signals	35
Structures	Facilities	11	Detectors	Signals	36
Employee	Resources	12	Head	Signals	37
Materials	Resources	54	Interconnect	Signals	38
Attenuators	Roadway	13	Poles	Signals	39
Bridge Structures	Roadway	14	Signals	Signals	40
Curbs	Roadway	15	Utilities	Signals	53
Ditch	Roadway	16	Maintenance history	Signals	NA
Dividers	Roadway	17	Preemption	Signals	NA
Equipment	Resources	18	Detector	Signals-ITS Site	43
Fences	Roadway	19	Sites	Signals-ITS Site	44
Fixtures	Roadway	20	Cabinet	Signals-ITS Site	45
Guardrail	Roadway	21	WIM	Signals-ITS Site	46
Medians	Roadway	22	CCTV	Signals-ITS Site	47
Mowables	Roadway	23	ATR	Signals-ITS Site	48
Overhead structures	Roadway	24	HAR	Signals-ITS Site	49
Road sections	Roadway	25	PDMS	Signals-ITS Site	50
Shoulders	Roadway	26	Tower	Signals-ITS Site	51
Sign	Roadway	27	DMS	Signals-ITS Site	52

*Text in red reflects the team's thoughts/additions/modifications to the original data table.

TABLE B.3
Road inventory EXOR database tables.

Table	Attributes
CityRoutes	ObjectID, Shape (line), NE_UNIQUE, Jurisdiction, County, City, RTEL_FOR_R, Ramp_Code, Section_NU, LRS_Road_N (name), LRS_Road_A, LRS_Road_1, Geoloc_LEN, Shape_Length
CountyRoutes	ObjectID, Shape (line), NE_UNIQUE, Jurisdiction, County, City, RTEL_FOR_R, Ramp_Code, Section_NU, LRS_Road_N (name), LRS_Road_A, LRS_Road_1, Geoloc_LEN, Shape_Length
HighwayRoutes_countylog	
HighwayRoutes_statelog	
HighwayRoutes_primary_only	
National_Truck_RTE	
Rural_Urban	
Proposed_6	
FUNC_CLASS	ObjectID, Shape (line M), IIT_NE_TYPE, IIT_Date_Modified, FUNC_CLASS, Shape_Length
Federal_Aid	ObjectID, Shape (line M), IIT_INV_TYPE, IIT_DESCR, Federal_Aid, NHS, Geoloc_LEN, Shape_Length
Corp_line	ObjectID, Shape (polygon), CorpName, INC_Number, Shape_Length, Shape_Area
Ref_Post_Exor	ObjectID, Shape (point), IIT_NE_ID, IIT_INV_TY, IIT_Primar, IIT_DESCR, IIT_NOTE, REF_POST_N

APPENDIX C: SAMPLE INDOT DATA NEEDS (CROSS-REFERENCED)

