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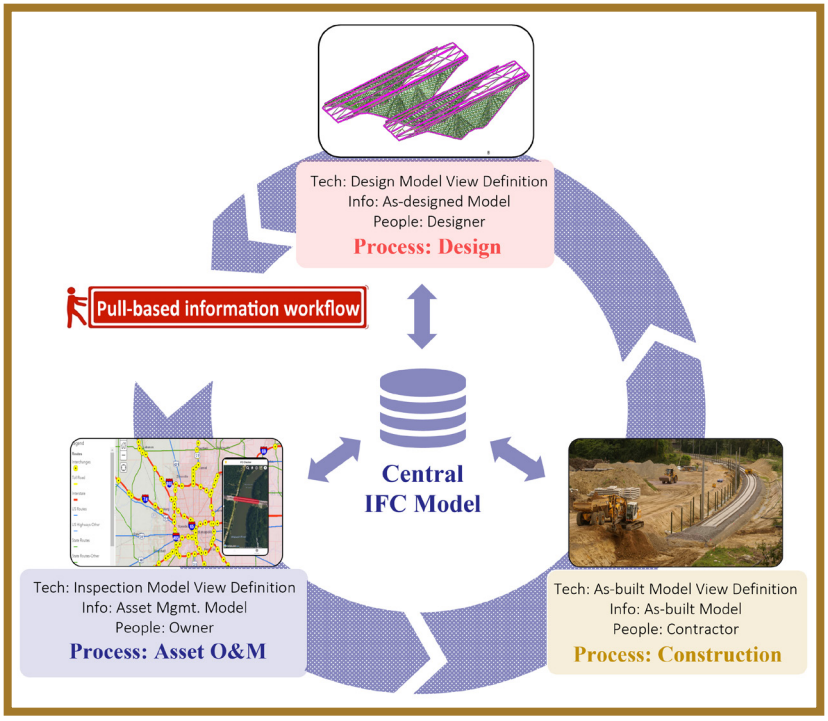
Life Cycle Integration of Building Information Modeling in Infrastructure Projects



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16. Abstract

Building Information Modeling (BIM) can provide solutions to many challenges of asset management, such as missing data, incompatible software, and an unclear business process. However, current implementation of BIM in infrastructure projects has only considers limited factors, such as technology application and digital information delivery, while issues of system compatibility and information needs are still missing. Different aspects of a business are interdependent and an incompatible development of various factors might result in different levels of BIM implementation or even project failure. Comprehensive research is needed to explore the key factors and challenges of BIM implementation in infrastructure projects. This study conducted interviews and surveys with key stakeholders of infrastructure projects to explore the challenges and potential solutions of BIM implementation. Here are the key findings from interviews with 37 professionals and surveys with 102 professionals from typical project stakeholders, including the INDOT owner, designer, contractor, and software vendors. Four main factors, challenges, and potential solutions were identified from content analysis of the interviews and further validated by the surveys. These factors include process factor (when), technology factor (how), people factor (who), and information factor (what). Corresponding solutions are proposed to refine the current workflow and practices.

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EXECUTIVE SUMMARY

Introduction

As an owner and facility manager whose responsibility is to build and maintain transportation infrastructure, the Indiana Department of Transportation (INDOT) must collect accurate and complete asset data throughout the life cycle of each project to effectively operate and maintain infrastructure assets in Indiana. Accurate and complete information is the key for effective asset operation and maintenance (O&M). However, current information management at many state Departments of Transportation (DOTs), including INDOT, is inefficient because information required for O&M can be inaccurate, incomplete, hard to locate, or even nonexistent. It is not uncommon for the O&M staff and engineers to have to (1) locate information after the fact in different file formats and different systems, (2) verify information accuracy with different stakeholders, and (3) manually recreate, recollect, and reenter information to O&M systems based on new site investigations. Some information might be invisible or physically inaccessible after the fact. This whole process is error-prone, time-consuming, repetitive, and can even be dangerous.

Building Information Modeling (BIM) was presented as a potential solution to many asset management issues; however, current implementation of BIM by many DOTs is limited to either technology application with new system compatibility issues or information delivery requirements without considering the actual information needs from downstream tasks. Different aspects of a business are interdependent; therefore, incompatible development of various factors might lead to different levels of BIM implementation and negatively affect overall project successes. Limited research was available regarding the key factors and potential challenges of BIM implementation in infrastructure projects. This study was funded by INDOT to explore the main challenges and potential solutions of BIM implementation through a case study with interviews and surveys of typical key stakeholders (owner, designers, contractors, and software vendors) of infrastructure projects.

Findings

Here are the key findings from interviews with 37 professionals and surveys of 102 professionals from typical project stakeholders, including the INDOT owner, designers, contractors, and software vendors.

- Four factors of BIM implementation were identified, including (1) isolation of project phases (process factor); (2) incompatibility of project technologies and interfaces (technology factor); (3) unclear definition of requirement and responsibility of project stakeholders (people factor); and (4) imperfect information collection and sharing (information factor).
- The four factors were mutually interdependent since focusing on a limited subset of individual factors can compromise the successful implementation of BIM.
- Specific challenges of each of the four factors (information, process, technology, and people) were identified for BIM implementation at INDOT.
- Potential solutions corresponding to the identified challenges of the four factors were tested with preliminary findings. One example is the following five solutions for the technology factor: (1) use model view definition to check missing data in IFC files and allow users to customize IFC schema for QA/QC with their own specs; (2) increase feasibility of data conversion via IFC; (3) use natural language processing technology to help the INDOT asset management team extract information from the inspection reports; (4) develop a window-based application and a mobile application to improve usability of IFC data (e.g., BIM-GIS integration); and (5) use an IFC-central model to solve information management issues among different stakeholders.

Implementation

The following recommendations are provided for future implementation of the research findings.

- INDOT and other state DOTs can use the framework of the four factors (i.e., process, people, technology, and information) to better understand, plan, evaluate, and improve BIM implementation in their infrastructure projects and organizations.
- In terms of process, INDOT and other state DOTs can use pull-based workflow instead of push-based workflow to require upstream phases to provide information based on the actual information needs of downstream phases.
- In terms of technology, INDOT and other state DOTs can use the proposed IFC-central model to reduce information management issues among different stakeholders in construction projects. The developed window application can quickly extract information from IFC files and the developed mobile application can collect maintenance data easily and accurately.
- In terms of people, INDOT and other state DOTs can better outline the relationship and responsibilities among the key project stakeholders, determine what information to collect, and create workflows with a format compatible with the asset management of state DOTs.

In terms of information, INDOT and other state DOTs can better understand and define the deliverables, formats, timing, and responsible parties of different types of information at different stages of a project.

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1. INTRODUCTION

Collecting accurate and complete information of infrastructure projects is the key to successful asset operation and maintenance (O&M) (Cai et al., 2015; Motamedi & Hammad, 2009), because asset O&M is a complex process that requires intensive data (Halfawy & Figueroa, 2006). Nowadays, urbanization and increasing traffic volumes have made the transportation system more complex, which also increases the difficulty of asset O&M (France-Mensah et al., 2017). A well-developed asset O&M system can improve efficiency, coordination, and cost-effectiveness of asset O&M decisions (Halfawy & Figueroa, 2006). Building information modeling (BIM) is a systematic approach to achieving life-cycle information delivery and management of infrastructure assets (Pocock et al., 2014). A successful implementation of BIM requires an integration of different factors of a business, such as process, technology, people, and information (Chen et al., 2014). However, in current practices, issues such as incompatibility of project software and apps (Hua, 2013), unclear definitions of business process and workflow (Abanda et al., 2015), isolation of project phases (Artto et al., 2008), and inaccurate infrastructure asset information (Ouertani et al., 2008), have caused obstacles in accessing data at the phase of asset O&M. Specifically, information required to operate and maintain infrastructure assets is either inaccurate, missing, or hard to find. More importantly, the spatial information has not been integrated with asset data, which has further caused difficulties to analyze infrastructure data in a spatial way. For example, Indiana Department of Transportation's (INDOT's) O&M team needs to spend a decent portion of their budgets and time to rebuild the database of asset inventory after the construction phase is complete (Cai et al., 2015), which is time-consuming and at times even hazardous.

The importance of accurate and complete asset information for effectively operating and maintaining infrastructure assets has been recognized by many state Departments of Transportation (DOTs), such as Connecticut DOT (CTDOT), Iowa DOT, Michigan DOT (MDOT), New York State DOT (NYSDOT), Ohio DOT (ODOT), Oregon DOT, Utah DOT (UDOT), and Wisconsin DOT (WisDOT). During past decades, some of these DOTs have developed processes for their infrastructure design and construction, which enable data to be transferred to the phase of asset O&M. However, INDOT has expressed current challenges with retrieving useful and accurate information for asset management. To enhance the efficiency of asset O&M at INDOT, this research has been funded in order to develop customized guidance for INDOT project teams, which will facilitate data flow on future INDOT projects.

2. PROBLEM STATEMENT

Asset O&M is a complex and data-intensive process and it requires accurate and complete data to make decisions. Collecting data after the completion of infrastructure construction for asset O&M is redundant work, wastes of time and money, and misses the optimal time to collect as-built information because some assets are not accessible after the construction is complete. More importantly, it could be hazardous because roads are open to the public. Therefore, collecting required data in the correct format at the ideal time can help improve the effectiveness of infrastructure asset O&M. To address the problem, this research will explore the following questions, which will contribute to the development of guidelines which can be applied to future INDOT projects. This will contribute to the life-cycle information delivery and management of infrastructure assets.

- What data is needed for the assets that INDOT owns and maintains?
- What is the best time or methodology to collect asset data?
- Who is responsible to collect, check, update, and maintain asset data and in what format?
- How to convert data needs of O&M to design requirements or documents?
- How to convert data needs of O&M to construction requirements or documents?

3. LITERATURE REVIEW

Federal Highway Administration (FHWA) defines asset O&M as a systematic approach to maintaining, upgrading, and operating physical assets cost-effectively (FHWA, 2017). The state DOTs, as departments that maintain and develop the transportation system and infrastructure, need to collect accurate and complete asset data such as as-built data, as-design data, and spatial data to effectively manage, operate, and maintain infrastructure assets (AASHTO, 2011; Cai et al., 2015). The decision makers within the DOTs also need to have an asset O&M system, combined with life-cycle optimization and analysis, to allocate increasingly limited budgets efficiently (Zhang, Keoleian, et al., 2010). Asset O&M is a complex and data-intensive process (Halfawy & Figueroa, 2006), which requires a successful data integration. A number of benefits of data integration have also been identified by FHWA, such as accuracy, correctness, integrity, consistency, completeness, faster processing time, lower acquisition cost, defensible decisions, and integrated decision making (Halfawy & Figueroa, 2006; Vandervalk et al., 2016).

Since data exchange performed by using paper-based documents can cause information loss, digital data delivery becomes the need of many DOTs. Also, digital data integration is an important part of asset management (Halfawy et al., 2002; Pantelias, 2005). Therefore, integrating the data in a consistent and unified format is the key for asset O&M (Halfawy & Figueroa, 2006). Optimal downstream usability should be developed such as consistent and logical names and symbology (UDOT, 2019). Data integration is not just simply

collecting all data occurring in different phases of a project. An effective data integration should collect data which is considered useful in later phases. Therefore, the level of detail and depth of data need to be determined (Pantelias, 2005).

Data integration includes collecting the (1) spatial information, (2) physical attributes, and (3) condition of the asset (Pantelias, 2005). For the aspect of collecting spatial information of asset, ESRI Geographical Information System (GIS) has been implemented to integrate infrastructure spatial data with inventory data to improve the capability of asset O&M. GIS has been proven to enable asset O&M teams to query, explore, and analyze infrastructure data in a spatial way. GIS can support asset management processes by enhancing the communication among different stakeholders, and can enable data reusability and sharing to eliminate duplication of efforts in gathering asset data (Halfawy et al., 2002; Halfawy & Figueroa, 2006). Additionally, asset spatial information is critical for asset O&M because (1) theoretically, asset data can be identified or referenced by their geographic locations (Halfawy et al., 2002; Halfawy & Figueroa, 2006), and (2) practically, asset O&M employees can know where exactly the problematic asset is. GIS has already been integrated into some states' information systems such as Texas DOT's GIS-integrated system for managing pavement maintenance and rehabilitation (Wang et al., 2003) and Illinois DOT's GIS-integrated management system for pavement (Bham et al., 2001). The development of GIS-integrated information systems have become more feasible and cost effective because of the availability of low cost hardware and software (Halfawy & Figueroa, 2006). Therefore, GIS will be adopted in future design and construction processes at INDOT. Modeling software such as Bentley OpenRoads can record physical attributes of assets such as length, width, materials, etc. (Halfaway et al., 2006), when engineers are instructed to include the required information in their modeling process. In addition, the condition rating (i.e., poor, fair, and good) of assets can be integrated as well to record asset condition data.

Researchers have developed two major administrative levels of asset management systems, including the project level system and the network level system respectively (Mbwana, 2001). The project level asset management system is used to predict the deterioration of an asset, and to choose proper preservation activities. The network level asset management system is used to ensure that each part of an asset management strategy will lead to an overall optimal solution for the entire asset network (Sathaye & Madanat, 2011). In 1982, Arizona developed an asset O&M system for pavement to optimize maintenance policies for the highway network (Zhang, 2013), which is based on linear programming. However, current asset O&M systems still lack enough information on optimization and sustainability considerations, which prevents DOTs from improving the performance of a transportation network. To improve the efficiency, life-cycle assessment (LCA) and life-cycle cost analysis (LCCA) were developed to evaluate environment and economic impacts of transportation infrastructure (Nathan & Scobell, 2012; Sathaye & Madanat, 2011). Current research efforts have only applied a limited number of parts of LCA and LCCA in asset O&M. Therefore, the life cycle integration of infrastructure information is incomplete (Zhang, Lepech, et al., 2010).

3.1 Business Process

The growing need to generate and collect infrastructure data has revealed the inefficiencies of the current approach of sharing and storing data at INDOT. The purpose of this project is to develop a guideline that can help INDOT manage their data flow more effectively such as converting infrastructure paper-based data into digital data. Therefore, several comparisons between INDOT and other DOTs were conducted to explore what asset data that INDOT currently collects versus what INDOT actually needs.

3.1.1 Assets and Attributes Comparison

A comparison was made between the data that INDOT has and the data that other DOTs have in their information delivery system, including CTDOT, Iowa DOT, MDOT, NYSDOT, ODOT, Oregon DOT, UDOT, and WisDOT.

The business processes of INDOT, CTDOT, Iowa DOT, MDOT, NYSDOT, ODOT, Oregon DOT, UDOT, and WisDOT have been explored. Even though there are a lot of overlaps, DOTs still have recorded some different asset information based on their specific needs. There is also some asset information that other DOTs have collected while INDOT currently does not, as shown in Table 3.1. The symbol "✓" means they have collected this type of asset information, "–" means they have not collected this type of asset information, and an empty cell means information was not available. Examples of asset attributes comparison are listed in Appendix A.

3.1.1.1 Connecticut DOT. CTDOT used performance measures to monitor the current state of assets as shown in Table 3.2 (CTDOT, 2018). The O&M team at CTDOT uses State of Good Repair (SOGR) to rate the condition and design maintenance plan. SOGR was used to measure the asset performance at many DOTs. On August 29, 2019, INDOT approved its Transportation Asset Management Plan (TAMP), which is a 10-year management tool bringing together all related business processes, and internal and external stakeholders (IN.gov, 2021). The INDOT TAMP will prepare a list of pavement and bridge assets and their conditions on the National Highway System to achieve the asset management objectives. For asset map tools, INDOT has adopted the Event Editor, a web tool configured to edit and save specific GIS event layers based on the Linear Referenced Network, and the

TABLE 3.1
Comparison of asset types between DOTs

Asset Type	INDOT	UDOT	ODOT	MDOT	Oregon DOT	NYSDOT	CTDOT	IowaDOT	WisDOT
Pedestrian assets (ADA)		–	✓	–	✓	N/A	N/A	N/A	N/A
Auto traffic recorder (ATR)	–	–	–	–	✓	N/A	N/A	N/A	N/A
Advertising devices	✓	–	✓	–	–	N/A	N/A	N/A	N/A
Bikeways	–	–	✓	–	–	N/A	N/A	N/A	N/A
Bridge	✓	–	✓	✓	✓	✓	✓	✓	✓
Cable barrier	✓	–	–	–	–	N/A	N/A	N/A	N/A
Crossover	✓	–	–	–	–	N/A	N/A	N/A	N/A
Detection devices	✓	–	–	–	–	N/A	N/A	N/A	N/A
Drainage	✓	✓	✓	✓	✓	✓	✓	✓	✓
Traffic barriers (e.g., delineators)	–	–	–	✓	–	N/A	N/A	N/A	N/A
Facilities (bicycle)	–	–	–	–	✓	✓	N/A	N/A	N/A
Facilities (tourists)	✓	–	✓	✓	✓	N/A	N/A	N/A	N/A
Facilities (fish barriers, fish passage)	–	–	–	–	✓	N/A	N/A	N/A	N/A
Cultural site (i.e., grave/cemetery)	✓	–	–	–	–	N/A	N/A	N/A	N/A
Guardrail and attenuators	✓	–	✓	✓	–	✓	N/A	N/A	N/A
Karst	✓	–	–	–	–				
Intelligent transportation system	✓	–	✓	–	✓	✓	N/A	N/A	N/A
Intersections	✓	–	✓	–	–	N/A	N/A	N/A	N/A
Lighting	✓	✓	✓	✓	–	N/A	N/A	N/A	N/A
Mechanical_BMP	✓	–	–	–	–	N/A	N/A	N/A	N/A
Miles of road	✓	✓	✓	✓	✓	✓	✓	✓	✓
Monitoring well (environmental)	✓	–	–	–	–	N/A	N/A	N/A	N/A
Park	–	–	–	–	✓	N/A	N/A	N/A	
Pavement (including pavement marking)	✓	✓	–	✓	✓	✓	✓	✓	
Post construction BMP	–	–	–	–	N/A	N/A	N/A	N/A	
Rest areas	–	–	✓	–	–	✓	N/A	N/A	N/A
Retaining wall	✓	–	✓	–	✓	N/A	N/A	N/A	N/A
Right of way sign	✓	–	✓	✓	–	N/A	N/A	N/A	N/A
Shoulder	✓	–	–	✓	–	N/A	N/A	N/A	N/A
Sidewalk	–	–	–	–	✓	N/A	N/A	N/A	N/A
Sign	✓	✓	✓	✓	✓	✓	✓	N/A	N/A
Signal	✓	✓	✓	✓	✓	✓	✓	N/A	N/A
Slide area	✓	–	–	–	–	N/A	N/A	N/A	N/A
Special marking	✓	–	–	–	–	N/A	N/A	N/A	N/A
Structure	✓	✓	✓	–	–	N/A	N/A	N/A	N/A
Snowmobile crossing	–	–	–	✓	–	N/A	N/A	N/A	N/A
Trail head approach	✓	–	–	✓	✓	N/A	N/A	N/A	N/A
Tunnels	–	–	–	–	✓	N/A	N/A	N/A	N/A
Filtration berm	✓	–	–	–	–	N/A	N/A	N/A	N/A
Utilities	✓	✓	✓	–	–	N/A	N/A	N/A	N/A
Highway buildings	–	–	–	–	–		✓		
Handhole	✓	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Vault	✓	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Service point	✓	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Dynamic Message Signs	✓	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tower	✓	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Shelter	✓	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cabinet	✓	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Road Weather Information System	✓	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Weigh stations/Weigh in Motion System	✓	–	–	✓	✓	N/A	N/A	N/A	N/A
Wetland	–	–	✓	–	–	–	–	–	–

Note: The symbol "✓" means they have collected this type of asset information, "–" means they have not collected this type of asset information, and an empty cell means information was not available.

Road Analyzer, a system to store road information. For asset data collection tool, INDOT uses the Collector for ArcGIS supported by ESRI, along with the asset data collection manual prepared by the INDOT geospatial team.

3.1.1.2 Iowa DOT. Iowa DOT started to apply its State of Good Repair (SoGR) transportation asset management plan beginning in 2011. Prior to that, Iowa DOT used "worst first" approach to managing its bridge assets and road assets, which was done by

TABLE 3.2
Performance measures for assets (CTDOT, 2018)

Asset	Performance Measure	Measure Definition
Bridges	Percentage of bridges classified as in a SOGR (by number of bridges)	SOGR is defined by CTDOT as a NBI condition rating of 5 or higher.
Pavements	Percentage of centerline miles in a SOGR	SOGR is defined by CTDOT as a PCI condition rating of 6 or higher.
Traffic signals	Percentage of traffic signals as in a SOGR	SOGR is defined by CTDOT as an age of 25 years or less. Traffic signal condition rating is age-based with the following thresholds: 0–15 years is good, 16–25 years is fair, and over 25 years is poor.
Signs-limited access	Percentage of signs as in a SOGR	SOGR is defined by CTDOT as an age of 17 years or less. Sign condition rating is age-based with the following thresholds: 0–12 years is good, 13–17 years is fair, and over 17 years is poor.
Signs-non limited access	Percentage of signs as in a SOGR	SOGR is defined by CTDOT as an age of 25 years or less. Sign condition rating is age-based with the following thresholds: 0–12 years is good, 13–17 years is fair, and over 17 years is poor.
Sign supports	Percentage of sign supports as in a SOGR	SOGR is defined by CTDOT as a condition rating of 5 or higher.
Pavement markings — line striping	Percentage of pavement markings as in a SOGR	For in-laid epoxy pavement markings, SOGR is defined by CTDOT as markings installed within 6 years. For epoxy pavement markings, SODR is defined by CTDOT as markings installed with 3 years. For water-based pavement markings, SOGR is defined by CTDOT as markings installed within 1 year.
Pavement markings — symbols and legends	Percentage of pavement markings as in a SOGR	For epoxy pavement markings, SODR is defined by CTDOT as markings installed with 3 years. For water-based pavement markings, SOGR is defined by CTDOT as markings installed within 1 year.
Highway buildings	Percentage of highway buildings as in a SOGR	SOGR is defined by CTDOT as condition rating of 3 or higher on a scale of 1–5.

Note: Table from *Highway Transportation Asset Management Plan* (CTDOT, 2018).

ranking the assets from the worst condition to the best and then generating a list of assets to repair until all available funds were utilized. The Iowa DOT defines a SoGR as a Bridge Condition Index (BCI) for all bridges. Iowa also has developed a Track-a-Plow application to track pavement performance (IOWA DOT, 2019).

3.1.1.3 Michigan DOT. MDOT has embedded GIS functionality for their transportation management system (TMS), which provides a statewide referencing system. Table 3.3 (Dye Management Group, 2014) shows the asset that MDOT records.

3.1.1.4 New York State DOT. NYSDOT has developed the Transportation Asset Management Plan to help articulate the investment strategy and process to manage the transportation assets within the NYSDOT, which can preserve and improve the safety of existing infrastructure. This Transportation Asset Management Plan not only established blueprint for life cycle management, but also for risk, performance management, service levels (Dominguez, 2019). The assets that NYSDOT currently collect are shown and compared in Table 3.1.

3.1.1.5 Ohio DOT. ODOT has developed an asset inventory matrix as shown in Figure 3.1 (ODOT, 2016). It summarizes what asset type ODOT collects, how they collect the data, who is responsible to

TABLE 3.3
List of assets of MDOT (Dye Management Group, 2014)

Asset	Asset Group
Atlas miles	Roadway
Total lane miles	Roadway
Bituminous surface lane miles	Roadway
Number of bridges	Large assets
Number of tourist facilities	Large assets
Number of signals	Overhead
Number of freeway lights	Overhead
Gravel shoulder miles	Roadside
Movable acres	In ROW
Number of culverts	Under roadway
Number of catch basins	Roadside
Number of signs	Roadside
Lineal feet of guardrail	Roadside
Concrete surface lane miles	Roadway
Number of sweepable approaches	Roadside
Paved shoulder miles	Roadside
Number of pump stations	Large assets
Curb miles	Roadside
Ditch miles	In ROW
Number of attenuators	Roadside
Lineal feet of existing ROW fence	In ROW
Number of delineators	Roadside
Number of guardrail endings	Roadside
Number of designated snowmobile crossings	Roadside
Number of weigh stations	Large assets
Non-motorized trail	In ROW
Lineal feet of sound wall	In ROW

Note: Table from *Monitoring Highway Assets with Remote Technology* (Dye Management Group, 2014).

Asset Inventory Matrix

Asset Type	Tier	Have Centralized Inventory	Collection Method	Collection/Update Cycle	Condition Assesment	Collected by	Central Office Sponsor	Central Office Contact	Status	Additional Resources Required	Anticipated Benefits
Pavements	1	Y	LRS	Annual	Y	Pavement Engineering	Pavement Engineering	Dave Miller	A	IT/OTS[1]	ROI[2], PDP[3], HPMS, Preservation Cost Savings (PCS)
Bridges	1	Y	LRS/GPS	Annual	Y	Districts	Structural Engineering	Amjad Waheed	B	SMS[1]	ROI[2], PDP[3], Safety, PCS[4]
Culverts	1	Y	LRS/GPS	5-10 years based on size, annually if deficient	Y	Districts/Consultant	Hydraulic Engineering	Jeff Syar	C	Staff/Equipment	Safety, PDP, PCS
Barrier/Guardrail	1	Y	Image Extraction	Replace/Repair	N	Districts/Technical Services	Roadway Engineering	Don Fisher	B	Staff/Equipment	Safety, PDP, PCS
Overhead Signs	1	Y	Image Extraction	3 year cycle	N	Technical Services	Traffic Operations	Jim Roth	A	Staff/Consultant	Safety, PDP, PCS
Post Construction BMP	1	Y	Manual/LRS	Per Project	Y	Districts/Hydraulic Engineering	Maintenance Administration	Thomas Lyden	C	Staff/Equipment	EPA Compliance/PCS
Tower Lighting	2	Y	LRS/GPS	2 year cycle	N	Districts	Traffic Operations	John MacAdam	C	Staff/Equipment	Safety, PDP, PCS
MSE/Retain. Walls	2	N	LRS/GPS	TBD	N	Geotechnical Engineering	Geotechnical Engineering	Steve Taliaferro	D	Staff	Safety, PDP, PCS
Excess Land/ Right-of-Way	2	N	Incorporate/Update Exisiting	Quarterly/Annaully	N	Districts	Real Estate	Drew Gilmore	D	Staff/Equipment	PDP, Economic Opportunity (EO)

Note: Figure from *Asset Inventory Matrix* (ODOT, 2016).

Figure 3.1 Asset inventory matrix (ODOT, 2016).

collect the data, and how often the data will be updated.

3.1.1.6 Oregon DOT. Oregon DOT collects asset information with an auto traffic recorder, which gathers traffic volume data for traffic congestion analysis. Oregon DOT collects asset information on bikeway, because they want to make sure the bike path remains serviceable. Traffic barrier plays an important role to guide traffic especially when a certain area is under construction. Oregon DOT collects traffic barrier information and intelligent transportation systems, which can provide useful information for traffic management. For example, cameras can be used to enforce traffic laws in certain area.

Some assets that INDOT currently does not collect are listed as follows.

- Auto traffic recorder (ATR) sites
- Advertising devices
- Bike paths
- Traffic barriers (delineators)
- Fish barriers
- Fish passage
- Intelligent transportation system (provide useful information for traffic management)
- Post construction BMP
- Rest areas
- Sidewalk
- Snowmobile crossing
- Traffic barriers
- Unstable slopes
- Weigh stations
- Wetland/Environmental/Endangered species

Oregon DOT has a roadway safety data and analysis program, which manages roadway assets of about 20,000 miles of lane, such as traffic signs, pavement markings, lighting, etc. An asset management database with a sophisticated spatial data tool (i.e., features, attributes, and conditions–statewide transportation improvement (FACS-STIP)) is used by Oregon DOT to manage their roadway assets. Specifically, FACS-STIP includes two parts: the Map Tool and Data To Go. Map Tool adopts ArcGIS to create geospatial maps with different base layers, while Data To Go allows users to retrieve asset information of interest (e.g., a specific highway point or a highway segment), as shown in Table 3.4 (Oregon DOT, 2020). Figure 3.2 (Oregon DOT, 2020) shows FACS-STIP, where users can select the asset they want to view and export.

3.1.1.7 Utah DOT. The attributes that INDOT and UDOT collecting were listed in Table 3.5. Currently INDOT has focused on signage and drainage information.