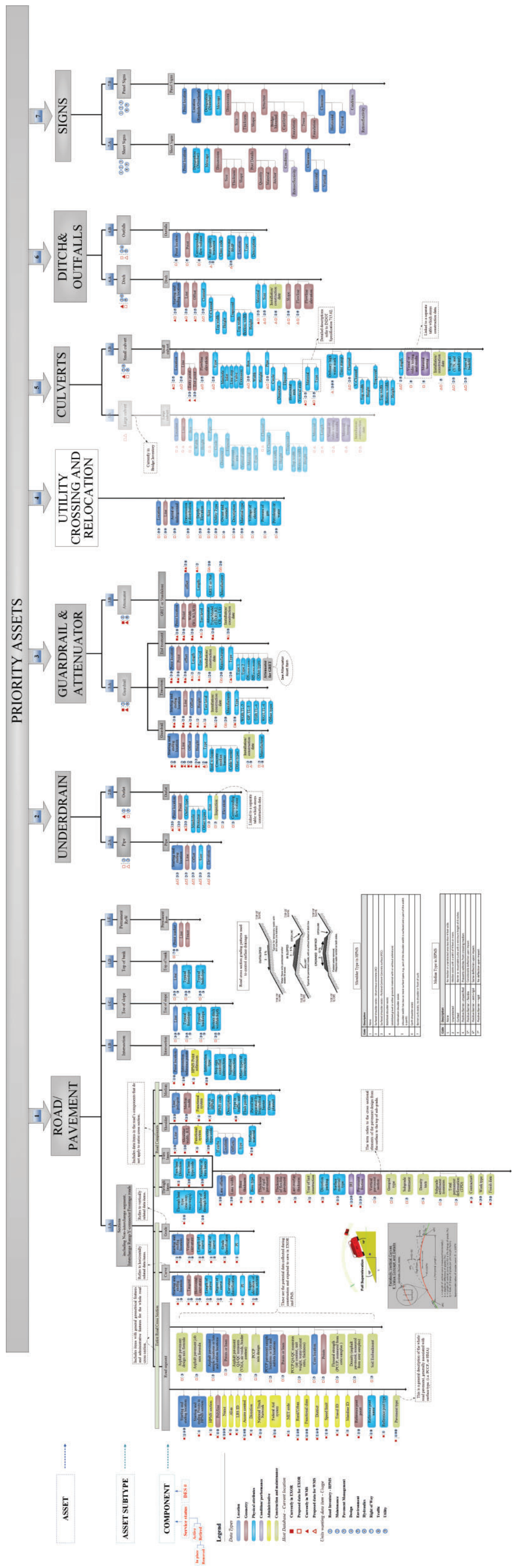
Asset	ID (Table B. 1.)	WMS Asset ID (Table B. 2.)	Component or subtype	WMS Module	Data						Owner/Steward				Database/ Software/ Interoperability	Data Collection
					Location	Geometry	Physical attributes	Condition/ performance measure	Administrative	Construction and maintenance	Data owner	Asset accountability	Data collector	User/Use		
Road	1	25	Segment/Section	Roadway	Starting and ending location	Line					Road Inventory		Road Inventory	HPMS reporting to FHWA on the extent and characteristics of state jurisdiction roadways	EXOR	
			Intersection			Horizontal curvature					Road Inventory		Road Inventory		WMS	
			Ramp/ Interchange Y			Vertical curvature					Road Inventory		Road Inventory			
			Connector/ Frontage Road						Functional class		Road Inventory		Road Inventory	Maintenance Operation		Roadway videolog for geometries
									Rural/Urban		WMS		WMS			
									District		WMS		WMS			
									Jurisdiction system, county/fed., municipal, RTEL, Ramp code, segment , and Met Code		Road Inventory		Road Inventory			
									National Truck Network NTN (0/1)		Road Inventory					
									LRS ID		Road Inventory					
									Federal Aid Systek		Road Inventory					
										Work Type						
										Finish Date						
							Name and two alias				Road Inventory					
							Access control (no, partial, full)				Road Inventory					
							# of through lanes				Road Inventory					
							Direction Parking				Road Inventory		Road Inventory			
							Mainline ID				WMS	Maintenance	WMS	Annual Highway Performance Monitoring System (HPMS) report	Deighton's Dtims	PathRunner XP Vehicle
							Lane width				Road Inventory		Road Inventory		SPMS--> EXOR	

Asset	ID (Table B. 1.)	WMS Asset ID (Table B. 2.)	Component or subtype	WMS Module	Data						Owner/Steward				Database/ Software/ Interoperability	Data Collection
					Location	Geometry	Physical attributes	Condition/ performance measure	Administrative	Construction and maintenance	Data owner	Asset accountability	Data collector	User/Use		
							Surface material			Pavement	Road Inventory		Road Inventory	Traffic safety	Microsoft Access	
							Base type				Road Inventory		Road Inventory	District-scoping maintenance, preservation, or restorative activities	WMS	
							Vertical pavement section				Road Inventory		Road Inventory	INDOT Office of Materials		
							IRI				WMS		Pathway Services (contractor) State Level INDOT Research Division	Office of Pavement Engineering	WMS	
							Pavement friction				Pavement		INDOT Research Division	Trafic Safety, District Scoping, Maintenance, Preservation or retroactive activities INDOT office of Materials Management		
							Thickness			Contractor#	WMS		INDOT Research Division	Office of Pavement Engineering, Office of Geotechnical Engineering		
	58						Toe of Slope				Survey / Aerial Engineering		Env. Svcs. Ecology & Waterway			
	70						Top of Bank				Survey / Aerial Engineering		Env. Svcs. Ecology & Waterway			
	1		Intersection		Point Location	Point										
Guardrail	25	21		Roadway	Starting and ending location	Line	Type				Tech Services		Operations		AMS - Roadway	
					Offset		Materials									
Underdrain	31	33		Roadway	Starting and ending location	Line	Size				Tech Services		Operations		AMS - Roadway	
					Offset											
						Point	Outlet									

Asset	ID (Table B. 1.)	WMS Asset ID (Table B. 2.)	Component or subtype	WMS Module	Data						Owner/Steward				Database/ Software/ Interoperability	Data Collection
					Location	Geometry	Physical attributes	Condition/ performance measure	Administrative	Construction and maintenance	Data owner	Asset accountability	Data collector	User/Use		
Roadside Signs	26	27		Roadway	Point location	Point	Message, Sheeting and painting materials, Font size, Structural support	Visibility Retroreflectivity			Tech Services		Operations		AMS - Raodway	
					Offset											
Utility/ Relocates	88/91				Location	Line										
					Owner											
Large Culverts	61			Roadway	Location	Line	Description, Size, Material				Survey / Aerial Engineering		Operations	Env. Svce. / EPWO / PM	AMS - Roadway	
Small Culverts	29	28		Roadway	Location	Line	Description, Size, Material				Tech Services	Bridge Inspection	Operations		AMS - Roadway	
Ditch	28	16		Roadway	Starting and ending location	Line	Description, Size, Material				Tech Services / Aerial Engineering		Operations	Utility / PM Env. Svcs.	AMS - Roadway	
Attenuator	24	13		Roadway	Point location	Point	ED, R1, R2, CR, or LS				Road Inventory		Operations	Tech Services	AMS - Roadway EXOR	
Striping	6	31		Roadway	Starting and ending location	Line	Type, Color, Size				Tech Services		Operations		AMS - Roadway	
Project Stationing Alignment	80				Starting and ending location	Lines	Station #				Survey / Aerial Engineering	Road		Inventory, Geotech, Maintenance		
Pavement Coring					Point Location	Point	Measure				District			Office of Pavement Engineering Office of Materials Management Division of Research		
Bore Holes	86				Point Location	Point	Measure				Geotech			Pavement Construction		

APPENDIX D: DETAILED DATA NEEDS FOR SEVEN PRIORITY ASSETS

A full-size version of this appendix is available for download at http://dx.doi.org/10.5703/1288284316005.



APPENDIX E: SURVEY QUESTIONNAIRE

<u>Purpose Statement:</u> The construction phase for delivering road infrastructure provides an opportunity for collecting asset data to be shared with and utilized in the operation and maintenance (O&M) phase to effectively maintain and manage assets. The goal of this survey is to determine the current status and vision of state transportation agencies in that regard from four perspectives: data collection in construction, IT support, road inventory—data storage and management, and data usage in O&M phase to support asset management functions (assets including, but not limited to, pavement, guardrails, culverts, ditches, underdrains, and signs and signals

<u>Acknowledgement:</u> This survey is part of a research project sponsored by the Indiana Department of Transportation (INDOT) through the Joint Transportation Research Program (JTRP) between INDOT and Purdue University. We thank you for spending your precious time to provide solicited information items and share your knowledge and vision with us. All self-identifying participants will receive a summary of survey results as well as access information for our technical report.

Responder Information:

	Information (1)
Name (1)	____________________
Position (2)	____________________
Unit (3)	____________________
Title (4)	____________________
Agency (5)	____________________
Street Address (6)	____________________
Street Address Contd. (7)	____________________
City, State (8)	____________________
Zip Code (9)	____________________
Contact Phone (10)	____________________
Contact E-Mail (11)	____________________

Please identify the area of your primary job function.