3.1.1.8 Wisconsin DOT. WisDOT has developed the Transportation Asset Management Plan to outline how future investment will be used in the next 10 years (2020–2029). WisDOT's Transportation Asset Management Plan also includes the strategy to ensure safe and efficient travel, optimal conditions of pavement and bridge, and a State of Good Repair of infrastructure (WisDOT, 2019). The assets that WisDOT focuses on are shown and compared in Table 3.1.

3.1.2 Update Cycle Comparison

Besides the asset type comparison, the update cycles among different DOTs are compared, as shown in Table 3.6. This table shows the comparison between Ohio and Indiana. Cells containing "NA" indicate that INDOT does not have information on update cycle for this asset. Cells containing blue text indicate that INDOT's update cycle is different from ODOT's update cycle.

TABLE 3.4
FACS-STIP (Oregon DOT, 2020)

Data to Go	Map Tool	Attributes
ADA ramps	Roadbed	Pavement, number of lanes, right shoulder, left shoulder, roadway composition
Approaches	Structures	Bridges, weight restricted bridges, retaining walls, major structures, tunnels
Auto Traffic Recorder (ATR) sites	Roadside	Sidewalks, ADA ramps, bicycle facilities, approaches, traffic barriers, sound barriers
Bicycle facilities	Drainage	
Bicycle facilities needs	Highway equipment	Signs, signals, ITS systems, weigh-in-motion sites, automatic traffic recorder stations
Bridges	Land and environment	Aggregate sites, fish barriers, fish passage, unstable slopes, wetlands
Culverts	Freight	Freight system highways, no reduction of capacity, high clearance routes
Fish barriers	Road network	Highway network, highway network by LRS, off-highway local, signed routes, mile points, mileposts
Fish passage	Functional class	Functional class, non-state functional class
Intelligent Transportation Systems (ITS)	Highway system class	Expressways, highway class
Pavement	Traffic data	AADT, projected AADT, posted speed, traffic flow, truck flow
Retaining walls	Crashes	SPIS, crash rates
Safety (crash, crash rates)	Boundaries	City limits, districts, regions
Sidewalks	Political boundaries	Congressional house, senate districts
Sidewalk needs	Project needs	Bridge, pavement, safety, STIP, bicycle facility, sidewalk
Sound barriers	Comments	Point, line
Traffic AADT		
Traffic barriers		
Traffic posted speed		
Traffic signals		
Traffic support (signs)		
Tunnels		
Unstable slopes		
Weigh-in-motion (MCTD) sites		

Note: Table from *FACS-STIP User Guide* (Oregon DOT, 2020).

Based on the comparison, several recommendations are made. Currently, there is no update cycle for advertising devices. It is recommended to update the information biennial to ensure it is functional. In addition, there is no update cycle for lighting. It is recommended to update the information every 2 years to ensure it is functional. For drainage, it is recommended to check its function every 5 to 10 years, or annually if it is deficient. INDOT does not have any information about the update cycle of overhead signs; therefore, it is recommended to update the information every 3 years to ensure accuracy and safety.

3.1.3 Performance Measure Comparison

In addition to the update cycle comparison, performance measurement is also compared among different DOTs, because checking the asset condition is a very important part for asset O&M. Based on the search from the INDOT and communication with INDOT team, it is found the information of performance measurement about seven areas. It is compared with other DOTs such as the Connecticut DOT as shown in Table 3.7 (CTDOT, 2018; INDOT, 2018). The symbol of "✓" means yes (they have it).

3.2 Technology Compatibility

Review of software like MicroStation and ArcGIS was conducted. OpenCities software could not be reviewed in detail due to limited material access. OpenCities Map is a 3D GIS system. It contains all the tools commonly used in construction except for red lining. CAD standards can be incorporated into mapping schema when required if files are available. Currently received files from pilot study project were reviewed to gain an overall understanding of INDOT's needs. However, common files with assets in both GIS and CAD format were not found. MicroStation files were obtained for one particular intersection of US-24 and drawings for other assets were not available, while GIS files of certain assets were at hand. Other state DOTs' websites were searched for similar sample open-source files. On receiving overlapping files, we tried to integrate them into OpenCities. Software like E-Builder and Bentley Synchro were also reviewed for construction project support.

Note: Figure from *FACS-STIP User Guide* (Oregon DOT, 2020).

Figure 3.2 FACS-STIP (Oregon DOT, 2020).

Some uniform format to depict all asset information in the geographic spatial context is ideal for facility management purpose. From reviewing the state of the art, we found the main challenge is to integrate BIM and GIS into a model sufficient for the facility management information need (combining geometric and semantic information). This has evolved into a new area called urban information modeling. Ontology (an embodiment of knowledge model) was recognized as a feasible media for such integration, with BIM data (e.g., using ISO standard data format industry foundation classes (IFC)) and GIS data (e.g., using standard data format CityGML). Alternatively, IFC also has the capability to bear such integration. We collected sample .dgn files from INDOT for bridge and pavement projects and did an initial testing of converting these files into different formats. It was found that the .dgn files can be exported to STP files (ISO 10303-21), but the export does not use the IFC schema. Some third-party tools (e.g., Trimble SketchUP) can help us with indirectly exporting .dgn files into IFC files. This is a great start because IFC is an ISO standard that was designed to be comprehensive. Figures from 3.3 to 3.8 show some sample screenshots during this model conversion. Figure 3.3 shows original bridge deck file in .dgn format. Figure 3.4 shows the .STP file opened in text editor. Figure 3.5 and Figure 3.6 show the same bridge deck in .SKP and IFC formats respectively. Figure 3.7 shows the IFC file opened in a text editor. Figure 3.8 shows the features from the feature schemas found in OpenCities Map.

To have a better overview of the current status of IFC applications at different DOTs, we have explored the IFC maturity at other DOTs, as shown in Table 3.8. We found that it was possible to gather some information about IFC use at other state DOTs. Many of the DOTs are looking into IFC as a standard for files during bridge design. Life cycle cost analysis is another sphere where IFC use is being researched. MDOT has introduced IFC schema in their safety checking workflow, and data integration in ProjectWise also has some scope in IFC use. IFC use in BIM is widespread while the use of BIM in long-term file storage is being looked into by DOTs. Table 3.9 shows the software used at INDOT.

Several different methods have been developed to integrate BIM and GIS, including ArcGIS data interoperability, semantic web and resources description framework graphs, semantic mapping approach, and open-source approach. These different methods are discussed below (Wan Abdul Basir et al., 2018). In addition, many BIM vendors have been developing proprietary solutions such as the ArcGIS GeoBIM that aims at integrating Autodesk BIM and GIS (Di Benedetto et al., 2021).

3.2.1 ArcGIS Data Interoperability

ArcGIS Data Interoperability is an extension package for ArcGIS to support the integration of IFC, DWG/DXF, and CityGML. One of Revit's plug-ins, FME Exporter for Revit 2018, can perform simple conversion with QUICK IMPORT by using IFC/RVZ data source. Even though, this method is straightforward, this method still has some disadvantages. For example, it can result in geometric errors and geometric information loss (Zhu et al., 2019). Specifically, the number of attributes is limited by this method, which can lead to serious semantic information loss. Autodesk Revit and Graphisoft ArchiCAD are adopted to integrate with GIS data. ArcGIS Data Interoperability is an extension package for ArcGIS to support the integration of IFC, DWG/DXF, and CityGML. One of Revit's plug-ins, FME Exporter for Revit 2018, can perform simple conversion with QUICK IMPORT by using IFC/RVZ data source. Even though, this method is straightforward, this method still has some disadvantages. For example, it can result in geometric errors and geometric information loss (Zhu et al., 2019). Specifically, the number of attributes is limited by this method, which can lead to serious semantic information loss. Autodesk Revit and Graphisoft ArchiCAD were adopted to integrate with GIS data.

TABLE 3.5
Drainage attributes comparison between Indiana DOT and Utah DOT

		Geometry Type		Attributes					
Asset	**Sub Asset**	**INDOT**	**UDOT**	**Attribute Item**	**Focused Asset List**	**High Level Asset List**	**Collected Models**	**UDOT**	**Reasons**
Drainage	Manhole	Point	3D geometry	Element ID	✓			✓	To allow downstream users to know the detail of drainage otherwise it will be really hard to access it after the construction is complete
				Pay item name				✓	
				Pay item number				✓	
				Unit of payment measurement				✓	
				Pipe attributes (shape, size, length, material, slope, flow rate, velocity)				✓	
				Drainage structures attributes (grate/cover type and elevation, calculated spread)				✓	
				Last edit operation	✓				The data collector identifies the last operation
				Vendor status	✓				Contractor can't edit "Submitted" records, INDOT can set Returned to Contractor
				INDOT status	✓				Project manager/engineer approves or returns (read only to vendor)
				Install date	✓				Is indirectly required
				Retired date	✓				This field is not available to the contractor. It is controlled by the reviewer/owner
				Asset name	✓				Is the human readable name for the asset and is system generated
				Rim elevation (decimal ft)	✓				Is indirectly required
				High pipe invert elevation (decimal ft)	✓				Is indirectly required
				Low pipe invert elevation (decimal ft)	✓				Is indirectly required
				Manhole depth (decimal ft)	✓				Is indirectly required
				Cover type	✓				Is indirectly required
				Wall material	✓				Is indirectly required
				Manhole type	✓				Is indirectly required
				BMP insert type	✓				
				Pavement cut depth (in)	✓				Is indirectly required
				Lined	✓				
				Owned by	✓				
				Manhole comment	✓			✓	Is desired

TABLE 3.6
Update cycle comparison

Asset	Update Cycle	
	INDOT	**Ohio DOT**
ADA	Continuous as needed (annual certification)	
AADT	Data is created once	
Access control	As needed but at least annually	
Advertising devices	NA	Biennial
Bridge	Continuous for new/retired	Annual
Contract	Continuous (candidate for replacement)	
Crossover	Project related	
District	Rarely (if ever) for further discussion	
Drainage	Continuous for new/retired	5–10 years based on size, annually if deficient
Facility_Type	Annual	
Federal_Aid	Annual	
Friction	Annual: 100% of the interstates, 33% of the other highways	
Functional_Class	Monthly	
Grade	Annual	
Guardrail and attenuator	Candidate removal from R&H	Replace/repair
Indiana_811	Candidate for retirement	
Lane	Annual	
Lighting	NA	2-year cycle
Maintenance_Plans	Continuous	
Median	Annual	
Noise barrier wall	NA	Replace/repair
Overhead signs	NA	3-year cycle
Parking	Not updated, candidate for retirement	
Pavement	Annual	Annual
PHFS	Not updated, candidate for retirement	
Railway-lines		2-year cycle
Reference_Post	Reviewed annually for RB book	
Right of way	NA	Quarterly/annually
Rural Urban	Annually during certified mileage report	
Sample_Section	Annual	
Signal	May need wholesale replacement and fall under traffic management	Replace/upgrade
Special markings	NA	Replace/repair
STRAHNET	Annual	
Surface_Contracts	Continuous	
Surface_Type	Needs review of accuracy/need	
Traffic_Count_Stati	Continuous review with updates to roadway inventory	
Traffic_Section	Continuous review with updates to roadway inventory	
Turn	As needed but infrequently	
Maintenance_plans	Continuous	

Note: Cells containing NA indicate that INDOT does not have information on update cycle for this asset. Cells containing blue text indicate that INDOT's update cycle is different from ODOT's update cycle.

3.2.2 Semantic Web and Resources Description Framework (RDF) Graphs

Semantic Web and Resources Description Framework (RDF) Graphs method integrates BIM and GIS through building Integrated Geospatial Information Model (IGIM) which offers a platform where GIS and BIM can be accessed through RDF directed graph. The steps required in this method include: (1) constructing O_{BIM} which represents constructing IFC-compliant ontology describing the hierarchical structure of BIM objects, the relationships of those BIM objects, the properties of those objects, and semantic indexing and retrieval of building information from the IFC model from the base of O_{BIM}, (2) constructing O_{GIS} which aims to construct GIS ontology of a building's geographic surrounding area, (3) ontology mapping which links similar concepts and relationships between O_{BIM} and O_{GIS}, (4) querying $O_{GIS\text{-}BIM}$, and (5) loading data onto $O_{GIS\text{-}BIM}$ (Hor et al., 2016).

TABLE 3.7
Performance measurement comparison (CTDOT, 2018; INDOT, 2018)

	INDOT		CTDOT	
Measure Area	**Yes/No**	**Measure Methods**	**Yes/No**	**Measure Methods**
Safety performance	Yes	Number of total fatalities Number of total serious injuries Rate of fatalities Rate of serious injuries Number of non-motorized fatalities and serious injuries		
Pavement and bridge condition	Yes	Percentage good interstate pavements Percentage good non-interstate NHS pavements Percentage poor interstate pavements Percentage poor non-interstate NHS pavements Percentage good NHS bridges Percentage poor NHS bridges	Yes	Percentage of bridges classified as in a state of good repair (SOGR) (by number of bridges) percentage of centerline miles in a SOGR
Freight reliability	Yes	Truck travel time reliability		
Congestion	Yes	Hours of excessive delay		
Travel reliability	Yes	Percentage interstate travel that is reliable percentage non-interstate NHS travel that is reliable		
Ridesharing	Yes	Non-single occupant vehicle travel		
Air quality	Yes	On-road mobile source emissions reductions		

Note: Table from *Highway Transportation Asset Management Plan* (CTDOT, 2018) and *Performance Measure* (INDOT, 2018).

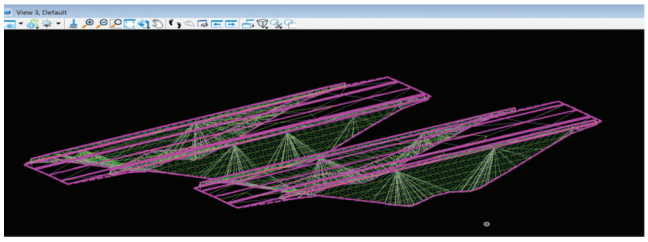

Figure 3.3 Bridge decks in .DGN.

```
ISO-10303-21;
HEADER;
/* Generated by software containing ST-Developer
 * from STEP Tools, Inc. (www.steptools.com)
 */

FILE_DESCRIPTION(
/* description */ (''),
/* implementation_level */ '2;1');

FILE_NAME(
/* name */ 'Bridge_Decks',
/* time_stamp */ '2019-09-11T15:53:59-04:00',
/* author */ (''),
/* organization */ (''),
/* preprocessor_version */ 'ST-DEVELOPER v16.13',
/* originating_system */ 'MicroStation Version 10.13.00.48',
/* authorisation */ '');

FILE_SCHEMA (('AUTOMOTIVE_DESIGN'));
ENDSEC;

DATA;
#10=ADVANCED_BREP_SHAPE_REPRESENTATION(
'Advanced Brep Shape Representation',(),#35722);
#11=ADVANCED_BREP_SHAPE_REPRESENTATION(
'Advanced Brep Shape Representation',(),#35791);
#12=ADVANCED_BREP_SHAPE_REPRESENTATION(
'Advanced Brep Shape Representation',(),#35792);
#13=ADVANCED_BREP_SHAPE_REPRESENTATION(
'Advanced Brep Shape Representation',(),#35828);
#14=CONNECTED_EDGE_SET('',(#10751,#10752,#10753,#10754));
#15=CONNECTED_EDGE_SET('',(#10755,#10756,#10757));
#16=CONNECTED_EDGE_SET('',(#10758,#10759,#10760,#10761));
#17=CONNECTED_EDGE_SET('',(#10762,#10763,#10764,#10765,#10766,#10767,#10768));
#18=CONNECTED_EDGE_SET('',(#10769,#10770,#10771,#10772,#10773));
#19=CONNECTED_EDGE_SET('',(#10774,#10775,#10776));
#20=CONNECTED_EDGE_SET('',(#10777,#10778,#10779,#10780,#10781));
#21=CONNECTED_EDGE_SET('',(#10782,#10783,#10784,#10785,#10786,#10787,#10788));
#22=CONNECTED_EDGE_SET('',(#10789,#10790,#10791,#10792,#10793,#10794,#10795,
#10796,#10797,#10798,#10799,#10800,#10801,#10802));
#23=CONNECTED_EDGE_SET('',(#10803,#10804,#10805,#10806,#10807));
#24=CONNECTED_EDGE_SET('',(#10808,#10809,#10810,#10811,#10812,#10813,#10814,
#10815));
#25=CONNECTED_EDGE_SET('',(#10816,#10817,#10818,#10819,#10820,#10821,#10822,
#10823,#10824,#10825,#10826,#10827,#10828,#10829,#10830));
#26=CONNECTED_EDGE_SET('',(#10831,#10832,#10833,#10834,#10835,#10836,#10837,
#10838,#10839,#10840,#10841,#10842,#10843));
#27=CONNECTED_EDGE_SET('',(#10844,#10845,#10846,#10847,#10848,#10849,#10850,
#10851,#10852,#10853,#10854,#10855,#10856,#10857,#10858,#10859));
#28=CONNECTED_EDGE_SET('',(#10860,#10861,#10862,#10863,#10864,#10865,#10866,
#10867,#10868,#10869,#10870,#10871));
#29=CONNECTED_EDGE_SET('',(#10872,#10873,#10874,#10875,#10876,#10877,#10878,
#10879,#10880,#10881,#10882,#10883,#10884,#10885,#10886,#10887,#10888));
#30=CONNECTED_EDGE_SET('',(#10889,#10890,#10891,#10892,#10893,#10894,#10895,
```

Figure 3.4 Bridge decks in .STP.

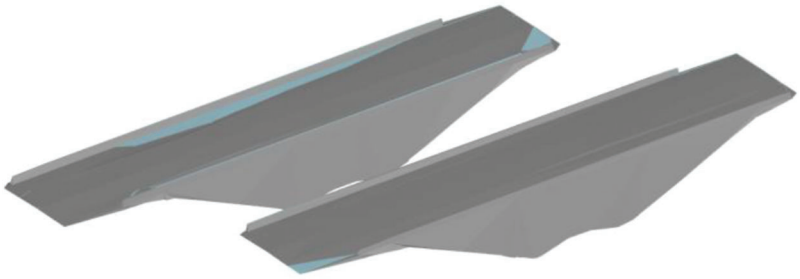

Figure 3.5 Bridge decks in .SKP.

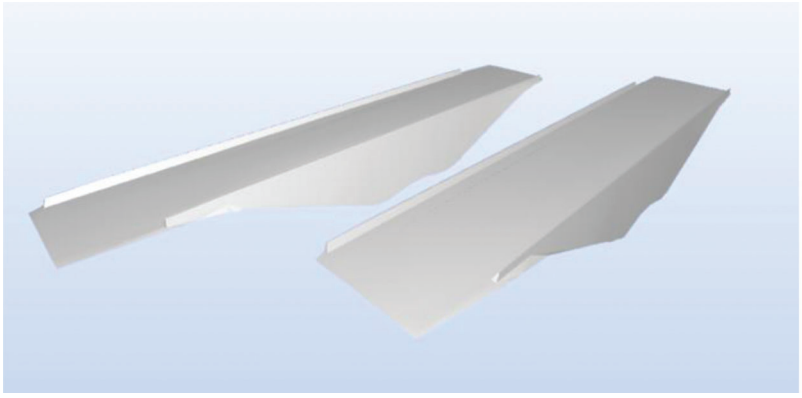

Figure 3.6 Visualization of bridge model in IFC.

Chapter19Concepts.py | TestCase_1.pl | results | Curved Wall.ifc | Bridge_Decks.stp | Bridge_Decks.ifc

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION (('ViewDefinition [CoordinationView]'), '2;1');
FILE_NAME ('', '2019-09-11T16:12:46', (''), (''), '', 'SketchUp Pro 2015', '');
FILE_SCHEMA (('IFC2X3'));
ENDSEC;
DATA;
#1 = IFCPROJECT('1WgbsfNIvEq9wuuL_5B5XT', #2, 'Default Project', 'Description of Default Project', $, $, $, (#20), #7);
#2 = IFCOWNERHISTORY(#3, #6, $, .ADDED., $, $, $, 1568232766);
#3 = IFCPERSONANDORGANIZATION(#4, #5, $);
#4 = IFCPERSON($, '', '', $, $, $, $, $);
#5 = IFCORGANIZATION($, 'SketchUp', '', $, $);
#6 = IFCAPPLICATION(#5, '2015', 'SketchUp Pro 2015', '2015');
#7 = IFCUNITASSIGNMENT((#8, #9, #10, #11, #15, #16, #17, #18, #19));
#8 = IFCSIUNIT(*, .LENGTHUNIT., .MILLI., .METRE.);
#9 = IFCSIUNIT(*, .AREAUNIT., $, .SQUARE_METRE.);
#10 = IFCSIUNIT(*, .VOLUMEUNIT., $, .CUBIC_METRE.);
#11 = IFCCONVERSIONBASEDUNIT(#12, .PLANEANGLEUNIT., 'DEGREE', #13);
#12 = IFCDIMENSIONALEXPONENTS(0, 0, 0, 0, 0, 0, 0);
#13 = IFCMEASUREWITHUNIT(IFCPLANEANGLEMEASURE(1.745E-2), #14);
#14 = IFCSIUNIT(*, .PLANEANGLEUNIT., $, .RADIAN.);
#15 = IFCSIUNIT(*, .SOLIDANGLEUNIT., $, .STERADIAN.);
#16 = IFCSIUNIT(*, .MASSUNIT., $, .GRAM.);
#17 = IFCSIUNIT(*, .TIMEUNIT., $, .SECOND.);
#18 = IFCSIUNIT(*, .THERMODYNAMICTEMPERATUREUNIT., $, .DEGREE_CELSIUS.);
#19 = IFCSIUNIT(*, .LUMINOUSINTENSITYUNIT., $, .LUMEN.);
#20 = IFCGEOMETRICREPRESENTATIONCONTEXT($, 'Model', 3, 1.E-5, #21, #23);
#21 = IFCAXIS2PLACEMENT3D(#22, $, $);
#22 = IFCCARTESIANPOINT((0., 0., 0.));
#23 = IFCDIRECTION((0., 1., 0.));
#24 = IFCSITE('3f8tiQ56bDXxkdlXTnYCmL', #2, 'Default Site', 'Description of Default Site', $, #25, $, $, .ELEMENT., (24, 28, 0), (54, 25, 0), 10., $, $);
#25 = IFCLOCALPLACEMENT($, #26);
#26 = IFCAXIS2PLACEMENT3D(#27, #28, #29);
#27 = IFCCARTESIANPOINT((0., 0., 0.));
#28 = IFCDIRECTION((0., 0., 1.));
```

Figure 3.7 Text file of bridge model in IFC.

3.2.3 Semantic Mapping Approach

Semantic mapping approach can apply correct semantics obtained from IFC models and construct CityGML data through performing a series of conversions in 3D models, including (1) semantic filtering and mappings, (2) extraction of the exterior envelope, and (3) a CityGML LOD3 building can be provided by geometric and semantic refinements (Donkers et al., 2013).

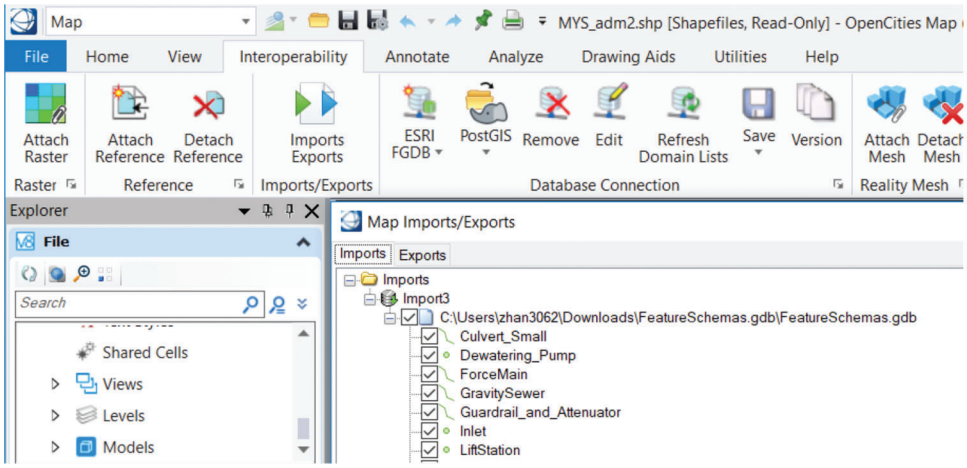

Figure 3.8 Features from the feature schemas.

TABLE 3.8
IFC maturity in different DOTs

Utilization	Iowa DOT	MDOT	WISDOT	NYSDOT	CalTrans	UDOT
Data standard for bridge design		–		–	✓	–
LCCA		–		–		–
Safety checking		✓		–	–	–
Cost related data exchange		✓		–	–	✓
Data integration with ProjectWise		–		–	–	
Data durability (storage)		–				–
BIM	✓	✓	✓	✓	✓	
Data integrity and accessibility		–			✓	✓
Extensible models		–				

3.2.4 Open-Source Approach

Open-Source Approach (OSA) can convert the IFC format into shapefile format. IFCOpenShell is used to parse the IFC files, which retrieves geometric information through the spatial structure of IFC (Donkers et al., 2013). Numpy is an open-source library in for Python programming which is used for mathematical functions on arrays operation. It is then adopted to process numbers (Harris et al., 2020). After that, an iterator, developed by pseudo-Python code, is used to search the Local Placement System (LPS) in the placement system and conduct coordinate transformation from LPS to WCS (World Coordinate System). The Automated Machine Guidance (AMG) is used to perform extrusion and the resultant faces are outputted as multipaths. Furthermore, a check is performed after completing each element to determine if all elements are thoroughly processed. If not, the process will go back to previous steps (Donkers et al., 2013).

TABLE 3.9
Software used in different phases in INDOT

Primary Usage	Program	Type	Data Type	Extension	Vendor	Comments
All phases	Electronic Records Management Systems (ERMS)	Final records				Document of record repository
Asset management	AssetWise (BIAS)	Database	Bridge, culvert database		Bentley	Inspection database used for bridge, culvert inspections, provides federal reporting, and reads ERMS historical plans
Asset management	ArcMap–roads and highways					Road inventory
Asset management, scoping, design	ArcMap	.shp, spatial database	GIS, CAD data	Multiple	ESRI	Spatial data—numerous examples, MS4 storm outfalls, wetland
Construction	AASHTO SiteManager				Bentley	Real-time progress updates to the 4D model enable a digital representation of the state of the project to be generated, improving communication and productivity with shared dashboards, as well as the reuse of that data in digital workflows
Design	MicroStation	CAD files	2d–3d CAD content	.dgn	Bentley	Spatially enabled CAD files
Design	OpenRoads designer	Civil design	All engineering content	.dgn	Bentley	Current release, not adopted yet
Design	InRoads SS3-SS4	Civil design	All engineering content	.dgn	Bentley	
Design	InRoads SS2	Civil design	Geometry	.alg	Bentley	Older design software–can still utilize this data
Design			Surface terrain	.dtm	Bentley	Older design software–can still utilize this data
Design			Survey field book	.fgb	Bentley	Older design software–can still utilize this data
Design			Storm and sanitary	.sdb	Bentley	Older design software–can still utilize this data
Design			Surface terrain	.dtm	Bentley	Older design software–can still utilize this data
Design			Template library	.itl	Bentley	Roadway typical for modeling
Design	Bentley Map	Any GIS	GIS, CAD data	.dgn, .shp	Bentley	Vehicle to and from GIS, also can edit GIS
Design	ProjectWise Interplot	Plotting engine	Plotting other content	.ips	Bentley	Plots various data to pdfs sets using Standards
Design			XML, Land XML	.xml	Open source	Used to exchange data from design applications
Design	*Mechanistic-Empirical Pavement Design Guide* (MEPDG)	Pavement	Pavement analysis		AASHTO	
Design	AutoCAD	CAD files	Consultant CAD files	.dgn	AutoDesk	Sometimes we save to this for contractors from MicroStation. We also must use converted data
Design	OpenRoads Designer	Civil design	All engineering content	.dgn	Bentley	Current release, not adopted yet
Design	InRoads SS3-SS4	Civil design	All engineering content	.dgn	Bentley	
Design	InRoads SS2	Civil design	Geometry	.alg	Bentley	Older design software–can still utilize this data

(Continued)

TABLE 3.9
(Continued)

Primary Usage	Program	Type	Data Type	Extension	Vendor	Comments
Design			Surface terrain	.dtm	Bentley	Older design software–can still utilize this data
Design			Survey field book	.fgb	Bentley	Older design software–can still utilize this data
Design			Storm and sanitary	.sdb	Bentley	Older design software–can still utilize this data
Design			Surface terrain	.dtm	Bentley	Older design software–can still utilize this data
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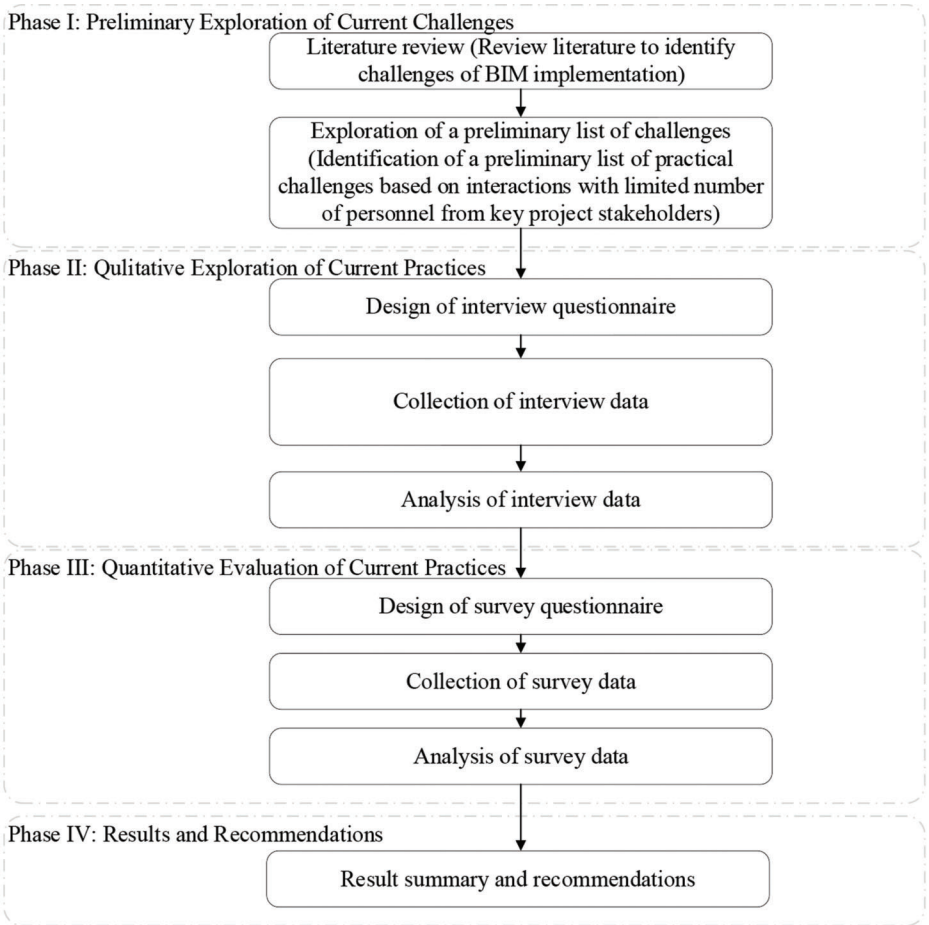
Design			XML, Land XML	.xml	Open source	Used to exchange data from design applications
Design	*Mechanistic-Empirical Pavement Design Guide* (MEPDG)	Pavement	Pavement analysis		AASHTO	
Design	AutoCAD	CAD files	Consultant CAD files	.dgn	AutoDesk	Sometimes we save to this for contractors from MicroStation. We also must use converted data
Design, construction	pdf file	pdf file		.pdf file	Adobe	Signed and unsigned electronic plans
Design, construction, project management	ProjectWise	File database	Most active design data stored here	Any	Bentley	Check in, check out of data. Reads and populates database information for use in CAD files
Design, contracts	CES	Cost estimating	Cost estimating		AASHTO	
Design, contracts	Bid tabs	Cost estimating	Cost estimating			
State police, scoping, design	Aries	Crash database				
Survey	Trimble business center		Survey or stakeout, AMG		Trimble	Used by our surveyors, contractors may use for AMG

4. METHODOLOGY

Detailed information about a project can be provided by the investigation of real projects through semi-structured interviews and surveys. Figure 4.1 shows the flow chart of the entire research method. First, a preliminary list of current challenges was identified through literature review and interactions with a limited number of key stakeholders. Then, the preliminary list of those identified challenges was used to design interview questionnaires (qualitative exploration), which were later on reviewed and validated with key stakeholders involved in this project. Once the interview questionnaires were confirmed, the interview was conducted with 37 different key stakeholders and the interview was analyzed through the content analysis by employing coding methods. Four main factors that are causing challenges were identified. Then, based on the challenges identified from the interview, the survey questionnaires were developed and validated with key project stakeholders. After that, the survey (quantitative evaluation) was sent out to potential participants involved in current INDOT projects to test the findings from the interviews (qualitative exploration).

4.1 Background of Pilot Study

Effective asset O&M requires accurate and complete information. However, current INDOT information management methods are inefficient because information collected by O&M is often inaccurate, incomplete, hard to locate, or not collected. The O&M staff and engineers have to: (1) locate information in different file formats and different systems after the construction is complete, (2) verify the accuracy of information by accessing the current condition and talking with different stakeholders, and (3) manually re-create, re-collect, and re-input information to O&M systems by on-site investigation. However, some information might be physically inaccessible after the construction, such as underground assets. This whole process is time consuming, error prone, filled with repeated work, and can even be dangerous since some road segments might already be open to traffic when data is collected on site. The key barriers are the isolation of project phases (process), unclear definition of information required and the responsibility of project stakeholders (people), and incompatibility of project technologies and interfaces (technology). An in-depth study of the process,



Note: Figure adapted from *Case Study of Building Information Modeling Implementation in Infrastructure Projects* (Guo et al., 2021).

Figure 4.1 Overview of research methodology (adapted from Guo et al., 2021).

people, and technology on a pilot project was completed to help outline the current workflow and identify specific gaps. Contract two of I-69 near Martinsville was the pilot study in this project, as shown in the green part of Figure 4.2. Figure 4.3 shows a detailed work area of Contract two.

4.2 Preliminary Exploration of Current Challenges

Several meetings and visits were conducted to outline the current business process and technology being utilized and to identify a preliminary list of current gaps from the stakeholders, including the owner (INDOT), consultant (HNTB), software vendor (Bentley), and contractor (Walsh) as shown in Figure 4.4.

For the owner (INDOT), the business process and technology adopted have been observed and discussed. Specifically, the statewide geospatial manager of INDOT holds regular meetings with different offices to understand their data needs and provides technical support/training. The research team observed the discussion process between the GIS manager and the

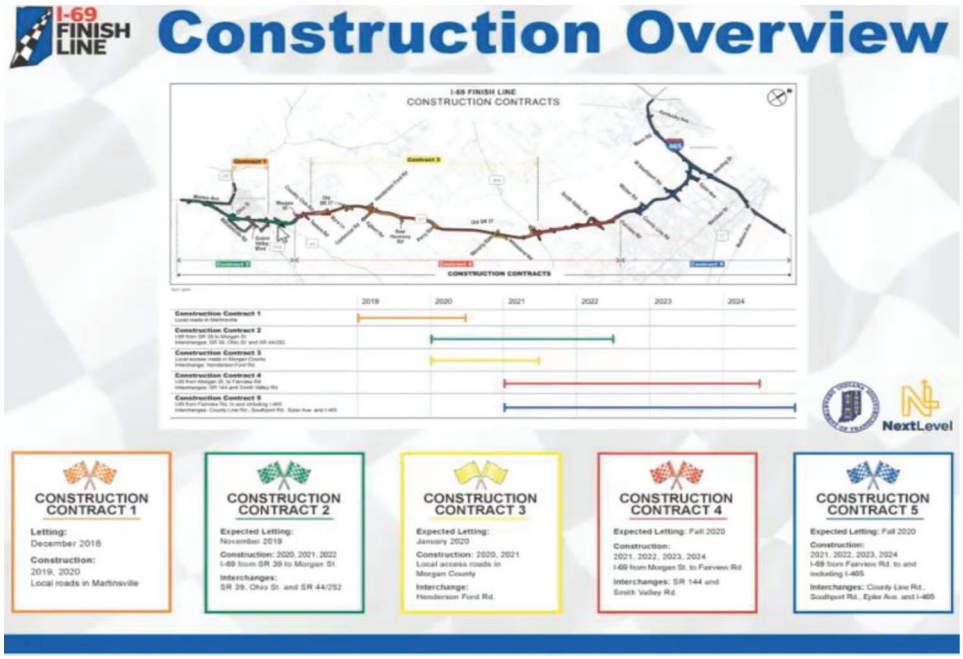


Figure 4.2 I-69 construction overview.

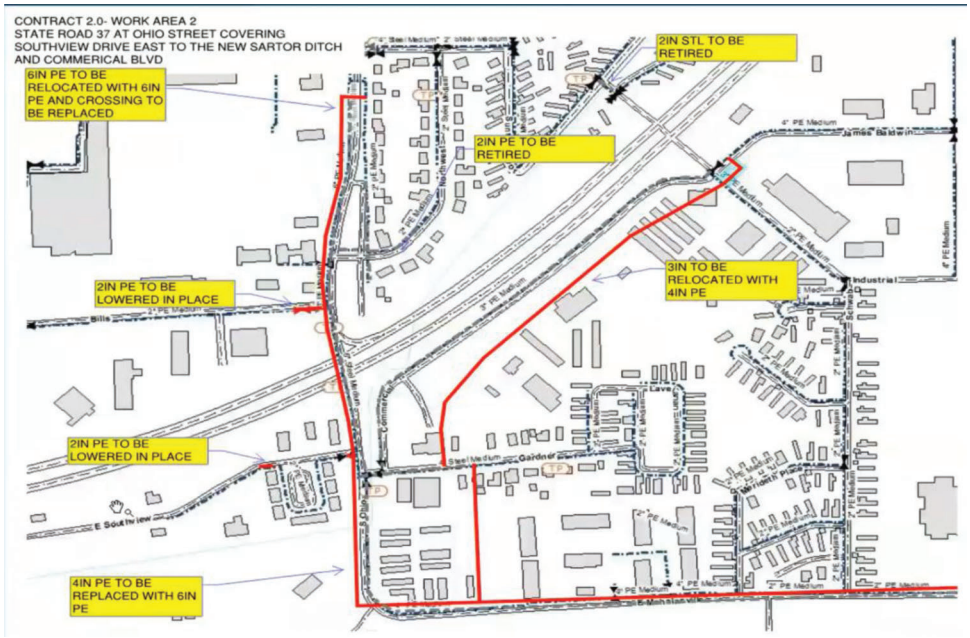


Figure 4.3 Work area of contract two.

office of Intelligent Transportation System (ITS) on December 18th, 2019. The key contacts from ITS included engineers from the site, staff from the financial office, and the ITE engineering director. The GIS manager first introduced the interface and function of GIS. Then the ITS team named the asset list and their geometry type based on their need, challenges, and information inconsistency. The GIS manager and the ITS team also discussed what other attributes of each asset should be recorded, as shown in Figure 4.5. Since the environmental and maintenance focused asset list is developed based on discussion, necessary information may be missing. The research team sought feedback from ITS about the value of the comparison among different DOTs, and the ITS team confirmed that it is useful to compare what other DOTs have collected for their asset O&M.

INDOT's ArcGIS system has also been explored. In this system, different types of maps are available and some of them are useful for the research team to better understand the business process and technology. For example, INDOT CULVERTS recorded various types of culvert information. Culvert types are recorded with unique signs, as shown in Figure 4.6. Interchanges recorded roadway information, as shown in Figure 4.7. INDOT categorizes lighting information depending on whether it is a high mast lighting, roadway lighting, or underpass lighting. Different lighting is denoted by different colors as shown in Figure 4.8.

The INDOT GIS manager was shadowed on January 7th, 2020, and January 8th, 2020, to understand the workflow of the GIS manager. A GIS member meeting is held every week. All GIS members can talk about what they have achieved in the past

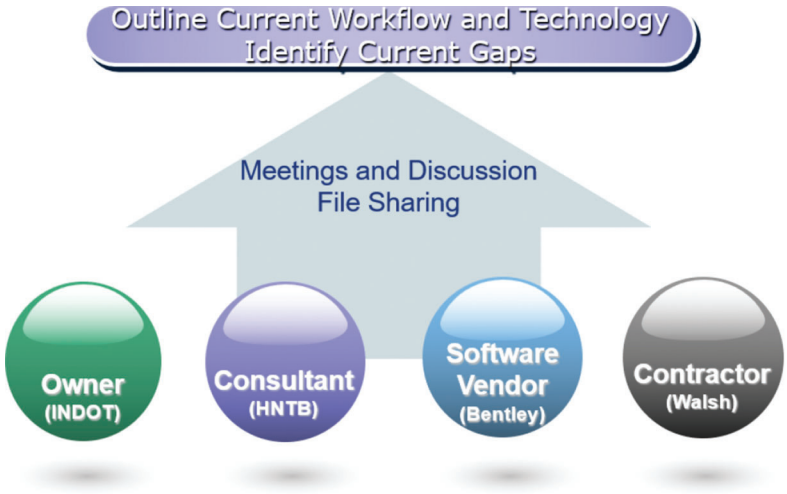


Figure 4.4 Identification of current gaps from different stakeholders.

Item# from Email 2/5/2019	Layer name	Geometry type		Allowed values	Default value for new records
1,2,3	Karst	Point	Last Edit Operation	**New**, Moved, Changed attributes, Moved and Changed, Retire	**New**
			Vendor Status	**Collected**, Reviewed, Submitted, Returned to Contractor	**Collected**
			INDOT Status	**Pending**, Returned, Approved	**Pending**
			Opening Type	Sinkhole, Spring/Seep	*Null*
			Intervention	**None**, Controlled	**None**
			Asset Name	(Keyed in) Text(20) FORMAT:	*Null*
			Retired Date	Format MM/DD/YYYY	*Null*
			Inspection Date		
			Inspection Ccomment		
			Karst Intervention Condition	Excellent, Very Good, Good, Satisfactory, Fair, Poor, Serious, Critical, Imminent Failure, Failed, Unknown	*Null*
4	Mechanical_BMP	Point	Last Edit Operation	New, Moved, Changed attributes, Moved and Changed, Retire	**New**
			Vendor Status	**Collected**, Reviewed, Submitted, Returned to Contractor	**Collected**
			INDOT Status	Pending, Returned, Approved	**Pending**
			Install Date	Format MM/DD/YYYY	*Null*
			Retired Date	Format MM/DD/YYYY	*Null*
			Asset Name	(Keyed in) Text(20) FORMAT:	*Null*
			DES	Keyed in Text(7)	*Null*
			BMP Type	Oil separator, Trash separator	*Null*
			Seperator Max Capacity	Long Integer	*Null*
			Has Bypass	Y/N	**No**
			Make	(Keyed in) Text(50)	*Null*
			Model	(Keyed in) Text(50)	*Null*

Figure 4.5 The environmental and maintenance focused asset list.

Figure 4.6 INDOT culverts information.

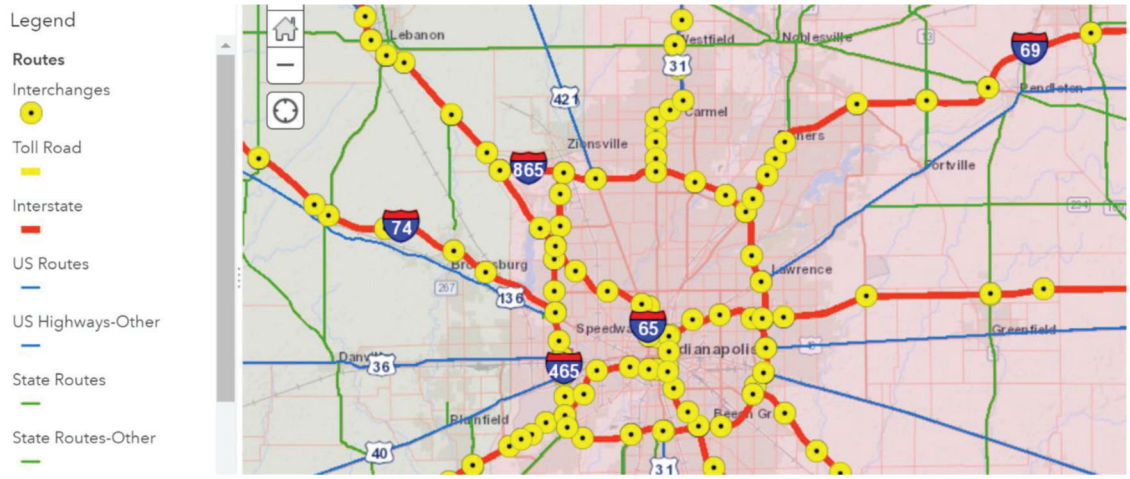


Figure 4.7 INDOT interchanges information.

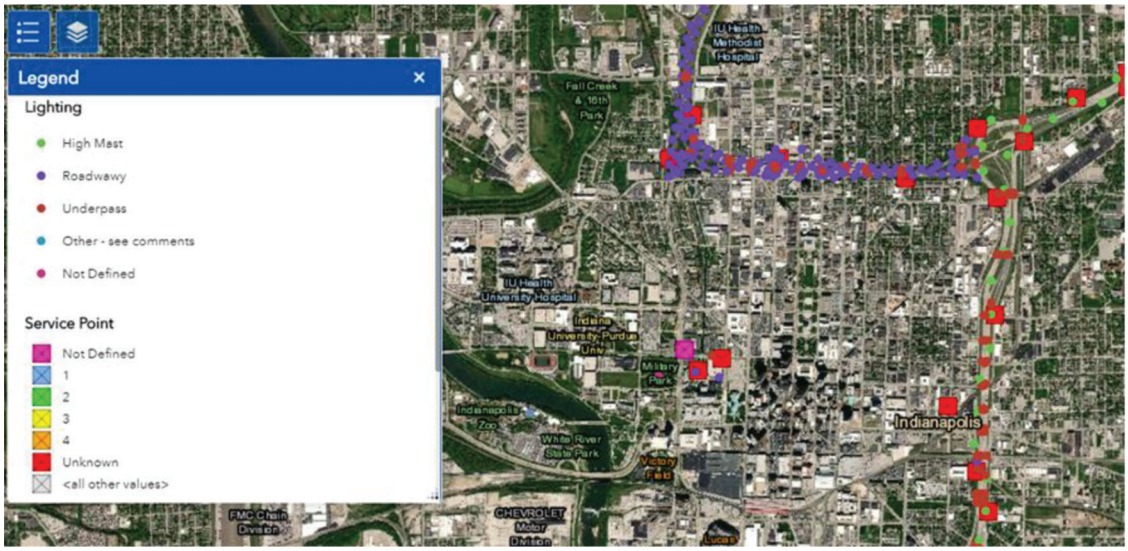


Figure 4.8 Lighting map.

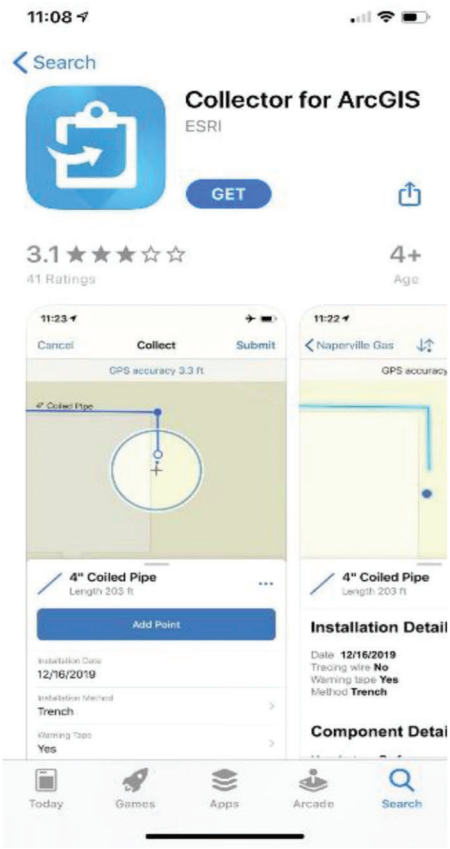


Figure 4.9 Collector for ArcGIS.

weeks. For example, what new function is achieved in the GIS software? The GIS manager also holds meetings with the Environment Department where the GIS manager can provide trainings, for example, on how to use the GIS, and what information can be edited in the system. Figure 4.9 shows the Collector app that site workers use to collect data and Figure 4.10 shows the surveyor that site workers use to collect location information. One of the GIS manager's main jobs is to publish maps of different assets. In order to do that, it usually takes half a day to process data and prepare the layer. Then, it takes several minutes to publish the layer to the server. In order to create layers and deploy assets, the GIS asset tables need to be developed first. A meeting that the GIS manager had with ITS team in West Lafayette on December 18th, 2019, was observed to understand the process to discuss what assets and attributes should be collected and create asset tables. Once the asset table is created and KML features are collected, the GIS manager needs to use ESRI's ArcToolbox to convert KML features to layers (note: KML denotes Keyhole Markup Language which is an XML notation for expressing geographic annotation and visualization within two-dimensional maps and three-dimensional Earth browsers) (Li et al., 2013). Then the business owner joins to discuss with the GIS manger how the limited attribution fields within the KML data would map to the target feature class

Figure 4.10 Surveyor.

fields. After that GIS manager appends the data from the source into the target based on business owner's instructions. Layers and map are deployed in the QA environment for approval before making any adjustments to the map or data and before rolling out to the production environment. A meeting was held with the GIS manager and Bridge Inspection Engineer on June 17th, 2020, to discuss how to use Event Editor to manage and edit assets and attributes on the linear referencing system, as shown in Figure 4.11. The following is some key information.

- Event Editor can show the state history of the network.
- When setting up bookmarks, it is only for the user's reference, and it is stored in the user's profile.
- Event Editor can allow users to search by attributes.
- The database of Event Editor can record the time of last edit.
- Same PDF can be seen when driving northbound or southbound in a different database.
- Bridge points, bridge lines, and bridge clearances can be edited.
- All bridge information goes to the national bridge inventory at night and then synchronizes.
- The GIS system for our assets will be the official record of: Where is the asset? What is the name of the asset? Who owns it? It's supplemental information.
- Inspection engineers do a nightly check by using the bridge or the roadway inventory viewer versus the BIAS data to see if there were any missing bridge information.
- Federal Highway Administration informs INDOT about construction changes on roads and bridges.
- Roadway inventory is a group of people who are responsible for keeping the underlying road network up to date.
- ADT data is being collected in national bridge inventory by inspection engineer.
- Road analyzer tool can bring together linear reference data with asset, so asset can be in the map.

A meeting with INDOT construction team was also held to discuss the CAD files of I-69 near Martinsville

on January 9th, 2020. During that meeting, it was confirmed that these CAD files can be used as the pilot project to explore how to integrate those CAD files into OpenRoads SS4. During that meeting, it was found that the information provided by consultants might be inconsistent with the information that INDOT needs. For example, INDOT hopes everyone can work on a common environment; however, documents are currently delivered through USB drives. INDOT would like to share the data with all project participants, and require the data contain geographical information. However, the information provided is only in terms of CAD drawings.

With the consultant, the business process and technology adopted have been discussed. A meeting was held with consultants on February 7th, 2020. In the meeting of GIS initiative, one of the consultants on the design team of I-69 project, provided us with the information about using GIS to do right-of-way design, utility tracking, etc. Different utilities are coded by different colors, as shown in Figure 4.12. Different colors can be used to indicate which parts need to be removed before the utility work can be performed. Figure 4.13 shows a typical table that contains the attribute information of an item such as gas main. Some challenges of process and technology were identified through this meeting. First, how to standardize the process to meet the system need? Second, what is the approach to make GIS software, such as ArcMap, work with ProjectWise or MicroStation to achieve