❍ Construction (1)
❍ Road Inventory (2)
❍ Asset Management during O&M Phase (3)
❍ Information Technology (4)

If you are in the Asset Management area please provide a representative sample list of the assets:

____

Instructions: This survey is divided into four sections, one for each primary job function. Please answer the questions in the section corresponding to your primary job function. Answering questions to the best of your knowledge in the other sections is also greatly appreciated. Note: Most questions accept multiple responses.

Construction: This group of questions is associated with the primary job function of construction. Do you wish to answer the questions in this section?

❍ Yes (1)
❍ No (2)

1. What formats of design files/drawings are available to you for your use in construction?

❑ CADD Files (1)
❑ PDF Files (2)
❑ Paper Copies (3)
❑ Other—Specify below (4)

Please specify "Other" from the preceding question.

____

2. What geospatial referencing system is typically utilized on your construction projects?

❑ Project Station and Offset (1)
❑ Latitude / Longitude (2)
❑ Local Coordinate System (3)
❑ State Plane Coordinate System (4)
❑ UTM (5)
❑ State—Specific Geo-spatial Coordinate System (6)
❑ Other—Specify below (7)

Please specify "Other" from the preceding question.

____

3. How is your as-built data recorded, i.e., redlining or a new set of drawings?

❑ Redline of Record Paper Plans (1)
❑ Redline of Electronic Plans (2)
❑ CADD File Updates (3)
❑ Other—Specify below (4)

Please specify "Other" from the preceding question.

____

4. What is the standard data format/medium for reporting and archiving your construction records, i.e., Record Documentation?

- ❑ Paper Based (1)
- ❑ Video Recording (2)
- ❑ Electronic—CADD (3)
- ❑ Electronic—Site Manager or Equivalent Software (4)
- ❑ Electronic—PDF Files (5)
- ❑ Electronic—Microsoft Office or Equivalent (6)
- ❑ Other—Specify below (7)

Please specify "Other" from the preceding question.

____

5. What technology is typically available to field personnel during the construction inspection process?

- ❑ Survey grade GPS (cm) (1)
- ❑ GPS (m) (2)
- ❑ Vehicle odometer or measuring wheel (m+) (3)
- ❑ Professional judgment (4)
- ❑ Other—Specify below (5)

Please specify "Other" from the preceding question.

____

6. Please identify the business areas that utilize the data from your....Of which other units are you aware that utilize the data from your "Record Documentation"?

- ❑ Asset Management (1)
- ❑ Environmental Permitting (2)
- ❑ Operations and Maintenance (3)
- ❑ Strategic Planning (4)
- ❑ Design (5)
- ❑ Pavement Management (6)
- ❑ Other (7)

Please specify "Other" from the preceding question. Would you please provide some specific examples?

____

<u>Information Technology:</u> This group of questions is associated with the primary job function of Information Technology. Do you wish to answer the questions in this section?

- ❍ Yes (1)
- ❍ No (2)

1. What IT infrastructure for data management does your DOT employ throughout the life cycle of your transportation projects, i.e., what tools/business systems (e.g., Site Manager and ProjectWise) are used in design, construction, operations and maintenance, and road inventory?

    Design (1) ____________________

    Construction (2) ____________________

    Operations (3) ____________________

    Road Inventory (4) ____________________

2. Does the software/system used in the different stages of the construction process have the capacity to send and/or receive data from the other phases?
    - ❑ Design to Construction (1)
    - ❑ Construction to Operations (2)
    - ❑ Construction to Road Inventory (3)
    - ❑ Road Inventory to and from Operations (4)

3. What are the most significant barriers (limit 3) to the creation of a continuous data flow in which: design data serves as an input to the construction phase; files are updated to capture the discrepancy between as-designed and as-constructed assets; at the completion of construction, files automatically become the as-built data; and digital as-built data serves as input to the operation and maintenance phase to facilitate asset management tasks?
    - ❑ Organizational structure (1)
    - ❑ Business process (2)
    - ❑ IT infrastructure Hardware (3)
    - ❑ IT infrastructure Software (4)
    - ❑ Data interoperability (5)
    - ❑ Lack of protocol (6)
    - ❑ Lack of human resources (7)
    - ❑ Other—Specify below (8)

Please specify “Other” from the preceding question.