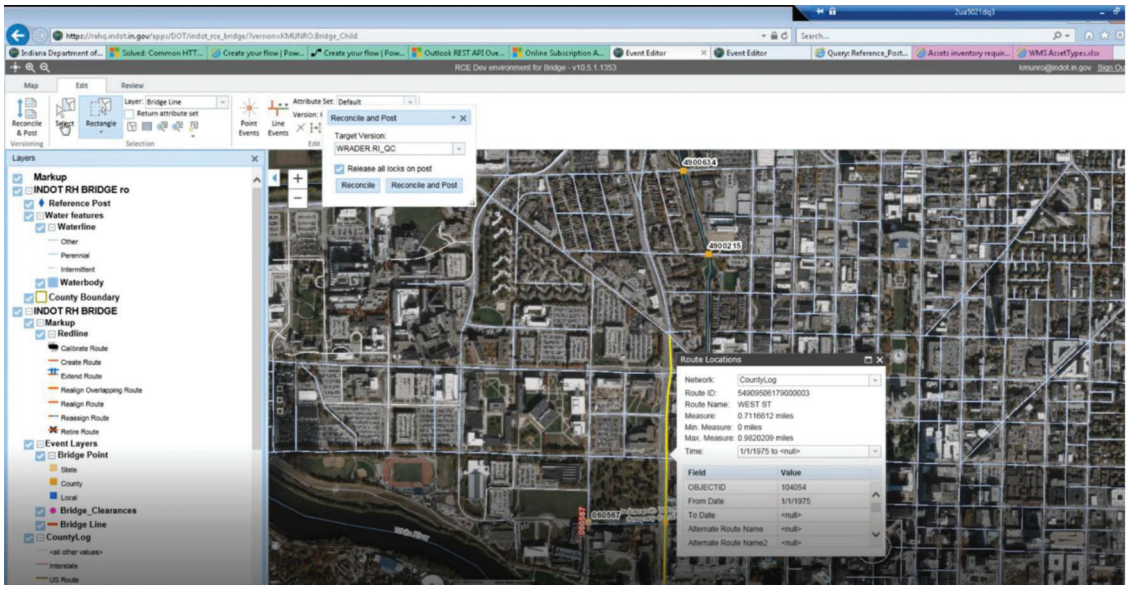


Figure 4.11 Interface of Event Editor.

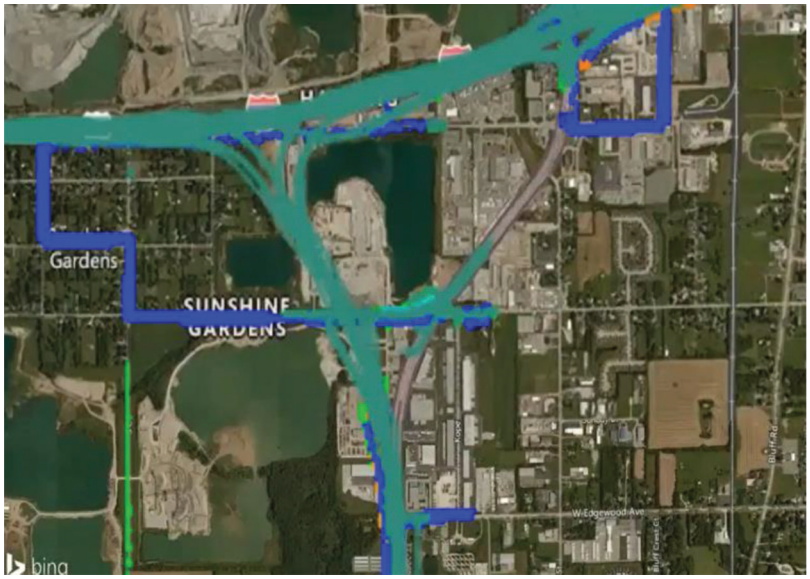


Figure 4.12 Different color-coded utilities.

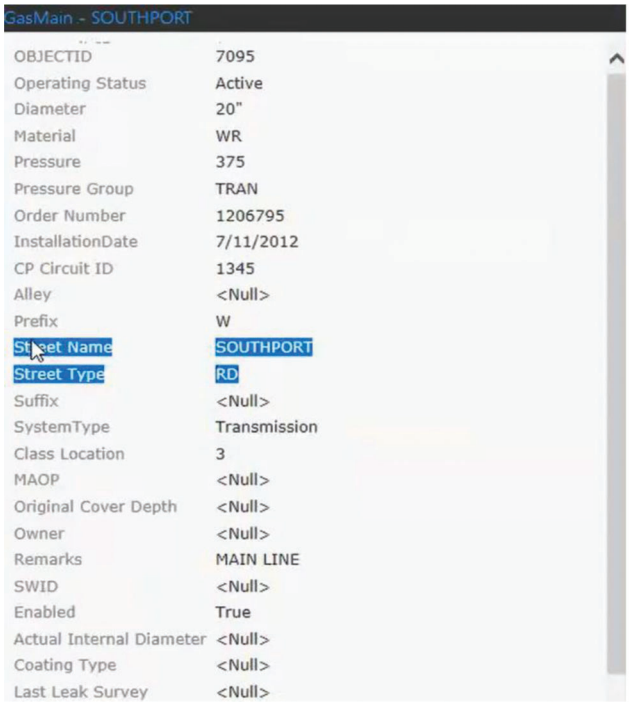


Figure 4.13 An example of attribute table (gas main).

automatic update? Third, what attributes of asset should be collected? Fourth, how to create an environment where everyone can work together? In addition, information is delivered though USB drive, which is less effective.

With the software vendor, the business process and technology adopted have been discussed. Specifically, a meeting was held with software vendor to identify current gaps on June 4th, 2020. For example, it was identified that schemas and properties are not all fully defined so that they usually become BuildingElement Proxy when exported to IFC. There are different people with different tools, different software, and different objectives. They need something that works across all of them. How does that come across via IFC? How are we collecting the data and tracking it over time? How to add in pay item numbers to IFC schema?

With the contractor, the business process and technology adopted have been observed and discussed. Specifically, an onsite visit to the contractor was conducted to observe the workflow and identify current gaps on June 19th, 2020. How contractors set up the base station (as shown in Figure 4.14), calibrated the site (as shown in Figure 4.15), and measured the location were observed. In addition, the contractor demonstrated how to process data and discussed the problems they have encountered (as shown in Figure 4.16). Some key information is listed as follows.

- Consultants use MicroStation for design. Contractors cannot directly read MicroStation files. Contractors can use DWG or DGN files for line work but for any surface or horizontal lines, it must be an XML file.

Figure 4.14 Robotic total station.

Figure 4.15 Site calibration.

- Sometimes civil engineers send contractors the file which is not in the right format and contractors must get it in the correct format. For example, contractors want to have XML while civil engineers usually send DTN files.
- Trimble is preferred by contractors because they can convert design files into automated machine guidance files.
- Sometimes when they do transitions in the XML format, there is missing data or corrupted data during the transition.
- Contractors must sign a waiver every time they receive 3D models. And consultants will tell contractors that the files are not for construction. Contractors then need to check and review the model closely and export it in the XML format.
- If the owner shares the 3D file in the bidding process, it will help contractors dramatically.
- Proper training and understanding of the software are key. Another key lesson is keeping up with the new technology. There's always a new version coming out.
- Excel, CSV, or PDF files are the information INDOT usually requests from contractors.

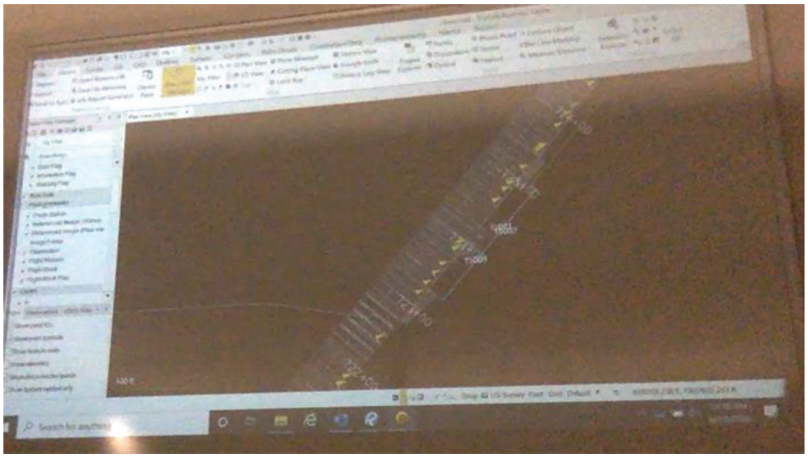


Figure 4.16 Data processing.

- INDOT also requests the as-built information. So INDOT has a record of their project.
- In the past, consultants would not give contractors models at all even if contractors sign a waiver. Contractors need to recreate the models themselves with their own cost and time. Since 2019, contractors have not seen the problem and have been able to receive models from consultants after bid.
- Contractors pass information to their subcontractors.
- Contractors do not get as-built from the consultants or INDOT of the locations of the underground utilities. Contractors must locate and mark them on the plans. It would be great if INDOT or the consultants could share with contractors that information.
- For the new layout, contractors need to locate the water, sewer, gas lines, and pipes. They will turn over the records to INDOT at the end of the project. There is no data in the records.

4.3 Qualitative Exploration of Current Practices

4.3.1 Design of Interview Questionnaire

Qualitative interview questionnaires have been developed to explore the current process, organization structure, information formats, and technologies of consultants, contractors, software vendors, and INDOT. Based on communication, document sharing, and visits with INDOT teams and a comprehensive literature review, current preliminary challenges were identified. Based on those preliminary challenges and literature review, interview questionnaires were designed. Four overall different types of questionnaires were developed for designers of record, contractors, software vendors and INDOT. Each questionnaire had three sections in general, including the first section with demographic information, the second section about business process, and the third section about the technology. Questionnaires were further customized to different stakeholders because they may have different challenges and potential solutions due to their different roles and the difference of their work. The interview questionnaire for the designers of record is in Appendix B, the questionnaire for contractors is in Appendix C, the questionnaire for software vendors is in Appendix D, and the questionnaire for INDOT is in Appendix E.

4.3.2 Collection of Interview Data

The interview questionnaires were sent to employees of INDOT road and bridge design offices, construction office, asset management office, designers of record, contractors, and software vendors to review and validate the content. Then the interview was conducted with bridge designers of record (four project managers or designers), road designers of record (seven project managers or designers), contractors (three project managers and engineers), software venders (four engineers or managers from Autodesk, Bentley, Rizing Geospatial, etc.), INDOT road design office (two project managers and engineers), INDOT bridge office (three project managers and engineers), INDOT construction office (ten project managers and engineers), and INDOT asset management office (five managers and engineers).

4.3.3 Analysis of Interview Data

With the recorded interviews, transcripts were prepared, and coding methods were used to extract key information. Specifically, descriptive coding is used as the first cycle coding method to extract key phrases or short passages from the transcript. Then pattern coding is used as the second cycle coding method to group similar key information. Finally, the current gaps of process, technology, people, and information were identified, and corresponding solutions were proposed.

4.4 Quantitative Evaluation of Current Practices

4.4.1 Design of Survey Questionnaire

With the challenges identified from the interview, quantitative surveys have been developed to explore current information users regarding their evaluation of

TABLE 4.1
Response summary

Stakeholders	People We Have Contacted	Total Responses Received
INDOT design	17	14
INDOT construction	26	22
INDOT asset O&M	4	7
INDOT facility management	1	4
Designers of record	38	20
Contractors	3	28
Software vendors	10	7
Total	*99*	*102*

current processes and technologies in documentations of design and construction, which are listed in Appendix G–K. A 7-point Likert scale questionnaire is used to quantitatively explore users' evaluation about current process and technologies. Some general questions are asked. For example, what do users think about the current documentation of design? And some specific questions are asked. For example: what do users think about whether CAD files are effective for documenting newly constructed assets?

4.4.2 Collection of Survey Data

For the data collection of survey, INDOT has helped the researchers to reach out to the stakeholders usually involved in INDOT projects. Survey links were sent to potential participants through email. There are 102 responses in total received from different stakeholders, as shown in the Table 4.1. For different stakeholders, they were asked general questions such as: what is your current position? How long have you worked in this position? What is the range of contract value in dollars for the majority of projects that you have been involved in? What are the typical delivery methods of the projects you have been involved in? Then they will be asked specific questions about their daily task.

4.4.3 Analysis of Survey Data

With the collected survey data, responses were counted to verify if the challenges identified from the interview were correct and also seek feedback from participants about the solutions that the researchers proposed.

5. FOUR MAIN BARRIER FACTORS

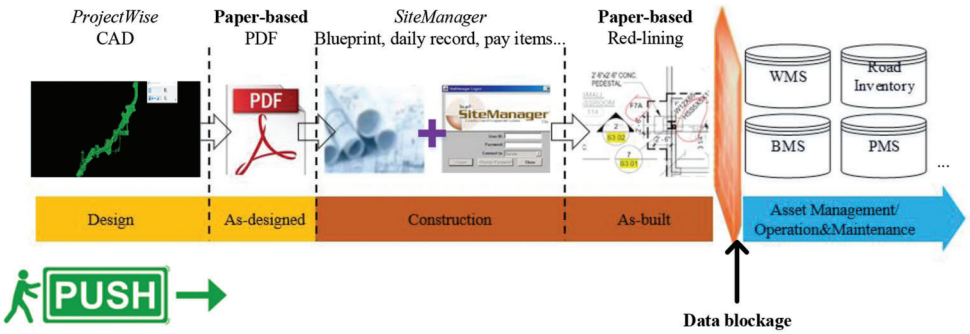
From the qualitative exploration and quantitative evaluation analysis, four main barrier factors are identified. These four factors are: information factor (information collection and sharing), process factor (isolation of project phases), technology factor (incompatibility of project technologies and interfaces), and people factor (unclear definition of requirement and responsibility of project stakeholders). All four factors have positive impacts on the successful implementation of BIM in infrastructure projects.

5.1 Process (Current Process, Gaps, and Potential Solutions)

5.1.1 Qualitative Exploration

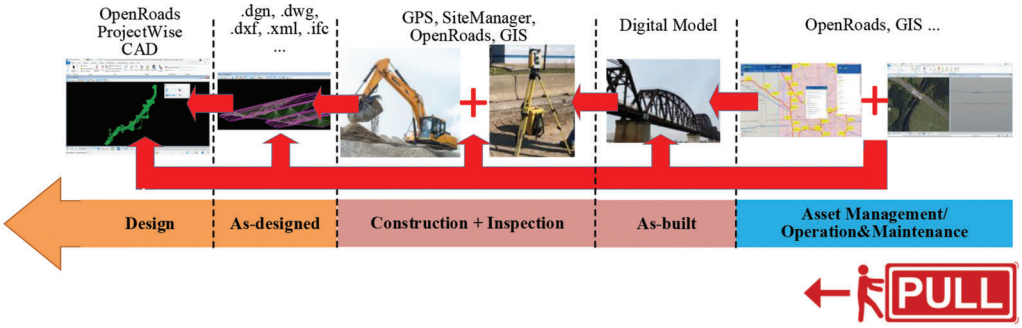
The first barrier of a continuous data flow is in business process, as ranked by INDOT information technology group (Cai et al., 2015). Business process dimension defines: (1) when the data required by O&M should be created, collected, stored, shared, and updated, and (2) the integration of data/information along the different phases of a project's whole life cycle. Currently, the construction data collection for construction inspection and documentation and the asset data collection for O&M are two separate processes (Cai et al., 2015). Very little asset data collected during construction phase is passed onto the asset management (Cai et al., 2015). O&M staff and engineers have to obtain in-place data, not to mention the asset data collection after the fact is unproductive, time consuming, error prone, and easily repeated work. To improve the process efficiency and information accuracy, a clear guideline of the process and workflow should be outlined.

Current practices of asset O&M at INDOT require extensive data collection activities in order to operate and maintain infrastructure assets, because the current push-type data flow (Figure 5.1) adopted at INDOT cannot provide accurate and complete data for asset O&M (Cai et al., 2015). Specifically, engineers design the model in CAD, then they deliver the drawings in paper-based PDF to contractors. During the construction phase, inspectors use SiteManager to record observations and measurements for contractor payment. Contractors also modify drawings as needed, which then takes a lot of time for resubmission and approval. More importantly, very little information of asset collected during the design and construction phases is passed onto asset O&M to provide information for bridge management system (BMS), pavement management system (PMS), and road inventory. In this push-type data flow, problems exist. For example, data is stored in an isolated way because it is stored in printed plan sheets. The data such as length, area, and volume are often lost in the delivery process. In addition, the data needs to be re-entered into different systems several times during the life cycle of



Note: Figure from *A Synthesis Study on Collecting, Managing, and Sharing Road Construction Asset Data* (Cai et al., 2015).

Figure 5.1 Current push-based workflow at INDOT (Cai et al., 2015).



Note: Figure from *Case Study of Building Information Modeling Implementation in Infrastructure Projects* (Guo et al., 2021).

Figure 5.2 Proposed pull-based workflow (Guo et al., 2021).

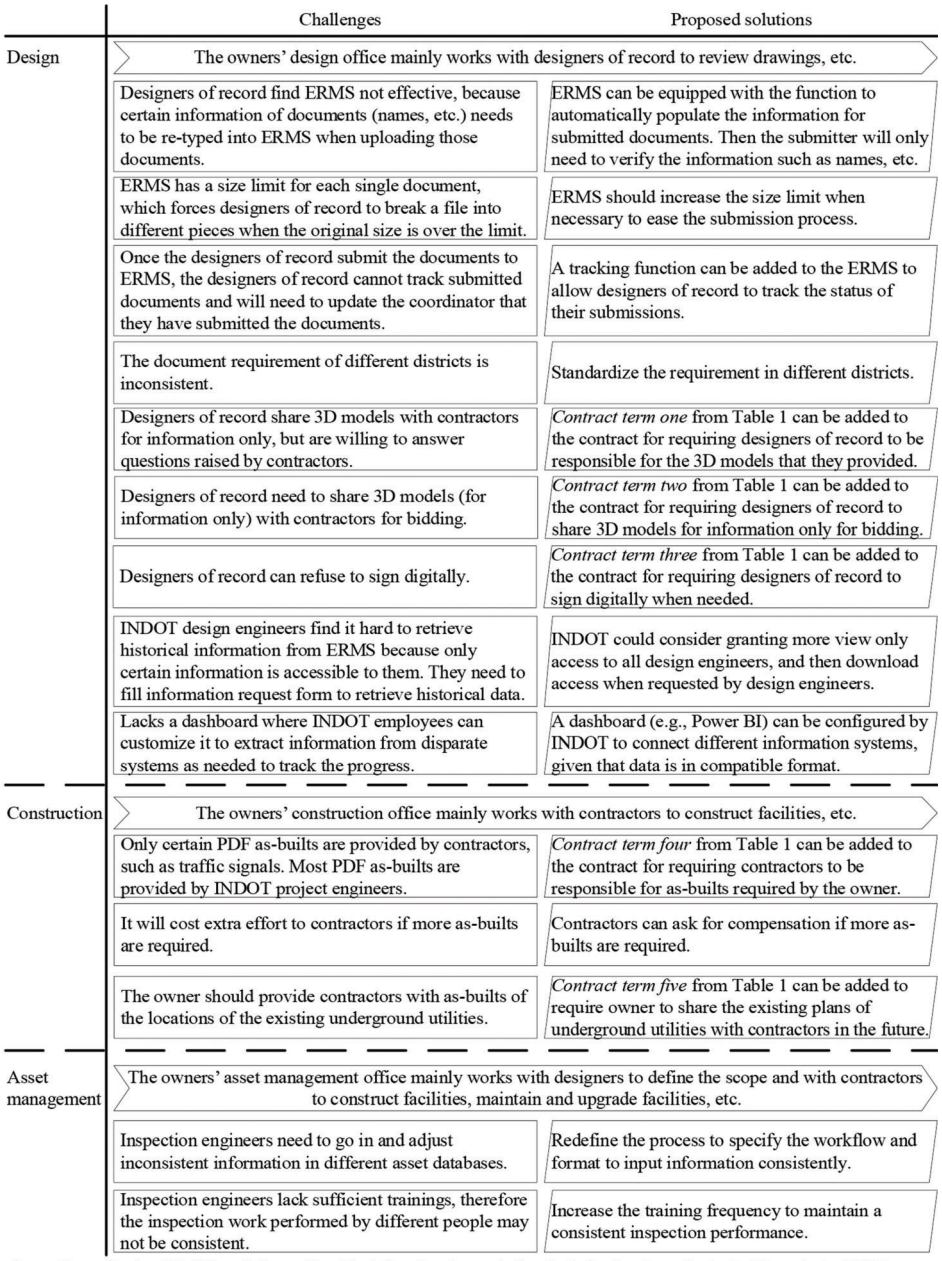
infrastructure projects because individual data sources can only provide a partial view of the infrastructure (Halfawy, 2010). This data flow lacks the ability to share and exchange information with other stakeholders in an efficient way.

The goal of this funded research is to develop guidance for INDOT on facilitating the data flow. Specifically, the proposed data flow is shown in Figure 5.2 (Cai et al., 2015; adapted from Guo et al., 2021). Researchers will study what data is needed during the asset O&M phase, and then develop guidance on when, who, and how to collect that data during design and construction phases. Researchers will also study how to solve the compatibility problems that exist between design models and GIS and BIM models.

Major process gaps that INDOT has are identified and proposed solutions are shown in Figure 5.3 (Guo et al., 2021). For example, when designers of record make minor mistakes in naming convention to upload documents to the electronic records management system (ERMS), an information sharing system used by INDOT, the design office staff cannot find the submitted documents, and the coordinator rejects the submission and asks the designers of record to resubmit, which is time-consuming. To solve the problem, ERMS can be developed and equipped with functions to automatically populate the required information for submitted documents. Then the submitter will only need to verify the information. Another challenge is that only certain PDF as-builts are provided by contractors, such as traffic signals. Researchers presented sample contract language and inquired of INDOT project engineers if they would accept moving the as-built task to contractors. Some of them think INDOT should be responsible for most as-builts as it is their responsibility to oversee the project progress. However, for certain as-builts such as traffic signals, many projects engineers thought it should be the contractor's responsibility, as it is hard to measure after the construction is complete. However, some project engineers think contractors should provide the majority of as-builts. For designers of record, major process gaps were identified, and solutions were proposed. For example, designers of record may only be willing to share 3D models with contractors as reference documents for information only, which is the current practice. In addition, designers of record may be reluctant to share the 3D models if they need to be contractually responsible for them. Similarly, for contractors and software vendors, major process gaps were identified, and solutions were proposed.

5.1.2 Quantitative Evaluation

The responses received were from bridge engineers and roadway engineers. Their experience ranged from 1 year to 30 years. The majority of projects they are responsible for adopt the delivery method of design bid



Note: Figure from *Case Study of Building Information Modeling Implementation in Infrastructure Projects* (Guo et al., 2021).

Figure 5.3 Refined workflow for process challenges (Guo et al., 2021).

build. From the interviews, designers of record were concerned about the current communication process between the INDOT design office and designers of record. Specifically, they said they had to contact a coordinator to transfer documents submitted through ERMS and had no ability to track the submitted documents. Therefore, INDOT design office was asked: how would you feel if the designers of record can talk with the design review staff in the INDOT design office directly? Based on the survey data, five INDOT design engineers were "very satisfied" with that, eight INDOT design engineers were "satisfied" with that, and one staff was neutral about this, as shown in Figure 5.4. One recommended solution is to adjust the communication channel to allow designers of record talk with the design review staff directly.

Currently, consultant designers of record share digital 3D models with contractors and INDOT when requested, but do not want to be contractually responsible. If INDOT wants to have designers of record provide 3D models for information only, designers can provide it with a disclaimer. Most designers are currently satisfied with this practice, as shown in Figure 5.5. However, If INDOT wants to have designers of record be contractually responsible for 3D models without a disclaimer, most designers

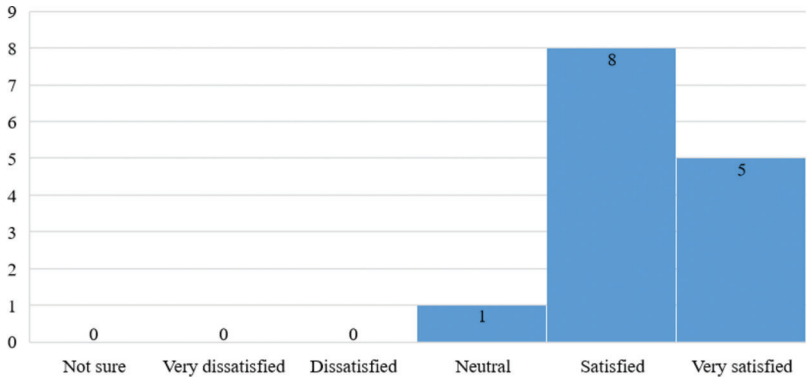


Figure 5.4 Satisfaction of current communication channel.

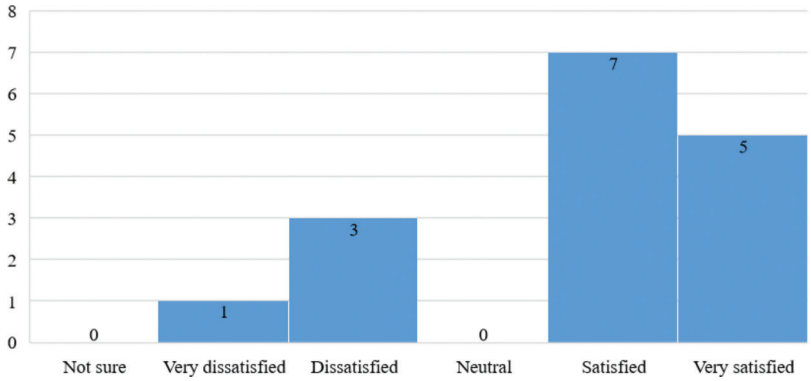


Figure 5.5 Satisfaction of submitting with disclaimer.

would be dissatisfied with such a change, as shown in Figure 5.6. In addition, when the research team asked designers about additional compensation if 3D models were required and designers of record would be contractually responsible for them, some said: "The amount of money required for this level of detail would be dependent on whether the information requested includes 3D modeling information or 2D information. The 3D modeling level of detail would require post-construction survey to ensure the contractor's final placement of features are documented correctly. Compensation would also be dependent on the size/length of the project." The best scenario would be to require asset information in GIS format (for items such as manholes, pipes, curb lines, signage, striping, etc. that require ongoing maintenance and monitoring). Such level of development (LOD) could be investigated further during the development of model development standards at INDOT. LOD standards could be implemented in model view definitions (MVDs) for QA/QC of 3D models submitted in IFC format.

The research team also double checked ERMS, about which many of the designers had concerns. Their concern was that ERMS was not effective when the naming of documents needs to be re-typed into the system. In the survey, one person even commented that "ERMS seems archaic. It is way off in so many places that even when something is submitted, it takes several steps to distribute. Departments within INDOT cannot get to the information they need. Everything has to go through one coordinator. I have seen PM's request to use of ProjectWise instead of ERMS to avoid the hassle. ERMS is clunky and prone to user input errors. We get scored negatively if a file is kicked back. It would save INDOT money if we could simplify the process because of the amount of time uploading files currently takes." Therefore, the research team asked: How would you feel if ERMS is equipped with a function to automatically populate the information from your submitted document and you just need to verify it instead of manually typing in everything? 13 participants were "Very satisfied," one participant was "Satisfied," and two participants were "Not sure," as shown in Figure 5.7. We would suggest improvement of ERMS and to equip it with such functionality. In the long-term, such functions could be developed to extract data from PDF submittals or IFC models automatically, so that INDOT could develop functions within INDOT proprietary systems to directly extract information.

5.2 Technology (Current Technology, Gaps, and Potential Solutions)

5.2.1 Qualitative Exploration

The second and third barriers are IT infrastructure software and data interoperability (Cai et al., 2015).

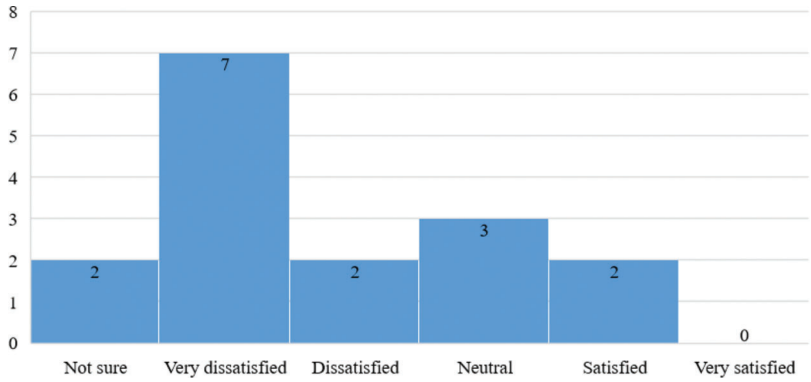


Figure 5.6 Satisfaction of submitting without disclaimer.

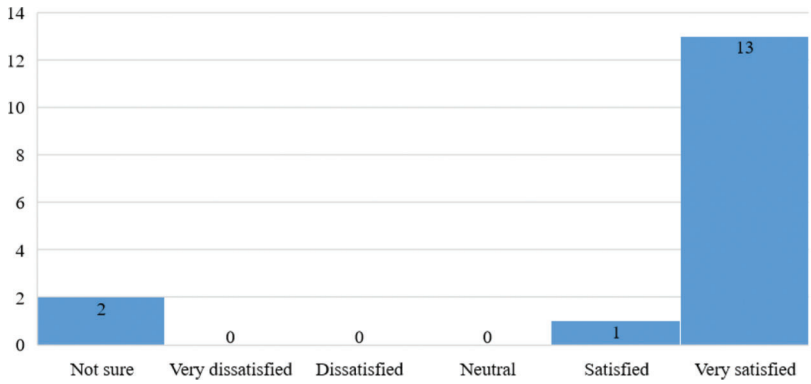
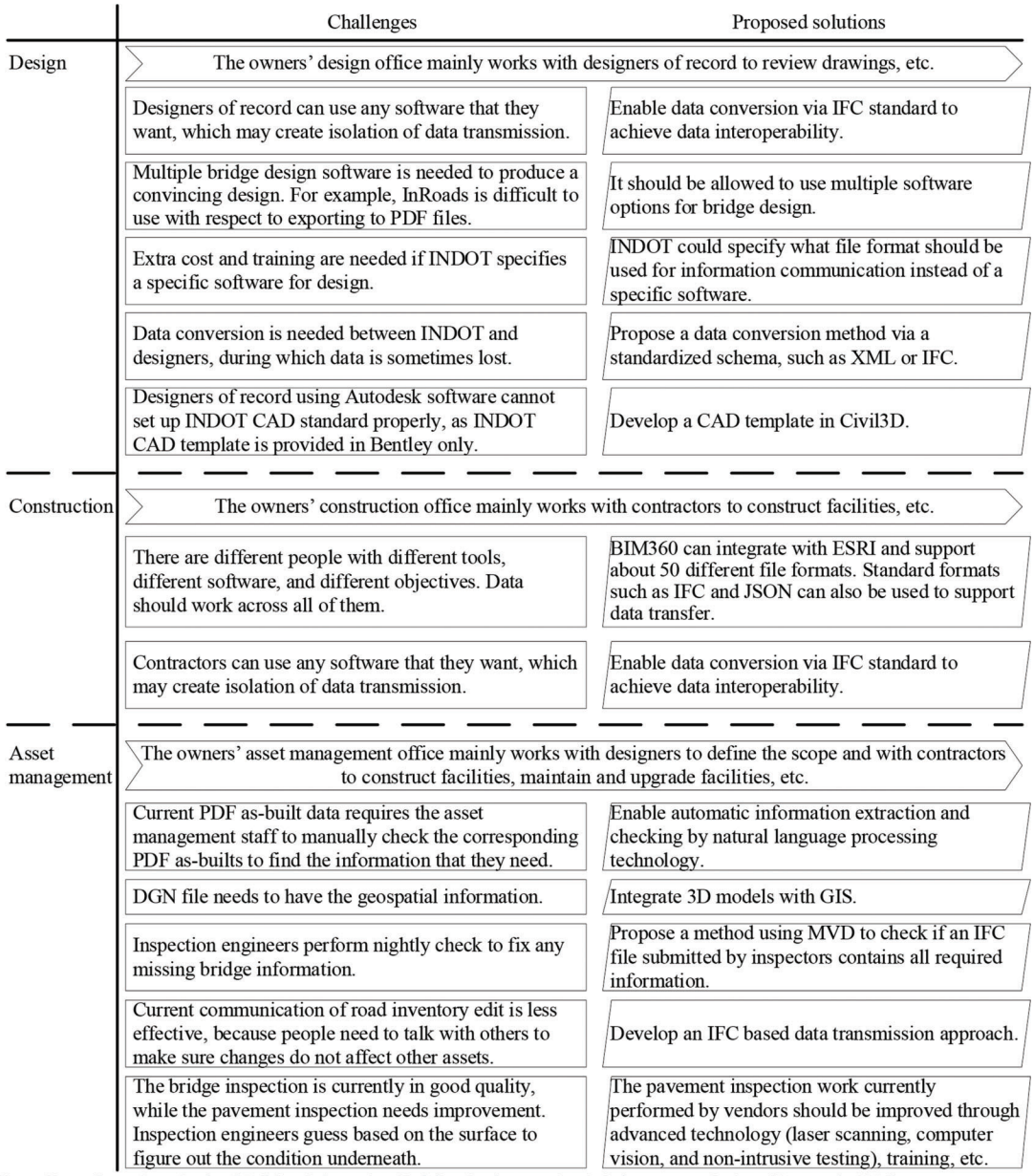


Figure 5.7 Satisfaction of ERMS.

Technology dimension defines: (1) how to convert the O&M information requirement to technical requirements of design documentation, (2) how to convert the O&M information requirement to technical requirements of construction documentations, and (3) outlining of information format and technical scheme to facilitate information exchange and compatibilities. With the recommended pull-type data flow for INDOT, the information needs and requirement from downstream O&M will be converted into requirement for construction and design documentations. Currently, there are several technical issues that block information flow and integration. Compatibility is one blocking barrier that prevents the data flow from upstream to downstream applications. The other issue is the use of a paper-based approach for design and construction documents. Figure 5.8 (Guo et al., 2021) shows gaps and proposed solutions from designers. For example, INDOT may deliver drawings created with Bentley software to designers while designers may use AutoDesk software, like Civil3D. The designer may then need to convert the data format before use. In addition, designers also commented that a CAD template should be provided in Civil 3D. Figure 5.8 (Guo et al., 2021) also shows gaps found in the interviews with contractors. Specifically, for example, to solve the data conversion challenge, BIM360 could be used since it supports 50 different file formats. Figure 5.8 (Guo et al., 2021) also shows gaps found in the interviews with software vendors. Construction management software vendors note that inspectors collect a lot of data and information, we propose that this information could be extracted and analyzed automatically by natural language processing technology. However, when INDOT needs to export data from a GIS database into Excel, some data could be missed. Therefore, more advanced technology could be used to extract information from the GIS database to alleviate missing data problems and increase information accuracy. Current gaps from INDOT design office are listed in Figure 5.8. INDOT should allow multiple software options for bridge because designers would like to check their design results among different software to ensure it is reasonable. Also, designers mentioned grouped data could be lost during the data conversion process. Therefore, a data conversion method via standardized schema should be proposed. In addition, people in INDOT design office mentioned InRoads being difficult to use with respect to pdf file exports. Therefore, more software should be explored before specifying the required CAD file. Current gaps from the INDOT construction office are listed. People from INDOT construction office requested as-built information be collected by contractors and even if contractors require more money for collecting as-builts. Also, contractors should be responsible for as-built



Note: Figure from *Case Study of Building Information Modeling Implementation in Infrastructure Projects* (Guo et al., 2021).

Figure 5.8 Refined workflow for technology challenges (Guo et al., 2021).

data, which would make the collected data more reliable. In addition, some projects require data conversion, and data conversion methods such as conversion via IFC or XML schema could be used to solve this gap. The current gaps from INDOT asset management office are listed. First, bridge inspection data could be subjective. For example, when looking at a deck, if one side of the deck is in bad condition, it is not clear if the whole bridge will take the average across its different parts or simply use the part checked as a representative. Therefore, a more detailed bridge inspection process should be defined with more objective quantitative data and evaluation methods. Second, pavement inspection should be given in a timely manner. New technology could be used to improve pavement inspection efficiency. Third, pavement and culvert inspection data needs improvement. Therefore, more training could be provided to pavement and culvert inspectors. Fourth, asset information is not updated after changes are made. INDOT assets management office could send inspectors to collect updated data.

The following section discusses possible ways to solve the technical gaps found in the interviews in detail. First, model view definition could be explored to check any missing data in IFC files. Model view

definition technology allows us to define customized IFC schema (Akanbi et al., 2020; Ren & Zhang, 2021). We can define customized IFC schema for INDOT based on what information is needed by INDOT at each stage. Taking beams of a bridge as an example, information related to a beam could be stored in an IFCBeam object. A lot of information could be collected from bridge inspection. However, if we are only interested in the location of the beam to check if the bridge is still in good condition, we can specify through MVD that the location information for beam must be included in the IFC file. IFCLocalplacement is used to store such location information. As shown in the red rectangle in Figure 5.9, the link between IFCLocalplacement and IFCBeam in the MVD means location information of a beam must be included. Then, we could also export requirements in the mvdxml file as shown in Figure 5.10. This requirement could be used repeatedly for QA/QC of models. This file could also help explicitly define what information is needed by INDOT during inspection task, e.g., to inform bridge inspectors.

After the requirement is defined and the data is collected, the IFC file containing bridge information (e.g., as shown in Figure 5.11) can be checked automatically. Figure 5.12 shows IFC file validation results. Green color means those highlighted parts contain all required information by INDOT. The items will be highlighted in red if related objects do not contain all required information. This technology can be used to help INDOT asset management office detect missing information quickly and precisely.

Second, standardized data conversion via IFC could be used to solve the data conversion challenge. For example, Zhu et al., 2019 developed algorithms to convert IFC files into shapefile, which is one of the commonly used GIS file formats. To help with creating 3D IFC models for bridges and other infrastructure, automation technology such as the one developed by Akanbi and Zhang (2020) can be used to reduce the amount of manual efforts needed in model development by automatically and algorithmically processing 2D PDF drawings into 3D models.

Third, the asset management team needs to manually extract and check information from GIS, pdf files. Therefore, the following technology is proposed to extract and check information automatically based on natural language processing technology as shown in Figure 5.13. In this proposal, data is first collected from the mobile device or survey form. Natural language processing technology will then be used to extract unstructured textural data from pdf. files and stored in a database. The data stored in a structured databased can be retrieved directly with querying languages. The required information could be extracted from pdf files automatically. The process costs less time and would be less error-prone than performing it manually. Lastly, the extracted information could be compared with standards to find deviations or error.

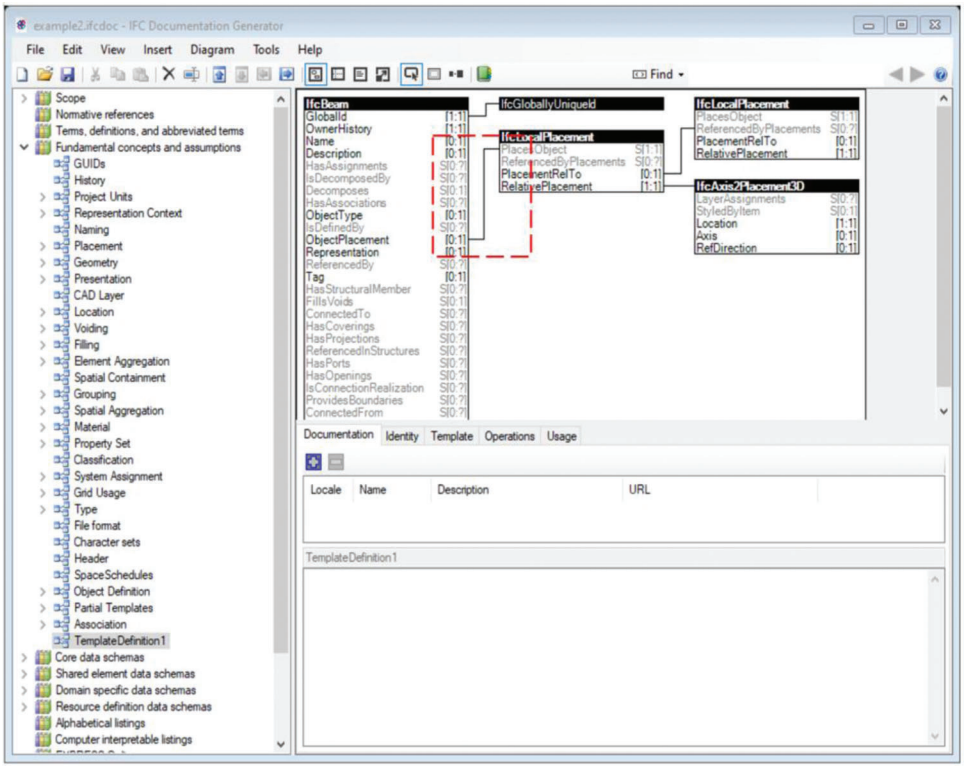


Figure 5.9 Define customized IFC MVD to check missing data.

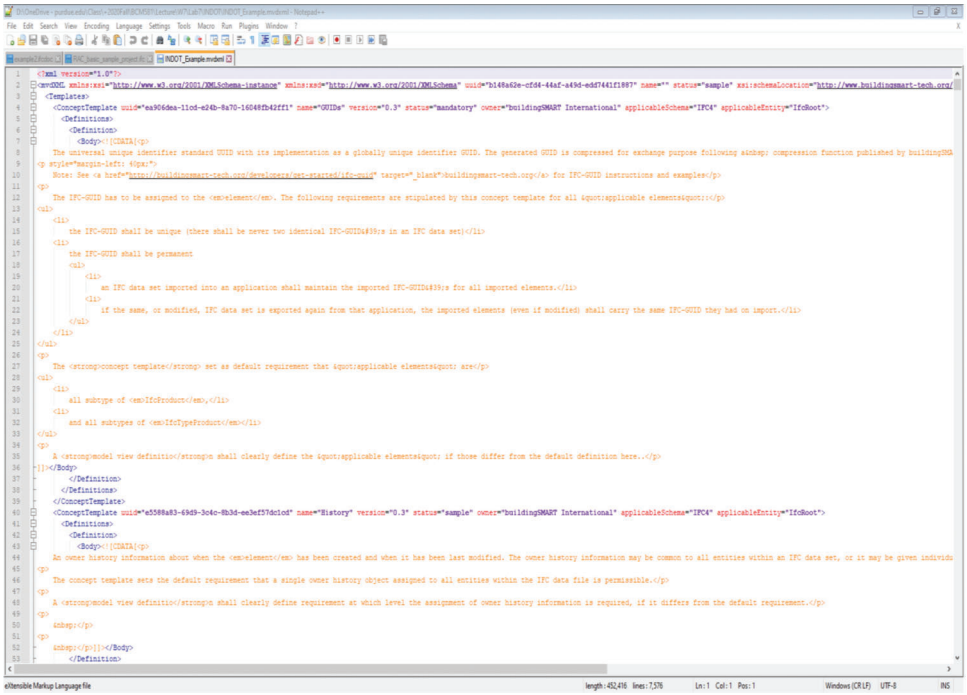


Figure 5.10 Customized IFC schema exported in the mvdxml file.

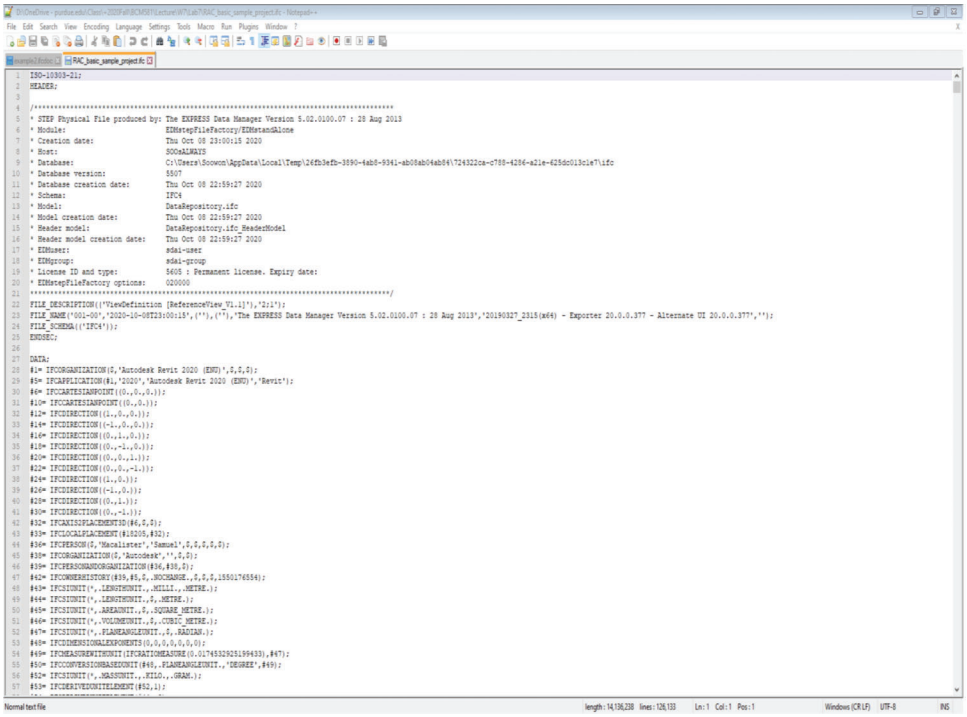


Figure 5.11 Example input IFC file.

5.2.2 Quantitative Evaluation

There are some data isolation problems currently. To solve the problem, INDOT could ask designers to use a specific software. The research team asked INDOT design staff: How would you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers to use one of the software vendors specified by INDOT? Most of INDOT design staff stated that they would be "satisfied" or "very satisfied" with that, as shown in Figure 5.14. However, after talking with the

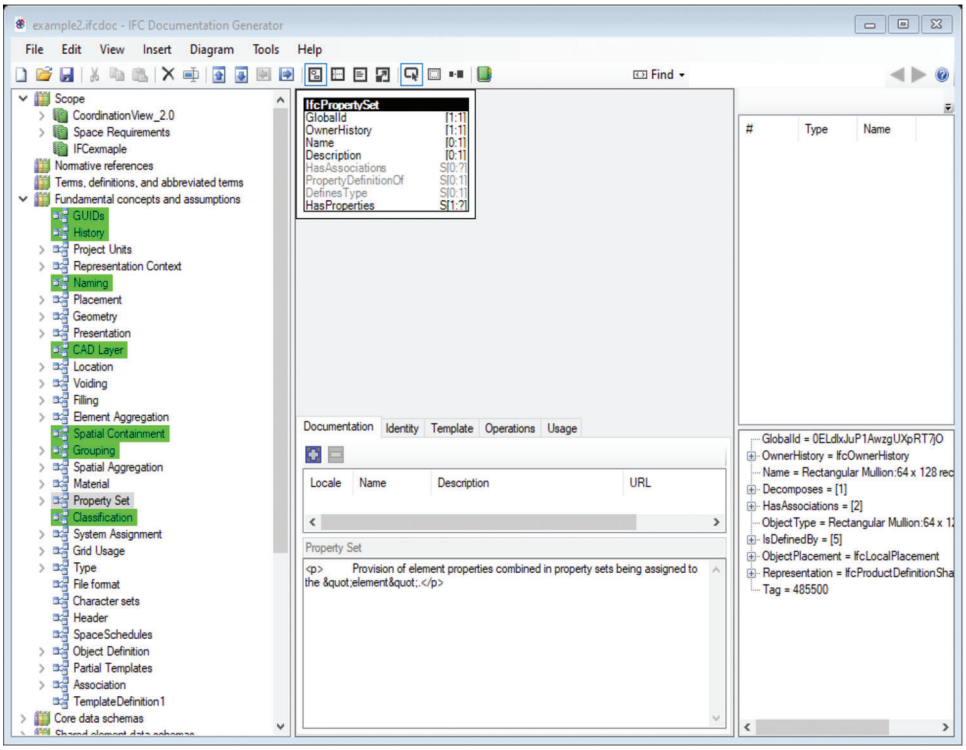


Figure 5.12 IFC file validation results.

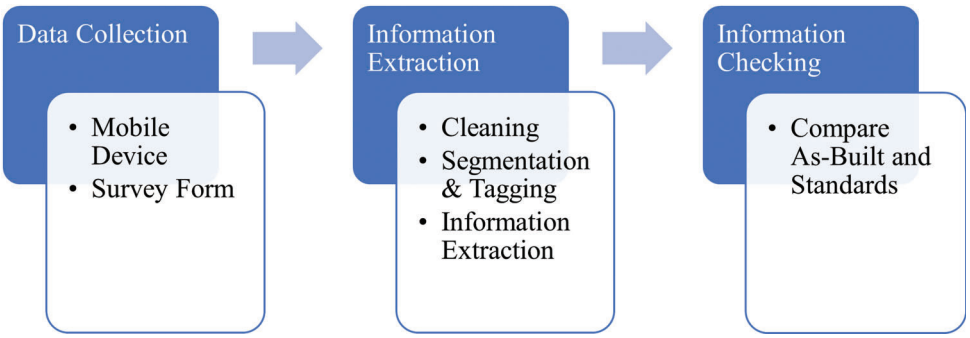


Figure 5.13 Workflow of automatic data extraction from text data.

interviewees, some people said if the product format can be used without any compatibility problems, there is actually no need of making such requirement. Therefore, we would propose to solve any possible compatibility problems to enable data conversion via IFC standard. In the survey, we asked questions like: How would you feel if INDOT allows the designers of record to use any software they want, in the data format accepted by INDOT, such as DGN, DWG, XML, and IFC? And based on the current survey data, most of the participants were "satisfied" or "very satisfied" with this approach, compared with those who were "dissatisfied", as shown in Figure 5.15. The research team checked with designers about the questions we asked INDOT to see if they agree. The research team asked: How would you feel if INDOT asks designers of record to use a specific software for engineering calculation and CAD drawing development? Most participants were "dissatisfied" with it, as shown in Figure 5.16 and Figure 5.17. Then the research team also cross checked with designers to see what they feel about using IFC. Most people were "satisfied" or "very satisfied" with it, as shown in Figure 5.18. In addition, some provided comments such as: "Ideal scenario would be requesting an open data standard such as IFC. I would like more information on the IFC and XML format to provide standardized data."

5.2.3 Data Interoperability Methods Proposed by Software Vendors

This part discusses current data interoperability methods proposed by software vendors, such as Autodesk, and FME.

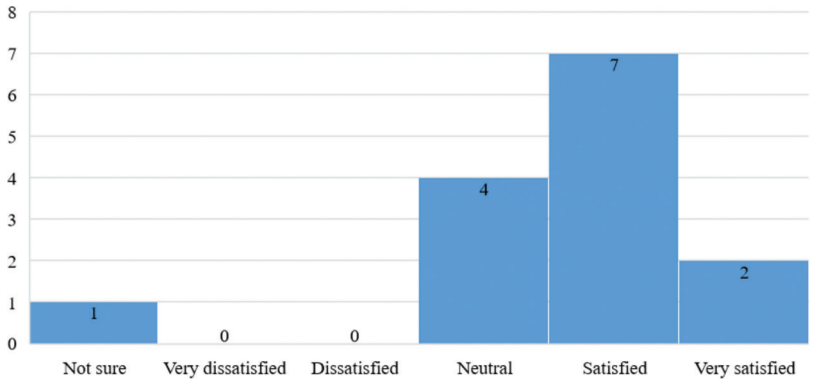


Figure 5.14 Satisfaction of data transmission.

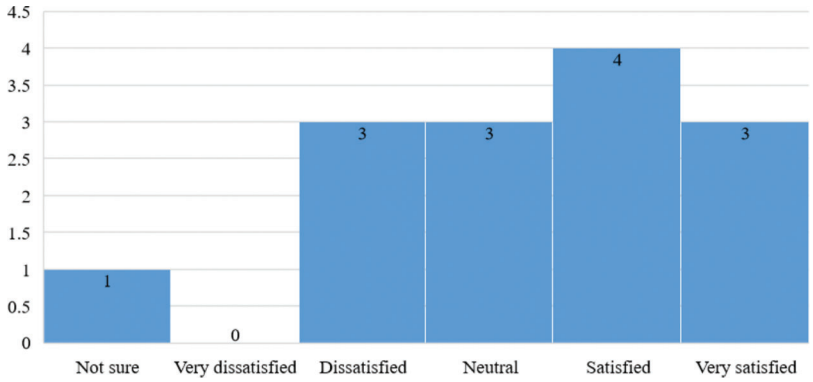


Figure 5.15 Satisfaction of software requirement.

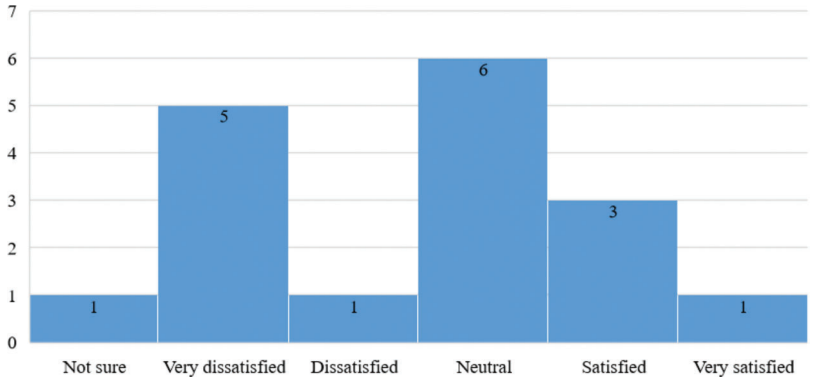


Figure 5.16 Satisfaction of use for a specific software to eliminate the data incompatibility (engineering calculation).

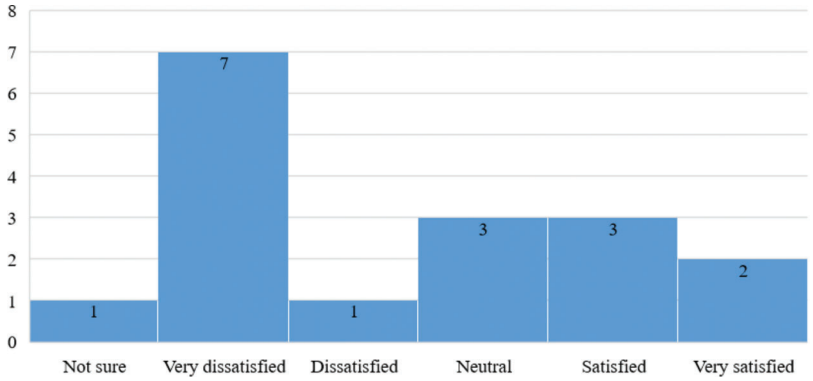


Figure 5.17 Satisfaction of use for a specific software to eliminate the data incompatibility (CAD drawing development).

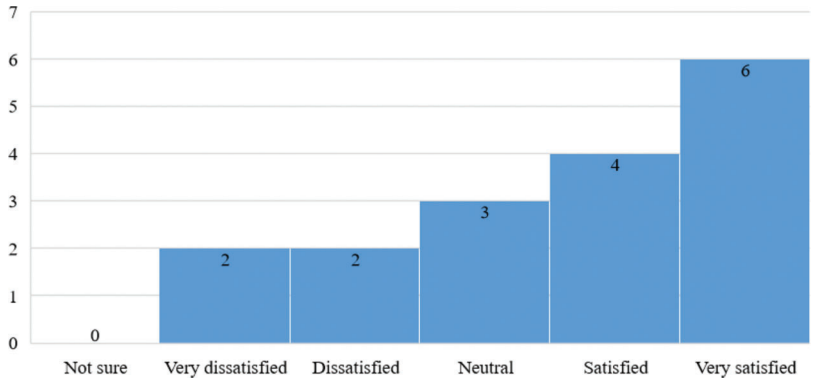


Figure 5.18 Satisfaction of use for any software that contractors or designers want but in an acceptable format.

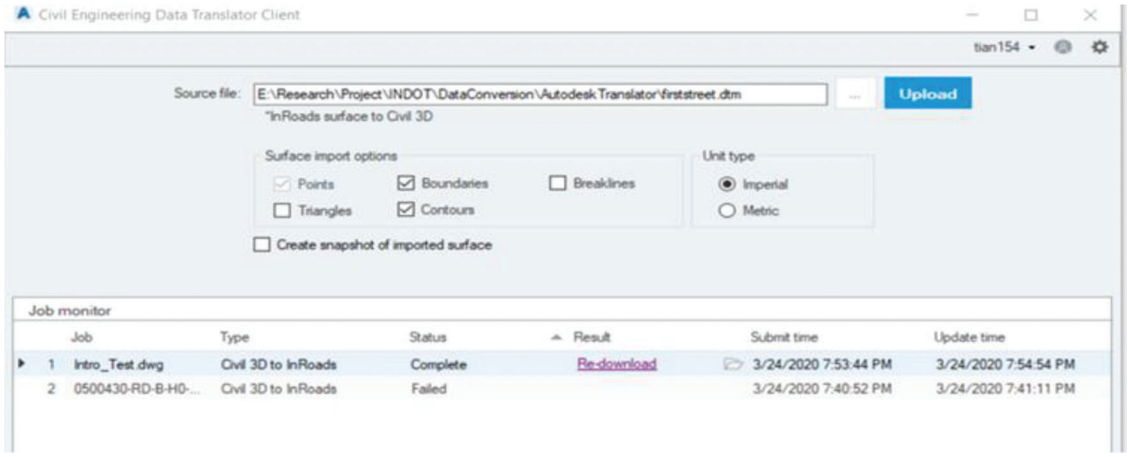


Figure 5.19 Choosing the targeted file format: either InRoads or GEOPAK.

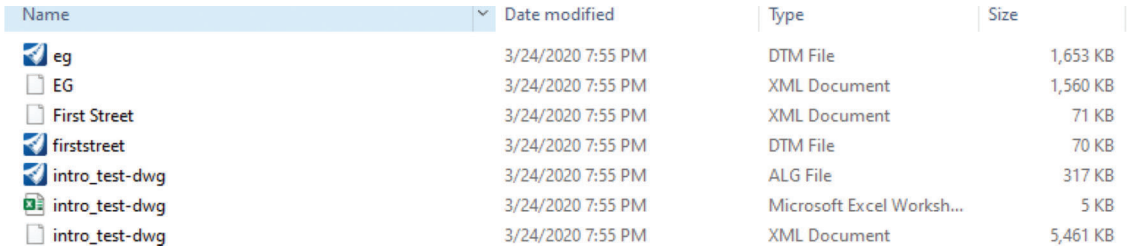
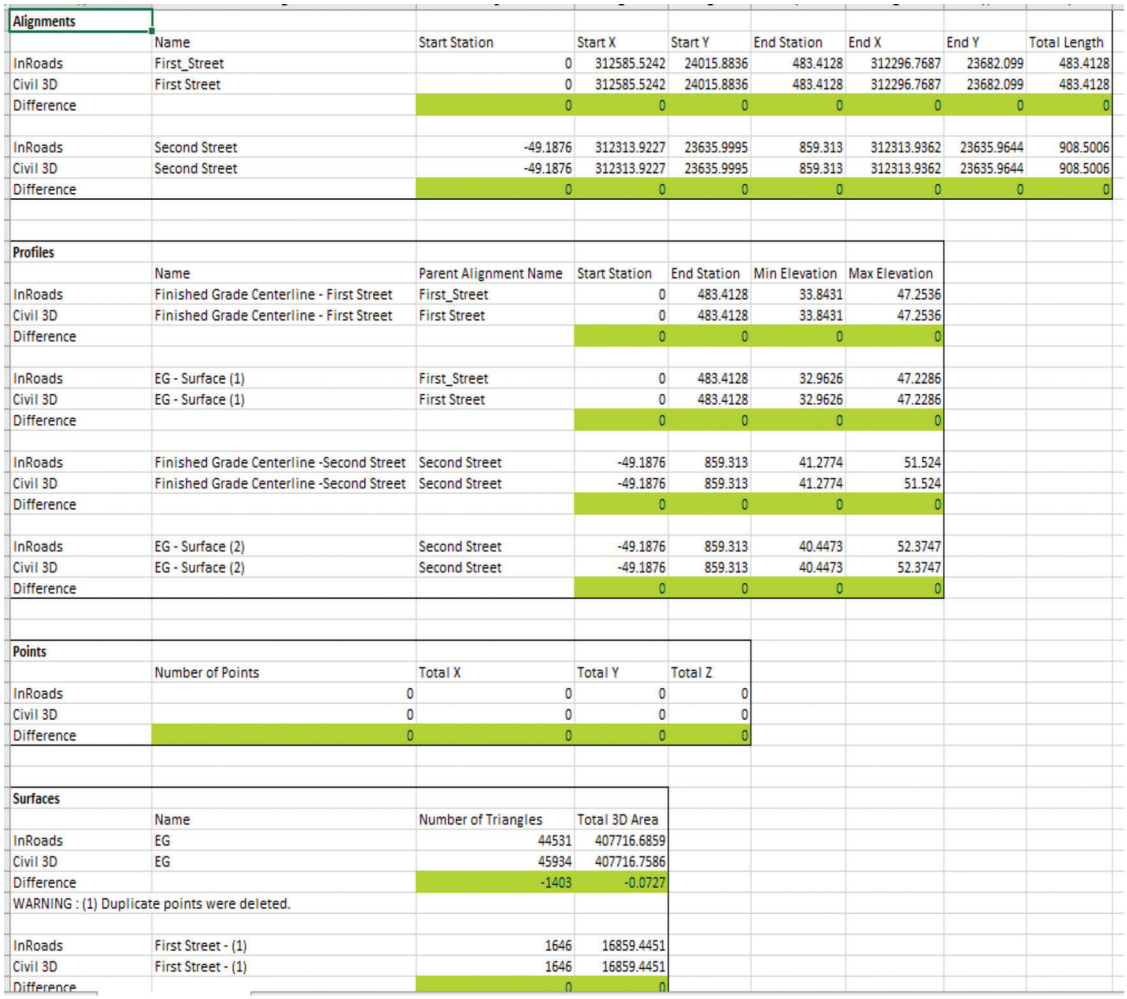


Figure 5.20 Translated results.

5.2.3.1 Civil Engineering Data Translator Developed by Autodesk. The Civil engineering data translator was published by Autodesk, which is a plug-in for Autodesk Civil 3D software. This translator can transfer data between Civil 3D (.dwg) and InRoads files (.datum, .alg), or GEOPAK files (.tin, .gpk). A pilot study using a sample .dwg file provided by Civil3D was conducted as the following steps.

1. First, the .dwg file was uploaded into this civil engineering data translator.
2. Second, the targeted file format was chosen as shown in Figure 5.19. In this pilot study, "Export civil 3D to Bentley InRoads" was selected.
3. Third, the .dwg file was transferred into InRoads files or GEOPAK files automatically based on the selection.
4. Fourth, the translated results, if translated successfully, were ready to download. The translated results contain one .xlsx file, LandXML files, .dtm files, and .alg files as shown in Figure 5.20. The .xlsx file summarizes the translation result as show in Figure 5.21. Also, the .dtm file can be translated back into the .dwg file as shown in Figure 5.22.

Also, the .dwg provided by INDOT was tested by this method, which could not be converted by this translator, as shown in Figure 5.23. This translator only supported .dwg file created by Autodesk Civil 3D. The potential



Alignments

	Name	Start Station	Start X	Start Y	End Station	End X	End Y	Total Length
InRoads	First_Street	0	312585.5242	24015.8836	483.4128	312296.7687	23682.099	483.4128
Civil 3D	First Street	0	312585.5242	24015.8836	483.4128	312296.7687	23682.099	483.4128
Difference		0	0	0	0	0	0	0
InRoads	Second Street	-49.1876	312313.9227	23635.9995	859.313	312313.9362	23635.9644	908.5006
Civil 3D	Second Street	-49.1876	312313.9227	23635.9995	859.313	312313.9362	23635.9644	908.5006
Difference		0	0	0	0	0	0	0

Profiles

	Name	Parent Alignment Name	Start Station	End Station	Min Elevation	Max Elevation
InRoads	Finished Grade Centerline - First Street	First_Street	0	483.4128	33.8431	47.2536
Civil 3D	Finished Grade Centerline - First Street	First Street	0	483.4128	33.8431	47.2536
Difference			0	0	0	0
InRoads	EG - Surface (1)	First_Street	0	483.4128	32.9626	47.2286
Civil 3D	EG - Surface (1)	First Street	0	483.4128	32.9626	47.2286
Difference			0	0	0	0
InRoads	Finished Grade Centerline -Second Street	Second Street	-49.1876	859.313	41.2774	51.524
Civil 3D	Finished Grade Centerline -Second Street	Second Street	-49.1876	859.313	41.2774	51.524
Difference			0	0	0	0
InRoads	EG - Surface (2)	Second Street	-49.1876	859.313	40.4473	52.3747
Civil 3D	EG - Surface (2)	Second Street	-49.1876	859.313	40.4473	52.3747
Difference			0	0	0	0

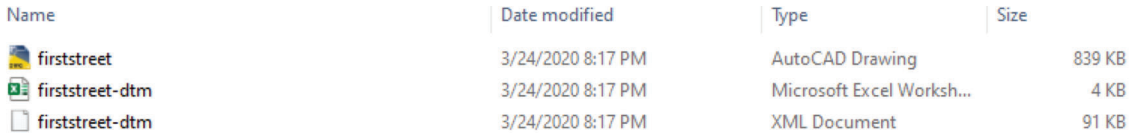
Points

	Number of Points	Total X	Total Y	Total Z
InRoads	0	0	0	0
Civil 3D	0	0	0	0
Difference	0	0	0	0

Surfaces

	Name	Number of Triangles	Total 3D Area
InRoads	EG	44531	407716.6859
Civil 3D	EG	45934	407716.7586
Difference		-1403	-0.0727
WARNING : (1) Duplicate points were deleted.			
InRoads	First Street - (1)	1646	16859.4451
Civil 3D	First Street - (1)	1646	16859.4451
Difference		0	0

Figure 5.21 An Excel (.xlsx) file summarizing translation results.



Name	Date modified	Type	Size
firststreet	3/24/2020 8:17 PM	AutoCAD Drawing	839 KB
firststreet-dtm	3/24/2020 8:17 PM	Microsoft Excel Worksh...	4 KB
firststreet-dtm	3/24/2020 8:17 PM	XML Document	91 KB

Figure 5.22 A .dwg file translated from .dtm file.

reason might be that .dwg files created by Autodesk Civil 3D and Bentley have different structures.

5.2.3.2 FME. FME was suggested by INDOT during a SAC meeting, as a software to enable data transformation among different formats. Pilot study conversion from IFC to CityGML was explored by using FME. The workflow to convert IFC into CityGML is displayed in Figure 5.24. The converted results are shown in Figure 5.25.

5.2.4 Method of Converting CAD Files into GIS Files as Proposed by this Research Team

This study tries to convert CAD files (such as .dwg, dgn) into GIS files (such as XML, CITYGML) via IFC schema. The .dwg files provided by INDOT were created by Microstation. The .dwg files can be opened in InRoads and OpenRoads directly as shown in Figure 5.26 and Figure 5.27.

In this project, we also explored how to convert IFC files into CityGML files. The CityGML is widely used in the GIS domain. An algorithm was developed to convert IFC 2×3 files into CityGML files. The CityGML files contain geometry and Geodata of infrastructure objects. The proposed workflow is shown in Figure 5.28. The algorithm contains two parts which are semantic mapping and geometry calculation which is discussed as follows.

- Semantic mapping: This step maps different IFC objects into corresponding CityGML object. For example, an IfcBuilding is mapped into a building in CityGML.

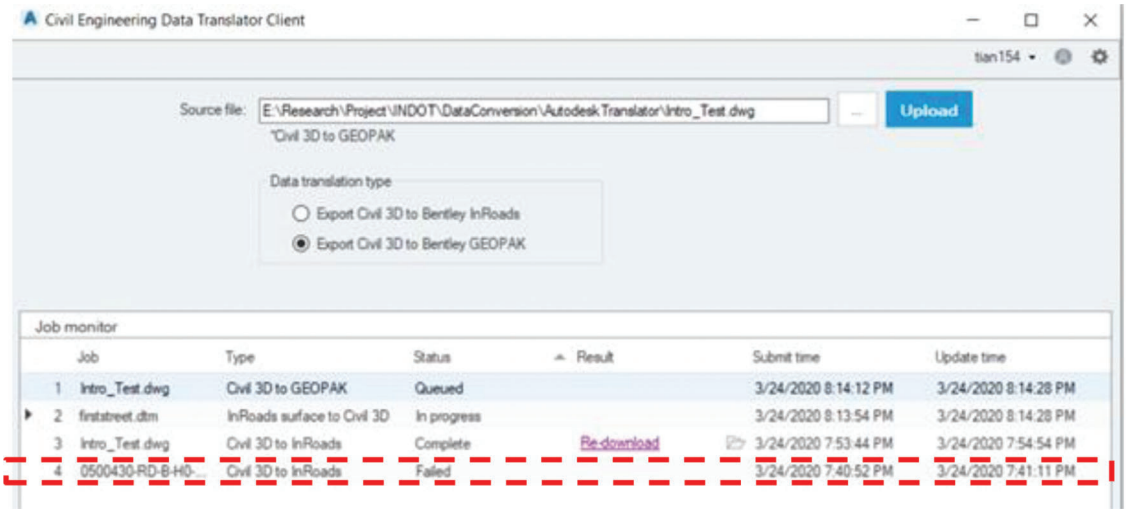


Figure 5.23 Failed results of data transfer by civil engineering data translator.

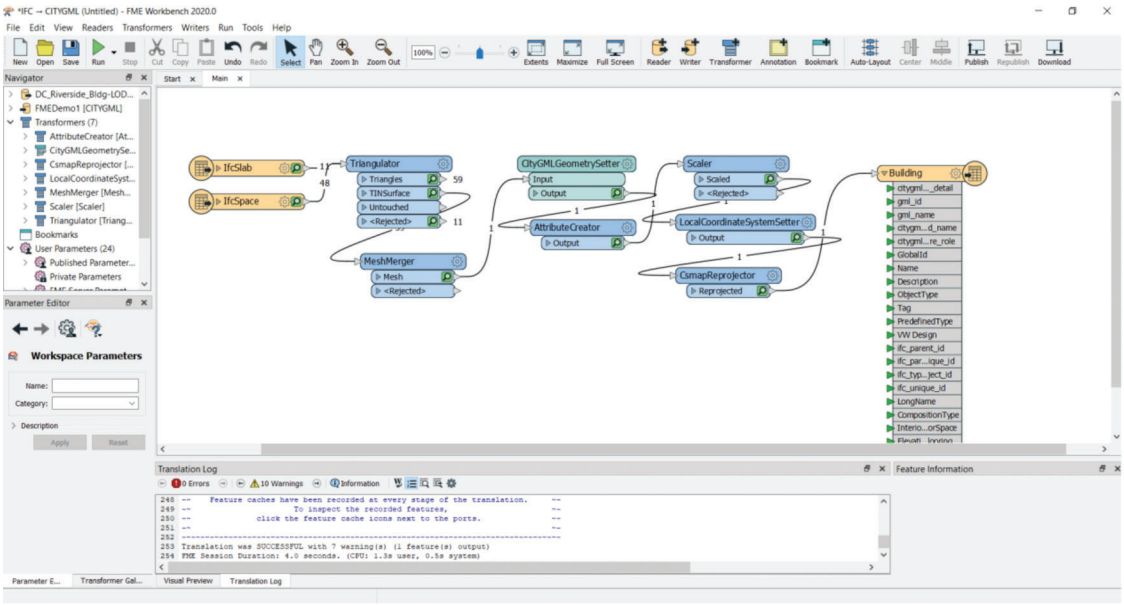


Figure 5.24 FME interface for converting IFC LOD 100 into CityGML.

- Geometry Calculation: IFC 2×3 and CityGML have different representations of geometric data. We need to compute geometric data needed in CityGML based on geometric information from IFC 2×3.

The current input and output are listed in Figure 5.29 and Figure 5.30

5.2.4.1 Semantic Mapping. The IfcBuildingElement Proxy was converted into building object in CityGML. Rule-based algorithms can be used to further identify what object the IfcBuildingElementProxy is representing, such as beams, columns, footings, slabs, and walls (Wu & Zhang, 2019). Then, a corresponding building object in CityGML could be used to store related information from IFC.

5.2.4.2 Geometry Calculation. Geometry calculation and conversion is required since IFC and CityGML employ different strategies to store geometric information (Deng et al., 2016). Objects' geometry is stored in absolute coordinates in CityGML and in relative coordinates in IFC (Zhang, 2018). For example, IfcBuilding geometry represents its relative position to its supertype, which is an IfcSite. Therefore, to convert objects from IFC into City GML, we need to add child object's geometric information to its parent object's geometric information until the final object is not a subclass object of any others.

The IFC files exported from .dwg files provided by INDOT do not have an IfcSite, as shown in

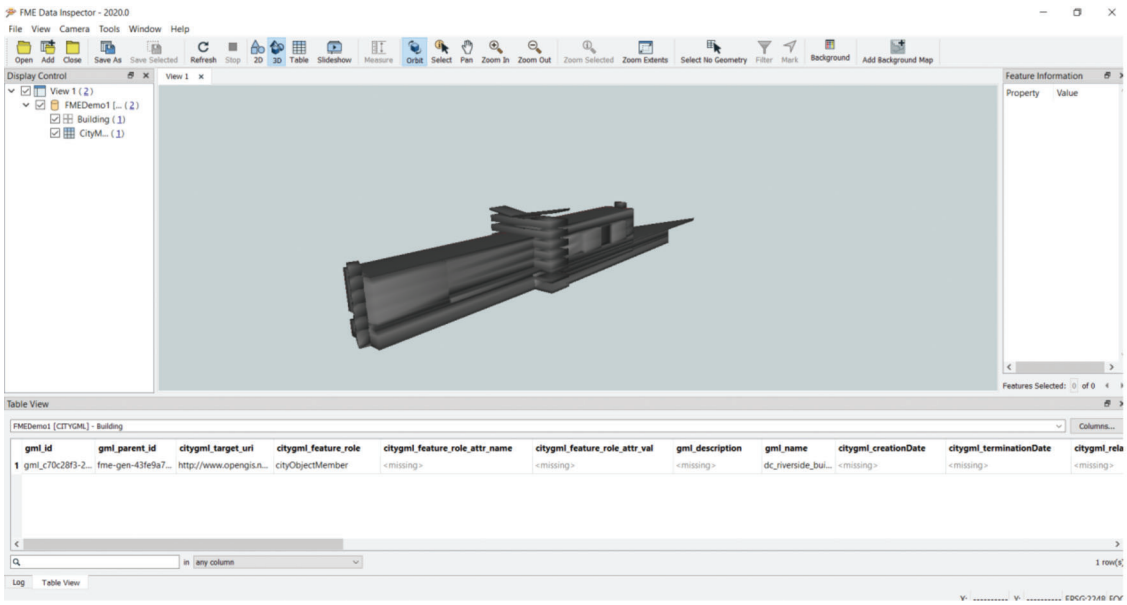


Figure 5.25 Converted CityGML file opened in FEM Inspector.

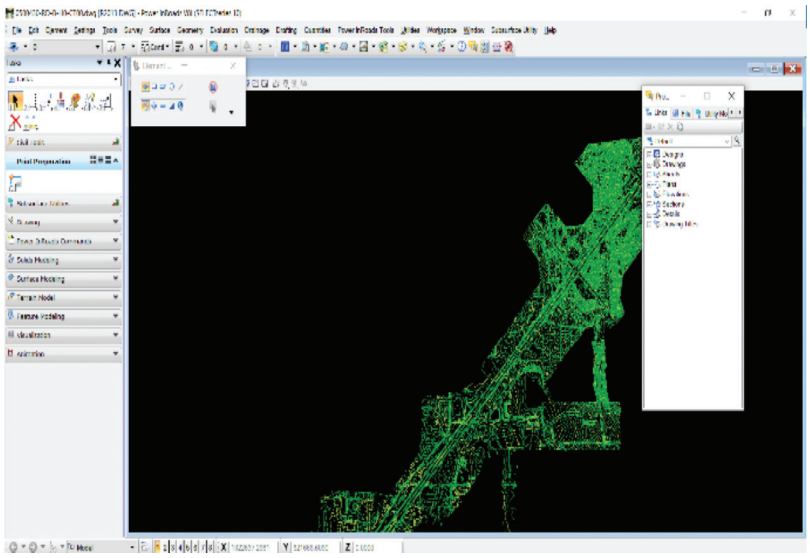


Figure 5.26 A .dwg file opened in InRoads.

Figure 5.31. Therefore, the location relationship between IfcBuilding and IfcSite is not considered in this study. In IFC schema, geometry for any IfcBuildingElementProxy is stored in IfcLocalPlacement and IfcProductDefinationShape.

Taking the first IFCBuildingElementProxy as an example which is *#254= IFCBuildingElementProxy ('2LmYFnwzDdKW0000000PYq',#57,$,$,$,#275,#285, $,$)*.

The #275 is an instance of IfcLocalPlacement and #285 is an instance of IfcProductDefinationShape. As shown in Figure 5.32, #85 represents another IfcLocalPlacement object referenced by #275 and # 282 represents its relative location.

The conversion of IfcLocalPlacement is finished as shown in Figure 5.33 and Figure 5.34.

IfcProductDefinationShape is used to define how geometric information is defined in IFC schema. Three methods are used to model solid objects in IFC, which are boundary representation, construction solid geometry, and swept solid, respectively (Donkers, 2013; Zhang, 2018). Their definitions and related characteristics are listed in Table 5.1.

Taking the first IFCBUILDINGELEMENTPROXY for example, which is *#254= IFCBUILDINGELEMENTPROXY('2LmYFnwzDdKW0000000PYq',#57, $,$,$,#275,#285,$,$)*.

The #285 represents an IfcProductDefinationShape, and its sub-objects are shown in Figure 5.35. We can convert IfcProductDefinationShape using a similar method as we have used in converting IfcLocalPlacement above.

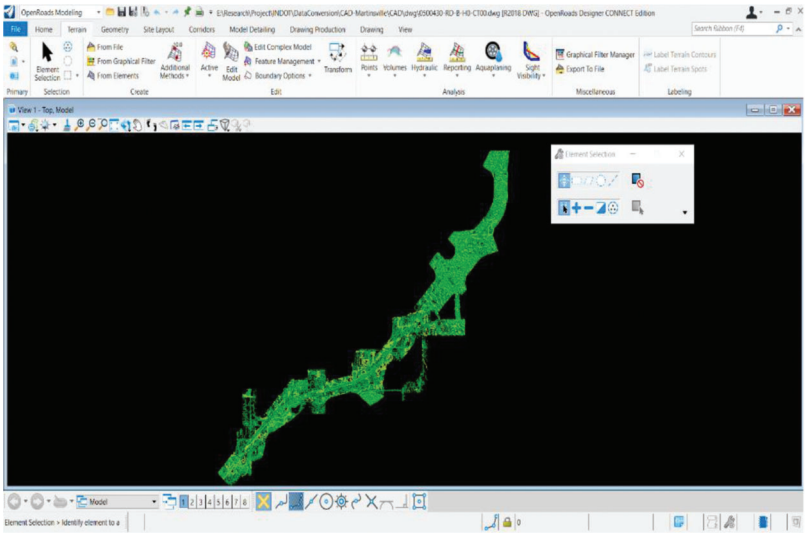


Figure 5.27 A .dwg file opened in OpenRoads.

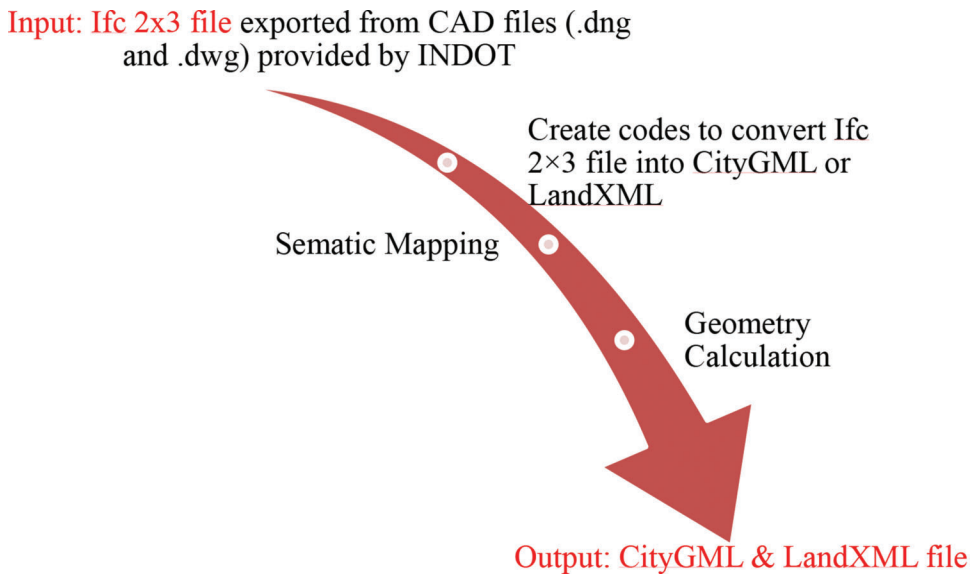


Figure 5.28 Proposed workflow to convert IFC into CityGML.

5.2.5 IFC Connector and IFC Checker Software Development by this Research Team

One mobile application and one windows application are developed to demonstrate potential solutions to help asset management team improve the workflow using a central IFC model. The windows application has initially included two functions, which are: (1) extracting one type of IFC data, and (2) check all information of a specific IFC object in one IFC file, respectively. The window application interface is shown in Figure 5.36. The users can select one IFC file by clicking on the "Select IFC file" button and then choose either: (1) "Get_IfcObject_Information" as shown in Figure 5.37, and one example output is shown in Figure 5.38; or (2) "Ifc_Info_Checking" button is shown in Figure 5.39, and one example output is shown in Figure 5.40.

The mobile app is developed to visualize and collect maintenance information. As shown in Figure 5.41, the inspectors can visualize the IFC model in the mobile app. Also, the inspectors can add maintenance information as shown in Figure 5.42.

5.2.6 IFC Central Model Proposed by this Research Team

The IFC central model is proposed to help different stakeholders deliver information smoothly as shown in Figure 5.43. The blue arrows in Figure 5.43

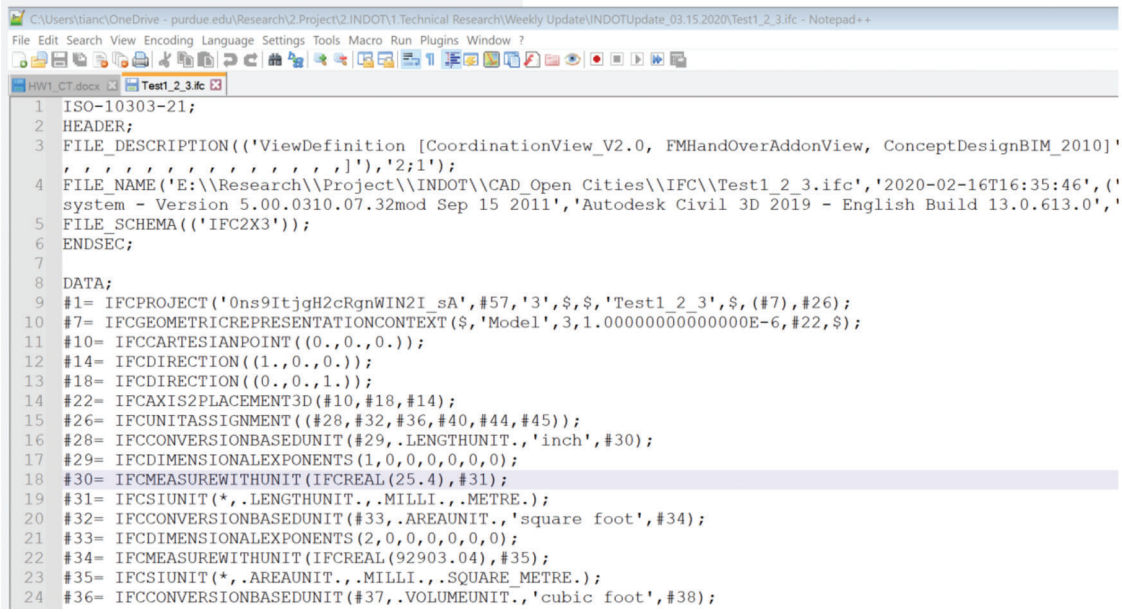


Figure 5.29 IFC Model before conversion.

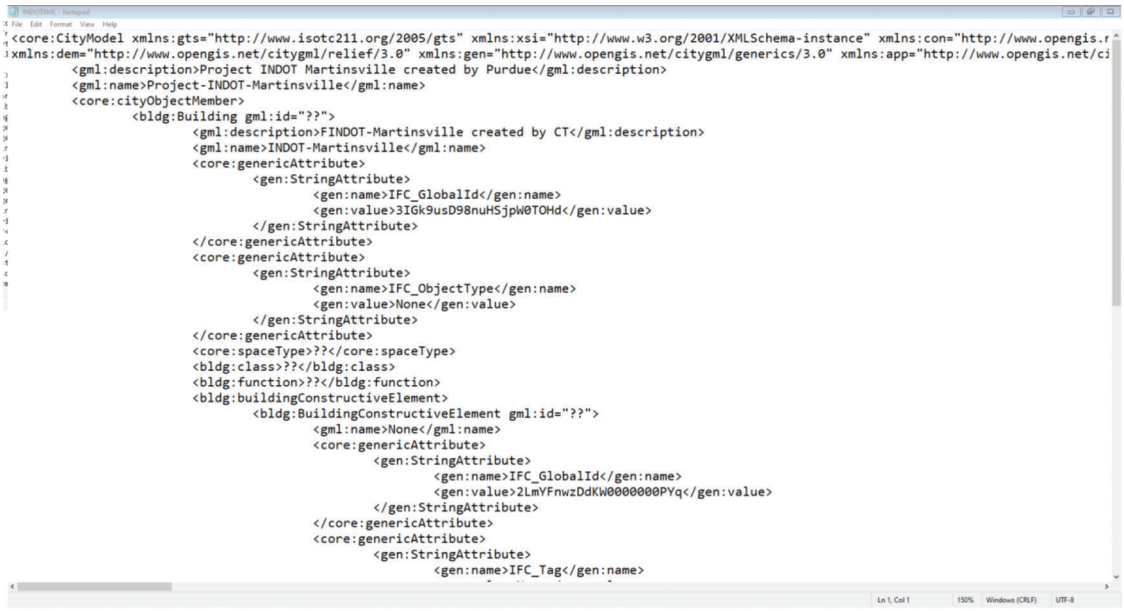


Figure 5.30 Model after conversion in CityGML format.