____

4. Are you aware of any technical initiatives in your organization to address data flow limitations?

- ❍ Yes (1)
- ❍ No (2)

Please elaborate on technical initiatives

____

Asset Management during O&M Phase: This group of questions is associated with the primary asset management and maintenance job functions during the Operation and Maintenance phase. Do you wish to answer the questions in this section?

- ❍ Yes (1)
- ❍ No (2)

1. What are the process and format for inventorying and documenting newly constructed assets?

	1. CADD Files (1)	2. Electronic File (2)	3. Paper Plans/Forms (3)	4. Verbal Notification (4)	5. Other (5)
Formal notification protocol in place (1)	❍	❍	❍	❍	❍
Informal notification from other DOT department (e.g.,construction) (2)	❍	❍	❍	❍	❍
DOT personnel in the local area are familiar with work in that area (3)	❍	❍	❍	❍	❍

Please specify “Other” from the preceding question.

____

2. What is the data updating process and format for work performed on an existing asset?

	1. CADD Files (1)	2. Electronic File (2)	3. Paper Plans/Forms (3)	4. Verbal Notification (4)	5. Other (5)
Formal notification protocol in place (1)	❍	❍	❍	❍	❍
Informal notification from other DOT department (e.g.,construction) (2)	❍	❍	❍	❍	❍
DOT personnel in the local area are familiar with work in that area (3)	❍	❍	❍	❍	❍

Please specify “Other” from the preceding question.

____

3. What technologies are available to field personnel when gathering asset data?

❑ Survey grade GPS(cm) (1)
❑ GPS (m) (2)
❑ Vehicle odometer or measuring wheel (m+) (3)
❑ Professional judgement (4)
❑ Other—Specify below (5)

Please specify “Other” from the preceding question.

____

4. What level of accuracy do you typically require for asset information?

- ❍ Survey grade GPS (cm) (1)
- ❍ GPS (m) (2)
- ❍ Vehicle odometer or measuring wheel (m+) (3)
- ❍ Professional judgment (4)
- ❍ Other—Specify below (5)

Please specify "Other" from the preceding question.

____

If your agency has quantitative standards for asset locational accuracy, please specify.

____

Road Inventory: This group of questions is associated with the primary job function of Road Inventory. Do you wish to answer the questions in this section?

- ❍ Yes (1)
- ❍ No (2)

1. What are the process and format for inventorying and documenting newly constructed assets?

	1. CADD Files (1)	2. Electronic File (2)	3. Paper Plans/Forms (3)	4. Verbal Notification (4)	5. Other (5)
Formal notification protocol in place (1)	❍	❍	❍	❍	❍
Informal notification from other DOT department (e.g.,construction) (2)	❍	❍	❍	❍	❍
DOT personnel in the local area are familiar with work in that area (3)	❍	❍	❍	❍	❍

Please specify “Other” from the preceding question.

____

2. What is the data updating process and format for work performed on an existing asset?

	1. CADD Files (1)	2. Electronic File (2)	3. Paper Plans/Forms (3)	4. Verbal Notification (4)	5. Other (5)
Formal notification protocol in place (1)	❍	❍	❍	❍	❍
Informal notification from other DOT department (e.g.,construction) (2)	❍	❍	❍	❍	❍
DOT personnel in the local area are familiar with work in that area (3)	❍	❍	❍	❍	❍

Please specify “Other” from the preceding question.

____

3. What technologies are available to you when collecting asset data?

❑ Survey grade GPS (1)
❑ GPS (2)
❑ Vehicle odometer or measuring wheel (3)
❑ Paper maps, inspection forms and reports (4)
❑ We do not collect asset data (6)
❑ Other—Specify below (7)

Please specify “Other” from the preceding question.

____

4. What level of locational accuracy do you typically require for asset information?

- ❍ Survey grade GPS (cm) (1)
- ❍ GPS (m) (2)
- ❍ Vehicle odometer or measuring wheel (m +) (3)
- ❍ Professional judgement (4)
- ❍ Other—Specify below (5)

Please specify "Other" from the preceding question.

____

If your agency has quantitative standards for asset locational accuracy, please specify.

____

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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