```
#%%
ifc_file01=ifcopenshell.open('E:/Research/Project/INDOT/CAD_Open Cities/IFC/Code/Test1_2_3.ifc') # IFC2_3 Schema INDOT
site=ifc_file01.by_type("ifcsite")
print(site)
```

```
[]
```

Figure 5.31 Code for exporting IfcSite from an Ifc file that was exported from a .dwg file provided by INDOT.

show information flow between stakeholders and different models. The red arrows Figure 5.43 show information flow between different types of models. The designer prepares as-designed model and then as-designed MVD (Arrow 1) is used to extract required and useful information which are required by asset management team into IFC model. Similarly, the contractors and inspectors prepare as-built model by LIDAR, etc. The collected as-built model should be filtered by as-built MVD (Arrow 2)

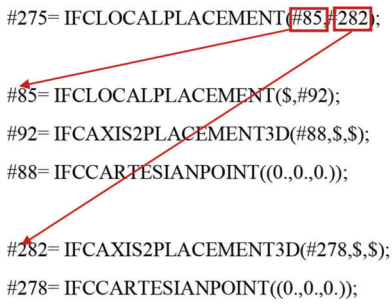


Figure 5.32 IfcLocalPlacement and its sub-objects.

```
In [93]: #conversion of IfcLocalPlacemnt
         for i in range (len(Buildingeles)):

         #for i in range (2):
             a=Buildingeles[i]
             xlocation=Buildingeles[i].ObjectPlacement.RelativePlacement.Location.Coordinates[0]
             ylocation=Buildingeles[i].ObjectPlacement.RelativePlacement.Location.Coordinates[1]
             zlocation=Buildingeles[i].ObjectPlacement.RelativePlacement.Location.Coordinates[2]
             print(a)
             relobj=str(Buildingeles[i].ObjectPlacement.PlacementRelTo)[23:24]
             #print (relobj)
             if relobj.isdigit():
                 xlocation=xlocation+Buildingeles[i].ObjectPlacement.PlacementRelTo.RelativePlacement.Location.Coordinates[0]
                 ylocation=ylocation+Buildingeles[i].ObjectPlacement.PlacementRelTo.RelativePlacement.Location.Coordinates[1]
                 zlocation=zlocation+Buildingeles[i].ObjectPlacement.PlacementRelTo.RelativePlacement.Location.Coordinates[2]
             print(xlocation)
             print(ylocation)
             print(zlocation)
```

Figure 5.33 Code to convert IfcLocalPlacement in Jupyter Notebook.

```
#254=IfcBuildingElementProxy('2LmYFnwzDdKW0000000PYq',#57,$,$,$,#275,#285,$,$)
0.0
0.0
0.0
#355=IfcBuildingElementProxy('2LmYFnwzDdKW0000000PYr',#57,$,$,$,#374,#384,$,$)
0.0
0.0
0.0
#450=IfcBuildingElementProxy('2LmYFnwzDdKW0000000PYs',#57,$,$,$,#469,#479,$,$)
0.0
0.0
0.0
#545=IfcBuildingElementProxy('2LmYFnwzDdKW0000000PZ6',#57,$,$,$,#564,#574,$,$)
0.0
0.0
0.0
```

Figure 5.34 Results of conversion of IfcLocalPlacement.

TABLE 5.1
Three methods defining solid objects in IFC

	How Are Solids Represented?	Representation Type	Geometry
Boundary representation	Represent solid by planar faces	"Brep"	Explicit
Construction solid geometry	Create solid bodies by one or more Boolean operations	CSG	Implicit
Sweep volume	Represent solid by 2D profile and a path	"SweptSolid"	Implicit

and written into the IFC model. Also, inspectors prepare inspection reports which will be filtered by inspection MVD (Arrow 3). The ESRI collector app could be used in this phase. The required information in written into the IFC model. Also, the IFC model could be converted into the asset management model as shown in Arrow 4. The asset management model could be consumed by asset management team directly.

#275= IFCLOCALPLACEMENT(#85,#282);

#285= IFCPRODUCTDEFINITIONSHAPE($,$,(#289));

#289= IFCSHAPEREPRESENTATION(#347,'Body','SurfaceModel',(#333));

#333= IFCSHELLBASEDSURFACEMODEL((#329));

#329= IFCCLOSEDSHELL((#295,#318));

#295= IFCFACE((#311));

#311= IFCFACEOUTERBOUND(#314,.T.);

#314= IFCPOLYLOOP((#299,#303,#307));

#299= IFCCARTESIANPOINT((1321403.10160662,630734.681709559,708.));

#303= IFCCARTESIANPOINT((1321404.2128247,630735.632446215,708.));

#307= IFCCARTESIANPOINT((1321404.49966667,630732.300166667,708.));

#318= IFCFACE((#322));

#322= IFCFACEOUTERBOUND(#325,.T.);

#325= IFCPOLYLOOP((#299,#307,#303));

#299= IFCCARTESIANPOINT((1321403.10160662,630734.681709559,708.));

#303= IFCCARTESIANPOINT((1321404.2128247,630735.632446215,708.));

#307= IFCCARTESIANPOINT((1321404.49966667,630732.300166667,708.));

Figure 5.35 IfcProductDefinationShape and its sub-objects.

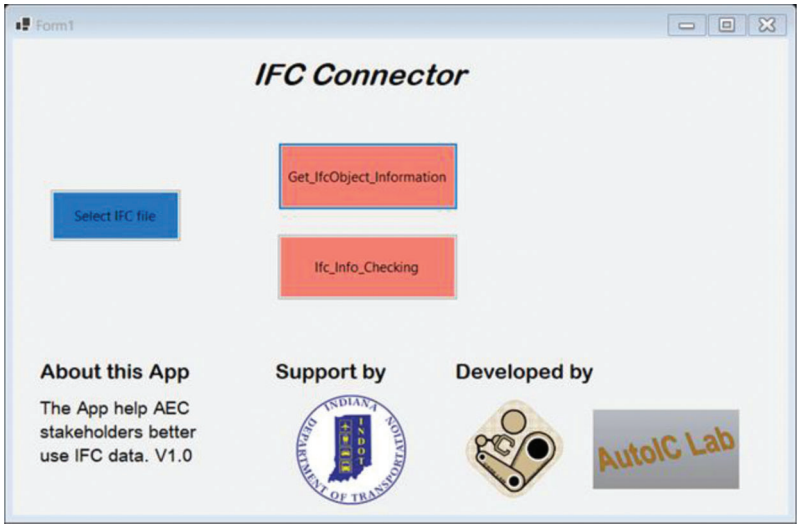


Figure 5.36 Interface of developed windows application.

Previous studies have shown that MVD is able to be applied in design, construction, and asset management phases. For design phase, MVD enhances structural analysis by clearly defining what type of information should be transferred between architectural models and structural models (Ren & Zhang, 2021). The main materials used in highway construction are steel, concrete, aggregate, and HMA. In addition, different types of information should be contained for different materials. For example, mass density, young's modules, shear modules, passion ratio should be contained for all steel, concrete and wood materials for design. Moreover, thermal expansion coefficient, ultimate stress, yield stress and comprehensive strength should be contained for steel and concrete materials. With the implementation of MVD, material information could be defined clearly. Also, the developed automatic information checking method help stakeholders check all required information quickly and accurately. For construction phase, clearly defined MVD helps

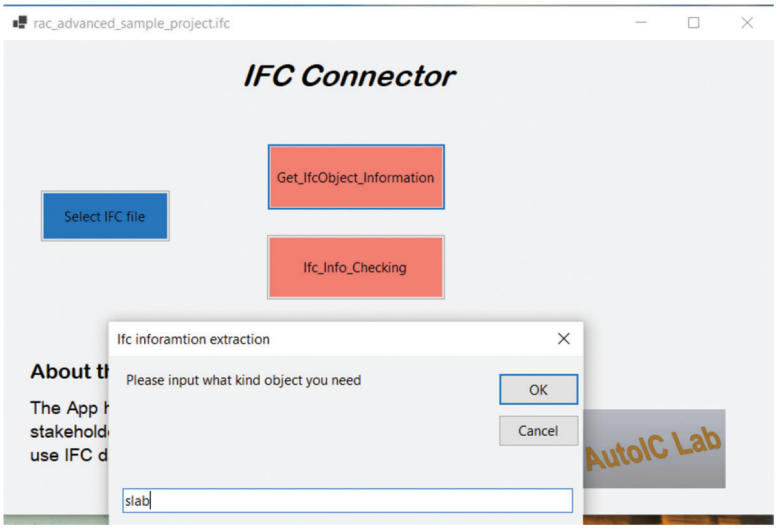


Figure 5.37 Specify which type of IfcObject to extract.

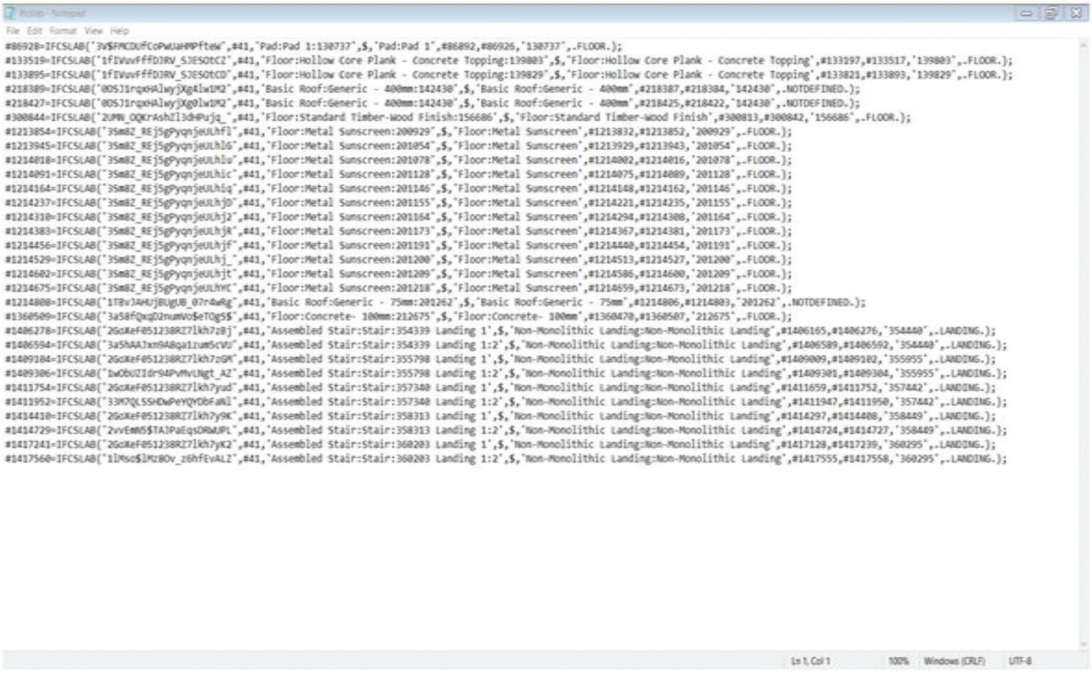


Figure 5.38 Example output of getting IfcObject information (graphical user interface could be added to visualize the corresponding objects).

contractors or inspectors extract required information from as-built model. For example, the as-built model could be collected from LiDAR scanning (Soilán et al., 2020). The MVD could help stakeholders extract required data from massive raw data quickly. For asset management phase, the MVD defines what types of information should be delivered to asset management team, which helps asset management team perform maintenance tasks in the future (Kim et al., 2018).

5.2.7 Current Data Conversion Method Proposed by HNTB

The research team had a discussion with HNTB on July 30th, 2021, about their methods to translate as-designed CAD files into GIS files. The HNTB displayed their work on converting CAD files of storm water assets into GIS files by Python programming language as shown in Figure 5.44. The converted

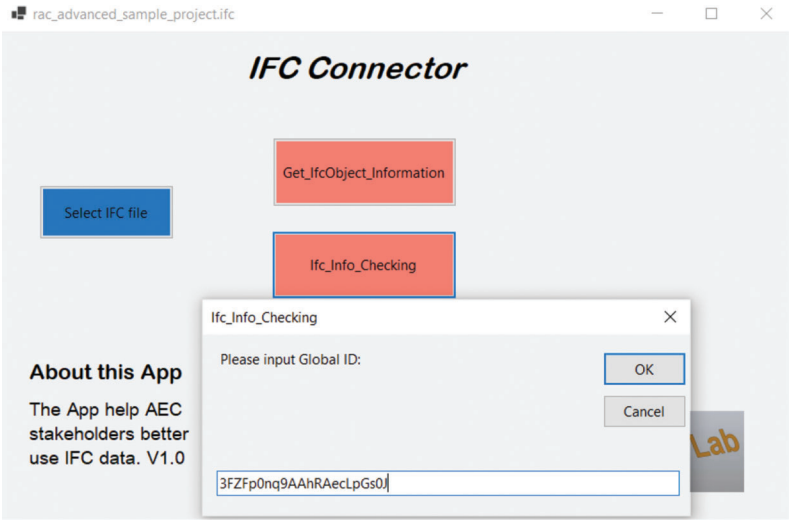


Figure 5.39 Specify Global ID of one IFC object.

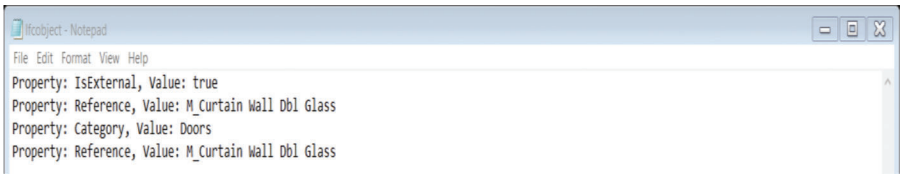


Figure 5.40 Example output of information checking.

results are shown in Figure 5.45. The steps HNTB mentioned are summarized as follows.

- Define data requirements for different classes.
  - Point feature classes.
    - Inlets.
    - Manholes.
  - Linear feature classes.
    - Small culverts.
    - Gravity sewers.
- Extract information from design files.
  - Report capability of InRoads SS2 was used to extract information into txt files.
- Transform information.
  - Point features.
    - Import txt files into Excel table.
    - The two columns containing X and Y geospatial coordinate were used to represent points in GIS space.
  - Line features.
    - Import txt files into Excel table.
    - Generate well-known text (WKT).
    - Import excel table into geopandas dataframe using Python.
    - Export information into shapefile.
- Load information into ArcGIS Pro.
- Quality control.
  - Visual review.
    - Review all geometry on the map and compare that to the construction detail sheets.
  - Data check.
    - Look at the attribute table and compare them with structured table to make sure every geometry loaded in GIS are shown in structured table.
- Submit as file geodatabase.
  - The files are submitted to INDOT as geodatabase which could be loaded into INDOT production system.

5.3 People (Current Relationship and Gaps)

5.3.1 Qualitative Exploration

The fourth and fifth top barriers are organization structure and lack of human resources (Cai et al., 2015). People dimension defines: (1) who will create, collect, store, share, and update the data in a format and approach required by O&M, and (2) project organization structure outlines the relationship and responsibilities among different project stakeholders. There are data blockage issues among consultants, contractors, and INDOT O&M office. With clear definition of project organization structure, INDOT can pass on the responsibilities to the stakeholders who are in the best position and at the right time to collect the data required by O&M, which can further relieve the lack of human resources issue.

Figure 5.41 Viewing IFC model in the GIS-based mobile app.

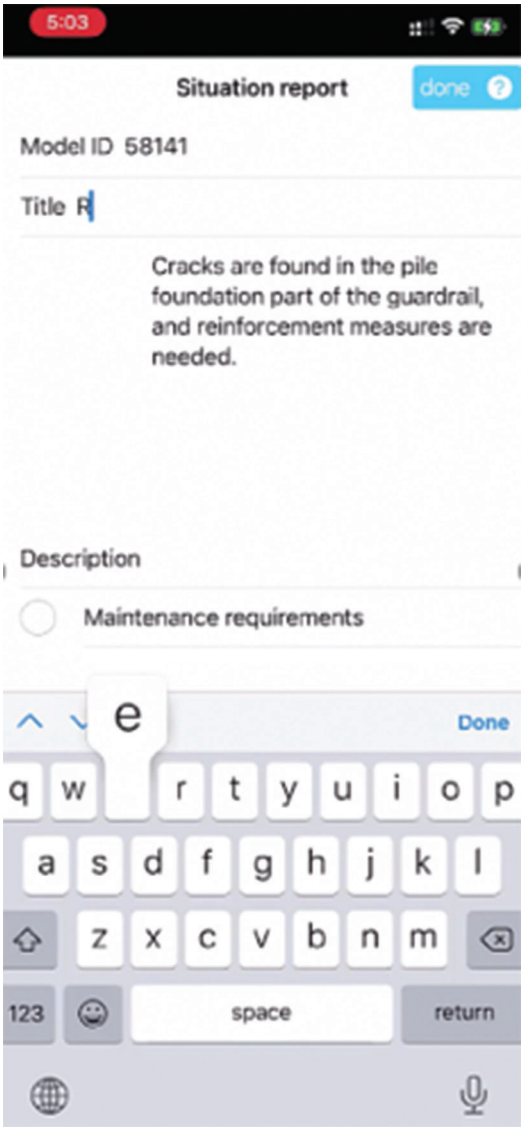


Figure 5.42 Add maintenance information to IFC model in the GIS-based mobile app.

In order to better understand the relationship of different stakeholders, meetings were held with INDOT O&M team. GIS managers need to (1) work with different business owners to discuss assets and their attributes, and then publish the map to GIS database, and (2) work with inspection engineers to update information in road inventory, national bridge inventory, and Indiana bridge inspection application system. A meeting was also held with INDOT design team on October 21st, 2019. The following is some key information extracted from the meeting with the design team.

- INDOT uses OpenRoads SS3 and SS4.
- INDOT has some old data in other formats.
- Bentley Map will allow to interact with GIS. It is similar to ArcGIS.
- INDOT may need to show the progress on the map so it is better to use Bentley Map.
- Project Interplot is used to plot PDF.
- Bentley InspectTech/AssetWise is an asset management inspection software.
- Bentley InspectTech/AssetWise can help get into the data and share the data back and forth.
- Inspection team will inspect the status of asset and give advice to asset management team.
- INDOT can share XML data.
- Asset management and scoping are using ArcMap.
- Land Surveying to locate existing conditions for design typically involves the use of robotic total stations and GPS rovers in field.
- AutoCAD file will be sent to contractor. Trimble Business Center is used for survey.

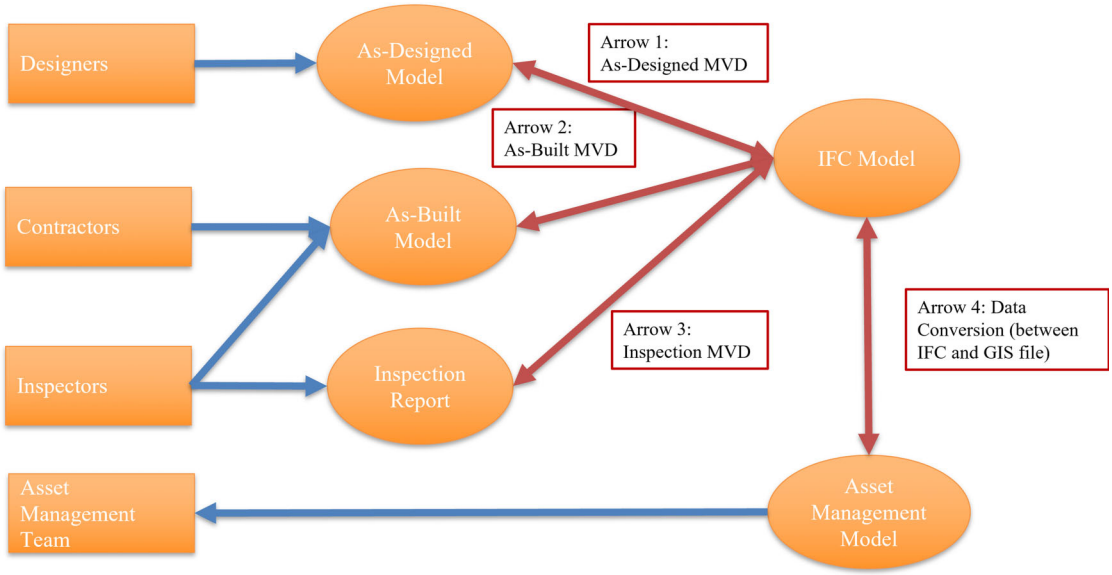


Figure 5.43 IFC central model.

```
in_file = "../../../data/raw/INDOT_IIM/Pipes H2S manual import.xlsx"
df = pd.read_excel(in_file, dtype={
    "ID": np.unicode_,
    "GeometryWKT": np.unicode_,
    "XBegin": np.float64,
    "YBegin": np.float64,
    "XEnd": np.float64,
    "YEnd": np.float64,
    "Span (in)": np.int32,
    "Height (in)": np.int32,
    "Pipe Shape": np.unicode_,
    "UpstreamInvert (ft)": np.float64,
    "DownstreamInvert (ft)": np.float64,
})
df.head()
```

[42]:

	ID	GeometryWKT	XBegin	YBegin	XEnd	YEnd	Span (in)	Height (in)
0	P-1100	LINESTRING (1300929.61 613043.06 590.70, 13008...	1.300930e+06	613043.0561	1.300855e+06	613112.4964	12	12
1	P-1101	LINESTRING (1301221.58 613353.30 590.80, 13011...	1.301222e+06	613353.2977	1.301143e+06	613426.3705	12	12
2	P-1103	LINESTRING (1301746.86 613924.88 593.94, 13017...	1.301747e+06	613924.8842	1.301779e+06	613960.0029	15	15
3	P-1104f	LINESTRING (1301813.27 613996.79 593.94, 13017...	1.301813e+06	613996.7877	1.301781e+06	613961.4721	15	15
4	P-1104	LINESTRING (1301777.42 613963.28 592.44, 13017...	1.301777e+06	613963.2819	1.301718e+06	614018.0795	18	18

```
df["GeometryWKT"] = df["GeometryWKT"].apply(shapely.wkt.loads)
gdf = gpd.GeoDataFrame(df, geometry="GeometryWKT")
gdf.head()
```

[43]:

	ID	GeometryWKT	XBegin	YBegin	XEnd	YEnd	Span (in)	Height (in)
0	P-1100	LINESTRING Z (1300929.610 613043.060 590.700, ...	1.300930e+06	613043.0561	1.300855e+06	613112.4964	12	12
1	P-1101	LINESTRING Z (1301221.580 613353.300 590.800, ...	1.301222e+06	613353.2977	1.301143e+06	613426.3705	12	12
2	P-1103	LINESTRING Z (1301746.860 613924.880 593.940, ...	1.301747e+06	613924.8842	1.301779e+06	613960.0029	15	15
3	P-1104f	LINESTRING Z (1301813.270 613996.790 593.940, ...	1.301813e+06	613996.7877	1.301781e+06	613961.4721	15	15
4	P-1104	LINESTRING Z (1301777.420 613963.280 592.440, ...	1.301777e+06	613963.2819	1.301718e+06	614018.0795	18	18

Figure 5.44 Convert CAD files into GIS files using Python.

5.3.2 Quantitative Evaluation

For the quantitative evaluation, the responses received were from field engineers and project supervisors at the construction office. Their experience ranged from 1 year to 24 years. The majority of projects they were involved in were adopting the delivery method of design bid build. Previously the research team asked the staff from INDOT construction office if they believe that contractors should provide digital as-builts, the staff of INDOT construction office said: "Currently, INDOT project engineers are responsible for creating most as-builts, except for traffic signals. It should be okay to move the responsibility from INDOT to contractors." The research team verified this with one contractor in the interview before. He did not like the idea of being responsible for as-builts because that could cause them a lot of extra work. So, in the survey, the research team asked INDOT staff: How do you feel about INDOT

Figure 5.45 Converted results opened in ArcGIS pro.

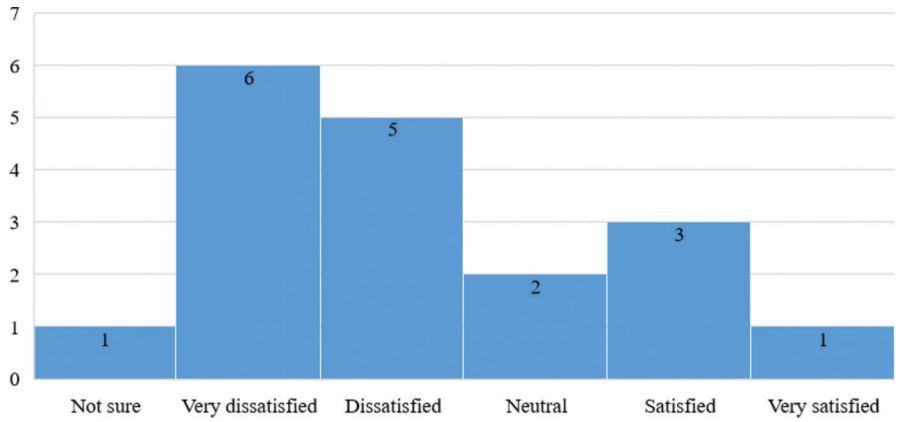


Figure 5.46 Satisfaction of INDOT (project engineers) for taking full responsibility for as-builts.

(project engineers) taking full responsibility for as-builts since the original drawings/plans are created by designers of record and the markups are added by contractors? Most of them seemed dissatisfied with that, as shown in Figure 5.45. However, when the research team asked: How do you feel about contractors being legally responsible for the as-builts provided to INDOT? Most of them seemed satisfied with that, as shown in Figure 5.46. More importantly, this study has summarized the communications and responsibilities among typical stakeholders, as shown in Figure 5.47 and Figure 5.48 (Guo et al., 2021).

5.4 Information (Current Information, Gaps, and Potential Solutions)

5.4.1 Qualitative Exploration

Information collection and sharing is another important barrier for the current workflow, which requires the support from all process, technology, and people aspects. Specifically, information collection and sharing require the responsible personnel to create, collect, store, share, and update the required data with the right process and with compatible software. For example, in the qualitative exploration the researchers found that a primary challenge was no data schema is currently provided to consultants and contractors. Therefore, the data delivered to owners does not completely match the owners' need, which later requires extra work to recollect data.

5.4.2 Quantitative Evaluation

In the quantitative evaluation, the researchers verified different databases used by INDOT to manage data. All relevant databases are listed in Table 5.2 (Guo et al., 2021), which explain their definitions and information input. For example, Event Editor is used by different disciplines to record information to the

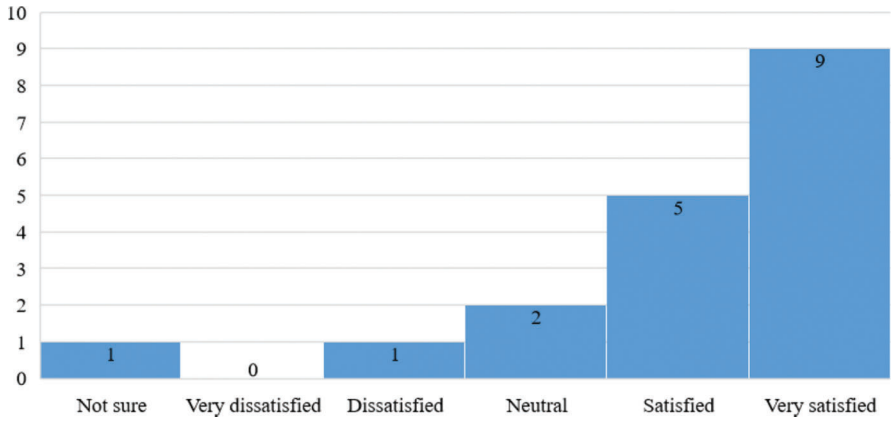
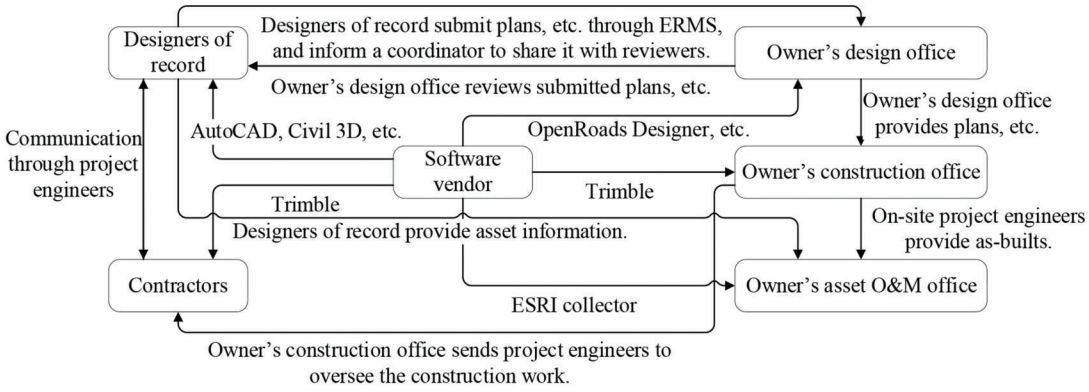


Figure 5.47 Satisfaction of contractors for taking full responsibility for as-builts.



Note: Figure from *Case Study of Building Information Modeling Implementation in Infrastructure Projects* (Guo et al., 2021).

Figure 5.48 Communications among typical stakeholders (Guo et al., 2021).

enterprise GeoDatabase. Then other systems, such as Indiana bridge inspection application system (BIAS), can access GeoDatabase to pull data from GeoDatabase to other data warehouse such as National Bridge Inventory, and Roadway Inventory. The GeoDatabase can also be accessed by viewers like Road Analyzer.

TABLE 5.2
Relevant databases, definition, and information input and update (Guo et al., 2021)

Information Applied	Databases	Definition	Responsible Parties
Digital drawings	MicroStation	Design drawings	Designer of record
Digital drawings	OpenRoads designer	Design drawings	Designer of record
Digital drawings	Civil 3D	Design drawings	Designer of record
Coordinates	Trimble surveying software	Survey the site	Contractor
Locations and details about assets and/or roadway characteristics	Event Editor	A web tool configured to edit specific enterprise GIS event layers on the Linear Referenced Network	Depends on the deployment of the editor which is configured to work with groups of event layers. Some disciplines using this tool are road inventory, pavement, bridge, traffic, and design
Bridge inspection data	InspectTech/ AssetWise	An application and database to store bridge and large culvert inspection data	Bridge inspector
The location of assets, in some cases asset characteristics, in some cases asset conditions	GeoDatabase	The institution's collection of authoritative spatial data and tools required to operate or analyze the data	It is distributed across the organization, which is subject to the asset's defined owner
Bridge and tunnel information	National bridge inventory	Store information of all bridges and tunnels in the United States that have roads passing above or below	Inspection engineer
Linear referenced event data	Road analyzer	A visualization tool that presents linear referenced event data as a straight-line diagram	Statewide geospatial manager: access to the application is available to the entire organization
Functional classification of roads, total mileage, the assets, etc.	Road inventory	Store road information	Inspection engineer

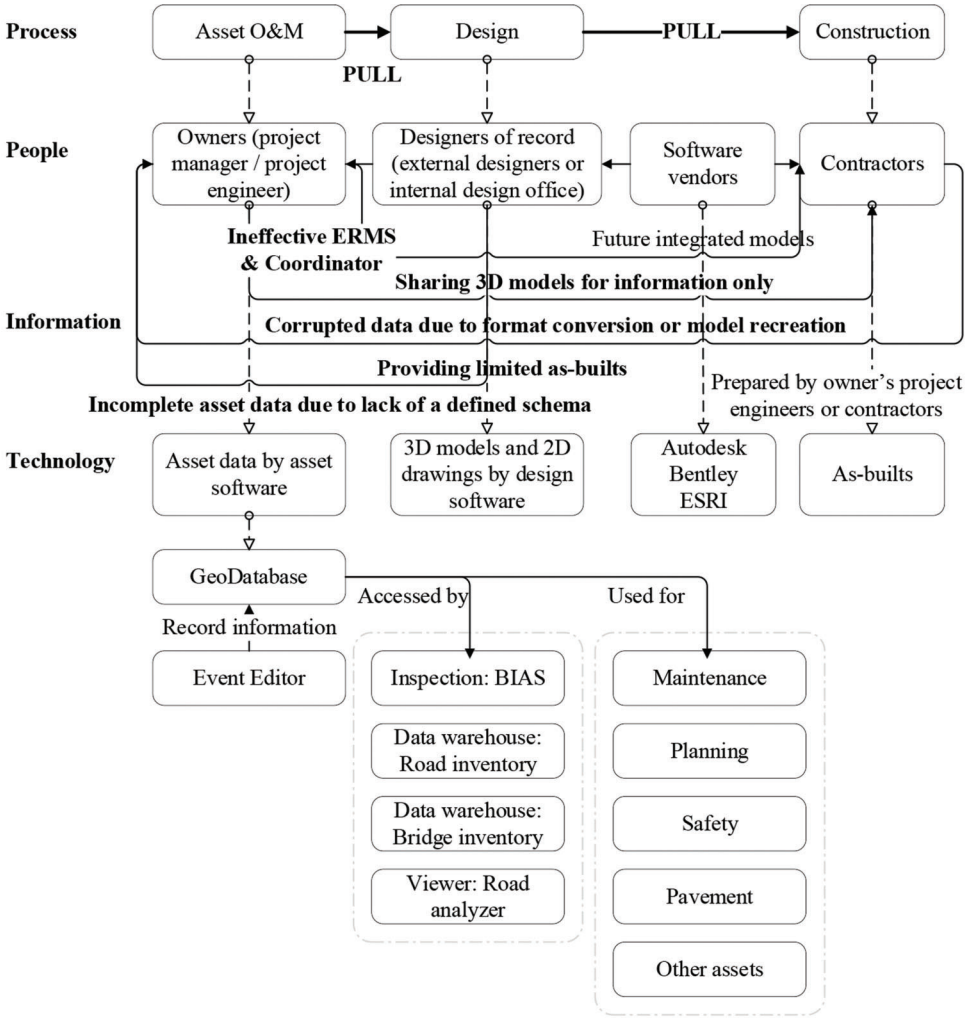
Note: Table adapted from *Case Study of Building Information Modeling Implementation in Infrastructure Projects* (Guo et al., 2021).

6. SUMMARY AND RECOMMENDATIONS

6.1 Summary and Findings

Previous research lacks comprehensive and systematic exploration of BIM implementation in infrastructure projects. Therefore, this study conducted a case study through the interviews and surveys with key stakeholders to explore the main challenges and potential solutions of BIM implementation. Interviews were conducted with 37 professionals and surveys were conducted with 102 professionals from stakeholders of the owner, designers, contractors, and software vendors. Four main factors and challenges along with potential solutions were identified from content analysis of interviews, including process factor (when), technology factor (how), people factor (who), and information factor (what). Here is a summary of gaps, as shown in Figure 6.1 (Guo et al., 2021). Overall, the current barrier is the lack of a clear workflow, which outlines *when, how*, and *what* information should be created, collected, stored, shared, and updated by *whom*.

- For the process factor, the current workflow starts with the design phase, followed by the construction phase, and ends at the asset O&M phase. The data of the upstream phases (such as design and construction phases) is pushed over to the downstream without considering the information need of downstream phases (such as O&M phase). The data need in the asset O&M phase is neither defined nor collected in the construction and design phases. This causes problems such as missed data, inaccurate data, and hard to find data during the asset O&M phase. The proposed workflow reverses the traditional workflow by first defining the data need from the asset O&M phase, and then converting the need for data requirement of the design and construction process.
- For the technology factor, currently consultants and contractors can use any software that they want, which later creates an isolation of data transmission due to the different file formats. In addition, data usually becomes BuildingElementProxy when exported to IFC, because schemas and properties are not all fully defined. Moreover, contractors always need to double check and export data into a format (such as XML) that they need due to the lack of a compatible data format. Last, consultants and contractors need to keep up with the new technology, because outdated version of software may start to have bugs in it.
- For the people factor, it needs to be clearly defined who takes the responsibility for creating, collecting, storing, sharing, and updating the data with the correct information format (e.g., IFC based data transmission) through compatible technology. For example, currently, some consultants are not willing to share digital files with contractors, even if contractors are willing to sign the waiver (i.e., a disclaimer that allows the party who shares not to be liable for the shared documents). Also, consultants are expected to share the 3D files with owners for a better bidding process. However, consultants currently do not share the 3D files for the



Note: Figure from *Case Study of Building Information Modeling Implementation in Infrastructure Projects* (Guo et al., 2021).

Figure 6.1 Current workflow and technology with identified gaps (Guo et al., 2021).

bidding process. In addition, inspection engineers need to go in and manually identify and adjust inconsistent information in different databases, which consumes time and is error prone. Also, contractors can refuse to sign electronically when it is not required in the contract.

- Successful information management requires support from all the other factors of process, technology, and people. Since data schema is not clearly defined by owners, data provided by consultants and contractors does not completely meet the need of owners, not to mention the missing or uncollected as-built attributes of assets. In addition, only as-builts in PDF or hard copy from contractors are provided to owners, while owners expect the digital file. Consultants and contractors currently can use any software that they want, which negatively affects the information flow because of data loss during data conversion. Also, consultants need to share the 3D files with owners not only for construction but also for bidding purpose, because it would help contractors dramatically if 3D files were available in the biding process. However, consultants currently do not share the 3D files with owners for the bidding process. In addition, civil engineers send contractors the file in a format that is not usable, which causes extra work and errors because contractors always need to double check and export it into the format (XML) that they need. In addition, contractors do not get as-built from the consultants or INDOT of the locations of the existing underground utilities, which creates extra work and difficulties to locate the utilities.

6.2 Recommendations and Implementation

Four factors of BIM implementation were identified, including (1) incompatibility of project technologies and interfaces (technology factor), (2) the imperfect information collection and sharing (information factor), (3) unclear definition of requirement and responsibility of project stakeholders (people factor), and (4) isolation of project phases (process factor). Figure 6.2 shows the overall pull-based life cycle integration of BIM in infrastructure projects from **t**echnology, **i**nformation, **p**eople, and **p**rocess (TIPP) factors.

The four factors were mutually interdependent since focusing on a limited subset of individual factors can

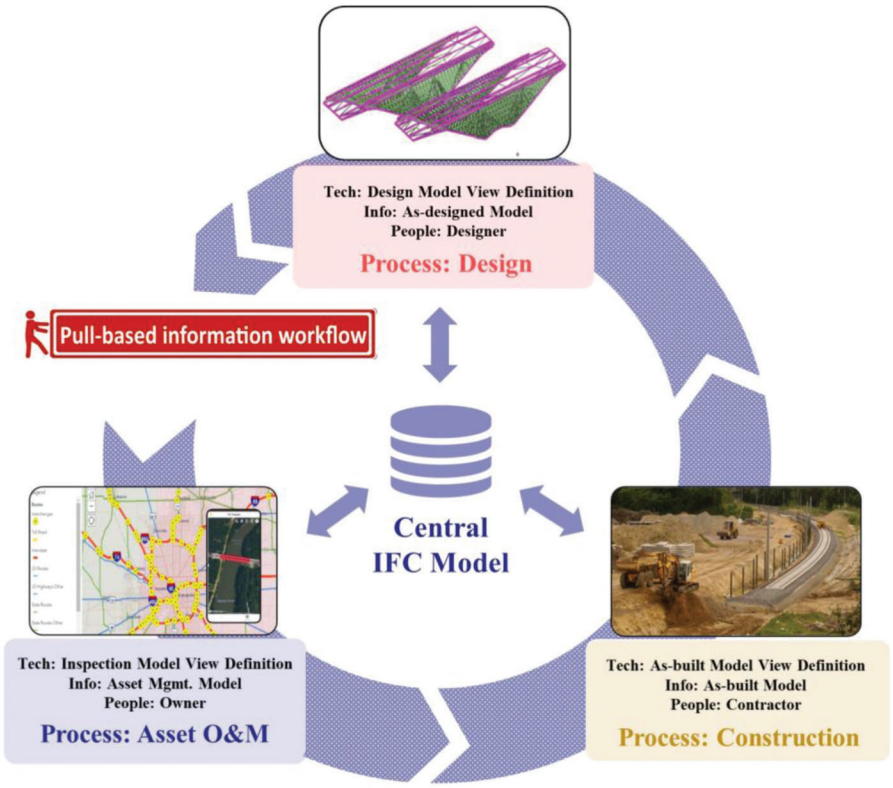


Figure 6.2 Life cycle integration of BIM in infrastructure projects.

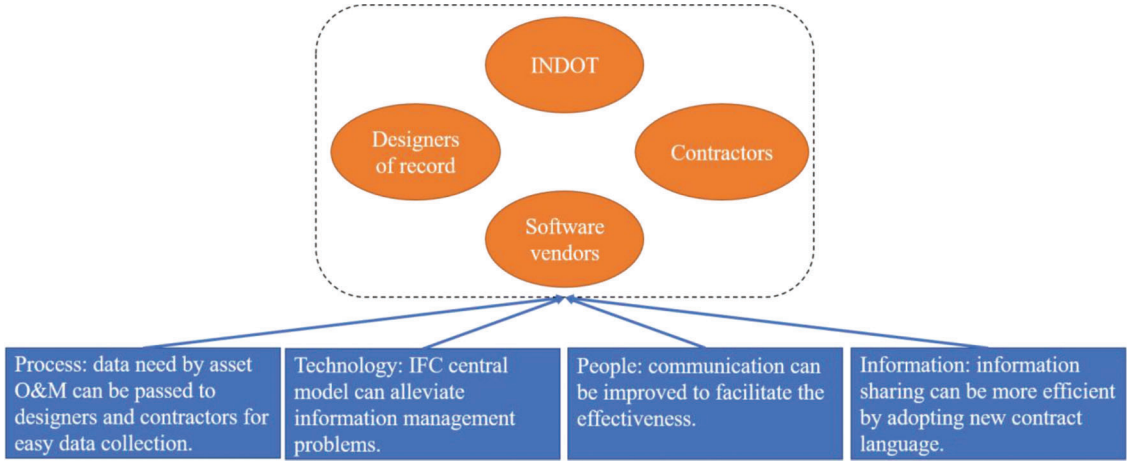


Figure 6.3 Sample of implementation potentials.

compromise the successful implementation of BIM. However, they all pointed to the use of the ISO BIM standard-industry foundation classes (IFC), as the most promising technical solution. The following recommendations and potential implementations are provided for further implementation of the research findings.

- INDOT and other state DOTs can use the framework of the TIPP factors to better understand, plan, evaluate, and improve BIM implementation in their infrastructure projects and organizations, as shown in Figure 6.1.
- In terms of process, INDOT and other state DOTs can use pull-based workflow instead of push-based workflow to require upstream phases to provide information based on the actual information needs of downstream phases. For example, as shown in Figure 6.3, the asset O&M team can provide a list of required information and formats to designers and contractors, so that the information need can be easily satisfied during the design and construction phases, which avoids data recollection after a project is complete.

- In terms of technology, INDOT and other state DOTs can use the proposed IFC-central model (see Figure 6.4) to alleviate information management problems among different stakeholders in infrastructure projects. For example, the developed window-based IFC connector application can quickly extract information from IFC files to serve various information retrieval needs in design, construction, and asset management phases (see details in Sections 5.2.5). The developed mobile application can be used to collect bridge maintenance data to be stored into the central IFC model directly from the inspection site (see details in Sections 5.2.5). In addition, simple Python scripts could be used to convert extracted data from the central IFC model into GIS files for asset management use (see details in Sections 5.2.4 and 5.2.7). As Figure 6.4 shows, what we have implemented in this project are only part of the high-level central IFC model vision (Figure 5.43) and completing this vision will require further research and development, but these readily developed technology in this project can already be immediately implemented in INDOT workflow to start saving time and cost in information management.
- In terms of people, INDOT and other state DOTs can better outline the relationship and responsibilities among the key project stakeholders in what information to collect and create with what IFC-compliant format and approach required by asset management of state DOTs. In addition, the communication channel can be improved. For example, designers can communicate with reviewers directly to solve potential design problems instead of communicating through a coordinator, as shown in Figure 6.3.
- In terms of information, INDOT and other state DOTs can better understand and define the deliverables, formats, timing, and responsible parties of different types of information at different stages of a project. For example, by using modified and improved contract language, different stakeholders can be clear about other stakeholder's need.

6.3 Expected Benefits and Cost Savings

With the research findings summarized above, the following benefits and cost savings can be achieved.

- Since INDOT and other state DOTs can use pull-based workflow instead of push-based workflow to require upstream phases to provide information based on the actual information needs of downstream phases, data flow can be streamlined and the asset O&M team will not need to recollect the data, which significantly saves time and money.
- The proposed IFC-central model can reduce information management issues among different stakeholders in infrastructure projects by efficiently and accurately extracting information from IFC files and collecting maintenance data. There can be much less need of manual efforts to retrieve useful data, which in turn could lead to time and cost savings.
- With a better outlined business relationship and responsibilities among the key project stakeholders, it will be clear what information to collect and create with a format and approach required by asset management need of state DOTs. Using this approach, data collected can be readily useful, which prevents the manual effort in data conversion and potential data loss during the conversion.
- With better defined deliverables, formats, timing, and responsible parties of different types of information at different stages of a project, different stakeholders can

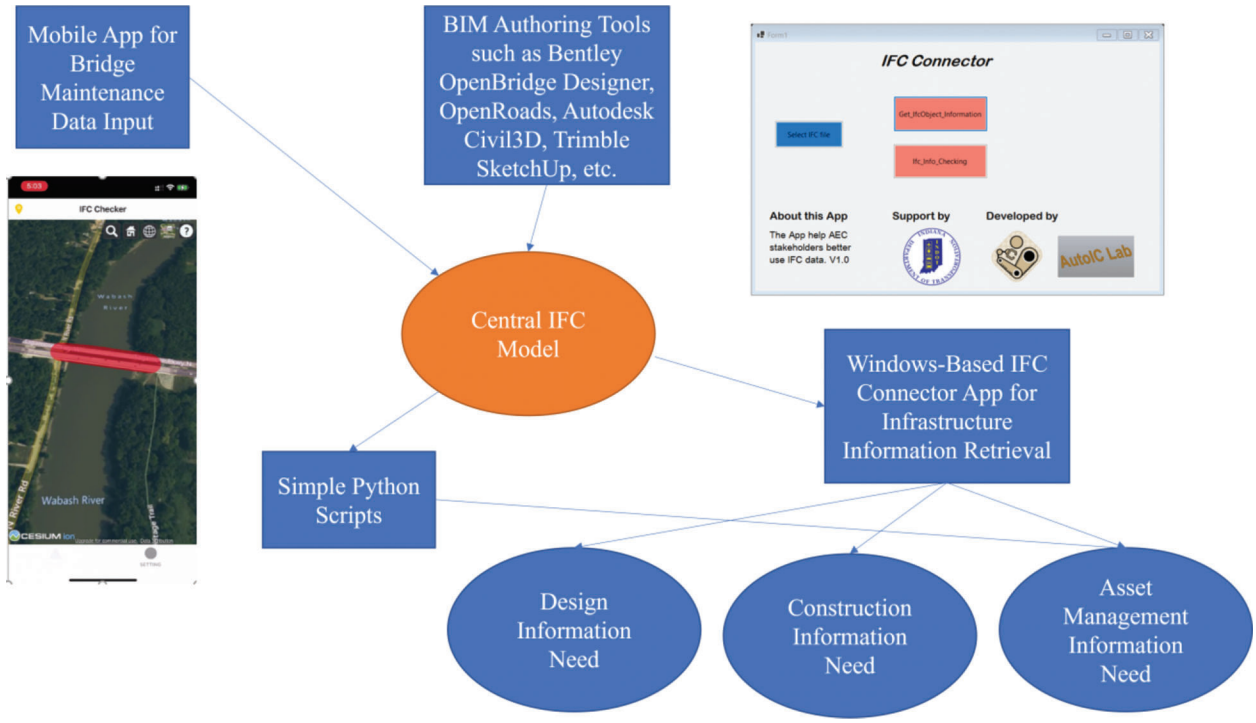


Figure 6.4 Example IFC-based technology implementation.

more easily fulfill their job, which avoids rework and further reduce the financial burden.

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APPENDICES

Appendix A. Asset Attributes Comparison

Appendix B. Qualitative Interview for Designers of Record

Appendix C. Qualitative Interview for Contractors

Appendix D. Qualitative Interview for Software Vendor

Appendix E. Qualitative Interview for INDOT

Appendix F. Quantitative Survey for Designers of Record

Appendix G. Quantitative Survey for Contractors

Appendix H. Quantitative Survey for Software Vendors

Appendix I. Quantitative Survey for INDOT Design Office

Appendix J. Quantitative Survey for INDOT Construction Office

Appendix K. Quantitative Survey for INDOT Asset Management Office

Appendix L. Contract Terms

APPENDIX A. ASSET ATTRIBUTES COMPARISON

		Geometry Type			Attributes			
Asset	**Sub Asset**	**INDOT**	**UDOT**	**Attribute Item**	**INDOT Focused Asset List**	**INDOT High Level Asset Needs List**	**Collected INDOT Models**	**UDOT**
Karst		Point		Last Edit Operation	✓	✓		
				Vendor Status	✓			
				INDOT Status	✓			
				Opening Type	✓			
				Intervention	✓			
				Asset Name	✓			
				Retired Date	✓			
Mechanical_BMP		Point		Last Edit Operation	✓	✓	✓	✓
				Vendor Status	✓			
				INDOT Status	✓			
				Install Date	✓			
				Retired Date	✓			
				Asset Name	✓			
				DES	✓			
				BMP Type	✓			
				Separator Max Capacity	✓			
				Has Bypass	✓			
				Make	✓			
				Model	✓			
				Manufacturer	✓			
Structural	Structural	Polygon		Last Edit Operation	✓	✓		
				Vendor Status	✓			
				INDOT Status	✓			

			Install Date	✓	
			Retired Date	✓	
			Asset Name	✓	
			Structural_BMP_Type	✓	
			Catchment Capacity (Acre-ft)	✓	
			Storage Capacity (Acre-ft)	✓	
	Structural_BMP_overflow	Point	Last Edit Operation	✓	
			Vendor Status	✓	
			INDOT Status	✓	
			Install Date	✓	
			Retired Date	✓	
			Asset Name	✓	
			Overflow Type	✓	
			Outlet Dimension	✓	
	Structures (Foundations Walls, Girders, Decks, etc.)	3D Geometry	Elevation		✓
			Material Properties		✓
			Location		✓
			Thickness		✓
			Length		✓
			Width		✓
			Depth		✓
			Type		✓
Drainage	Catch Basins, Diversion Boxes, and Manholes	3D Geometry	Element ID		✓
			Pay Item Name		✓
			Pay Item Number		✓
			Unit of Payment Measurement		✓
			Pipe Attributes (Shape, Size, Length, Material, Slope, Flow Rate, Velocity)		✓
			Drainage Structures Attributes (Grate/Cover Type and Elevation, Calculated Spread)		✓

Filtration Berm	PolyLine	Last Edit Operation	✓	✓	✓
		Vendor Status	✓		
		INDOT Status	✓		
		Install Date	✓		
		Retired Date	✓		
		Asset Name	✓		
		Berm Type	✓		
		Placement	✓		
Dewatering Pump	Point	Last Edit Operation	✓		
		Vendor Status	✓		
		INDOT Status	✓		
		Install_Date	✓		
		Retired Date	✓		
		Asset Name	✓		
		Capacity (GPM)	✓		
		Remote Data Access Y/N	✓		
		Make	✓		
		Model_Number	✓		
		Manufacturer	✓		
Inlet	Point	Last Edit Operation	✓		
		Vendor Status	✓		
		INDOT Status	✓		
		Install_Date	✓		
		Retired Date	✓		
		Asset Name	✓		
		Inlet Type	✓		
		Access Opening (in)	✓		
		Rim Elevation (Decimal ft)	✓		

		Low Pipe Invert Elev. (Decimal ft)	✓
		Access Material	✓
		Access Type	✓
		Owned By	✓
		Inlet Comment	✓
Open Drain (Ditch)	Polyline	Last Edit Operation	✓
		Vendor Status	✓
		INDOT Status	✓
		Constructed Date	✓
		Retired Date	✓
		Conveyance Type	✓
		Top Width (ft)	✓
		Bottom Width (ft)	✓
		Depth (ft)	✓
		Bed Material	✓
		Side Material	✓
		Fore Slope ratio	✓
		Back Slope ratio	✓
		Flow Direction	✓
		Owned By	✓
		Open Drain Comment	✓
Manhole	Point	Last Edit Operation	✓
		Vendor Status	✓
		INDOT Status	✓
		Install Date	✓
		Retired Date	✓
		Asset Name	✓
		Rim Elevation (Decimal ft)	✓

		High Pipe Invert Elev. (Decimal ft)	✓
		Low Pipe Invert Elev. (Decimal ft)	✓
		Manhole Depth (Decimal ft)	✓
		Cover Type	✓
		Wall Material	✓
		Manhole Type	✓
		BMP Insert Type	✓
		Pavement Cut Depth (in)	✓
		Lined	✓
		Owned By	✓
		Manhole Comment	✓
Gravity Sewer	Polyline	Last Edit Operation	✓
		Vendor Status	✓
		INDOT Status	✓
		Install Date	✓
		Retired Date	✓
		Asset Name	✓
		Sewer Type	✓
		Material	✓
		Span (Width)	✓
		Height	✓
		Pipe Shape	✓
		Flow Direction	✓
		Lined Year	✓
		Liner Type	✓
		In (from) Invert Elev. (from Survey)	✓
		Out (to) Invert Elev. (from Survey)	✓

		In (from) Depth	✓
		Out (to) Depth	✓
		Outlet Has RIP RAP	✓
		Owned By	✓
		Comment	✓
Force Main	Polyline	Last Edit Operation	✓
		Vendor Status	✓
		INDOT Status	✓
		Install Date	✓
		Retired Date	✓
		Asset Name	✓
		Material	✓
		Diameter	✓
		Height (If Not Circular)	✓
		Flow Direction	✓
		In (from) Invert Elev. (from Survey)	✓
		Outlet Ends At	✓
		Out (to) Invert Elev. (from Survey)	✓
		Owned By	✓
		Comments	✓
Lift Station	Point	Last Edit Operation	✓
		Vendor Status	✓
		INDOT Status	✓
		Install Date	✓
		Lift Station Retired Date	✓
		Asset Name	✓
		Has Wetwell	✓
		Control Gate	✓

		Total Rate of Flow (GPM)	✓
		Energy Source	✓
		Data Logger	✓
		Install Date	✓
		Owned By	✓
		Comments	✓
Emergency Lift Sites	Point	Last Edit Operation	✓
		Vendor Status	✓
		INDOT Status	✓
		Install Date	✓
		Retired Date	✓
		Site Operation Notes	✓
Culvert	Polyline	Last Edit Operation	✓
		Vendor Status	✓
		INDOT Status	✓
		Installed Date	✓
		Retired Date	✓
		Asset Name	✓
		Flow Direction	✓
		Upstream Material	✓
		Upstream Coating	✓
		Upstream Interior Texture	✓
		Upstream Span (Inside)	✓
		Upstream Height (Inside)	✓
		Upstream Shape	✓
		Upstream End Material	✓
		Upstream End Type	✓
		Upstream Cover Depth	✓

			Upstream Has RipRap	✓
			Downstream Material	✓
			Downstream Coating	✓
			Downstream Interior Texture	✓
			Downstream Span (Inside)	✓
			Downstream Height (Inside)	✓
			Downstream Shape	✓
			Downstream End material	✓
			Downstream End Type	✓
			Downstream Cover Depth	✓
			Downstream Has RipRap	✓
			Lined Year	✓
			Is Multi-Barrel	✓
			Length at Construction	✓
			On Skew	✓
			Owned By	✓
			Location Description	✓
			Culvert Comment	✓
	Outfall	Point	Last Edit Operation	✓
			Vendor Status	✓
			INDOT Status	✓
			Identified Date	✓
			Retired Date	✓
			Type	✓
			Outfall Source	✓
Trail Head Approach		Point	Last Edit Operation	✓
			Vendor Status	✓
			INDOT Status	✓
			Comments	✓

Noise Barrier	Noise Barrier Wall	Polyline	Last Edit Operation	✓	✓	
			Vendor Status	✓		
			INDOT Status	✓		
			Install Date	✓		
			Retired Date	✓		
			Asset Name	✓		
			Manufacturer	✓		
			Comments	✓		
	Noise Barrier Wall Door	Point	Last Edit Operation	✓		
			Vendor Status	✓		
			INDOT Status	✓		
			Install Date	✓		
			Retired Date	✓		
			Asset Name	✓		
			Door Text	✓		
			Door Lock status	✓		
			Door is Operational	✓		
Cultural Site	Grave	Point		✓	✓	
	Cemetery	Polygon		✓		
Monitoring Well (Environmental)		Point	Permit No	✓		
			Visual Type	✓		
			Depth (ft)	✓		
			Status	✓		
			Status Date	✓		
			Owner	✓		
Fence in ROW with Sign		Polygon		✓		✓
Special Marking		Point	Last Edit Operation	✓	✓	
			Vendor Status	✓		
			INDOT Status	✓		

			Aligned With	✓	
			RoadName On	✓	
			RoadName Intersecting	✓	
			Direction	✓	
			Install Refurbish Date	✓	
			Marking Type	✓	
			Legend Text	✓	
			Marking Color	✓	
			Last Condition	✓	
			Last Condition Date	✓	
			Retired Date	✓	
Guardrail and Attenuator	Polyline		Last Edit Operation	✓	✓
			Vendor Status	✓	
			INDOT Status	✓	
			Install Refurbish Date	✓	
			Retired Date	✓	
			Guardrail Type	✓	
			Leading Attenuator Type	✓	
			Trailing Attenuator Type	✓	
			Direction Served	✓	
Signs	Point	3D Geometry	Last Edit Operation	✓	✓
			Vendor Status	✓	
			INDOT Status	✓	
			Install Refurbish Date	✓	
			Retired Date	✓	
			Asset Name	✓	
			Sign Services Direction	✓	
			Sign Position	✓	
			Number of Signs	✓	

		Sign Type	✓		
		Sign Code	✓		
		Sign Text	✓		
		Sign Height (in)	✓		
		Sign Width (in)	✓		
		Install Type	✓		
		Install Year	✓		
		Comment	✓		
		Multi Part	✓		
		Base Pay Item Name and Number			✓
		Post Pay Item Name and Number			✓
		Sign Pay Item Name and Number			✓
		Sign ID			✓
		Sign Description			✓
		Sign Color			✓
		MUTCD Code			✓
Roadway	3D Breakline with Exterior Boundary Elements	Pay Item Name			✓
		Pay Item Number			✓
Pavement Marking	Line and Shape	Pay Item Name		✓	✓
		Pay Item Number			✓
		Material (Tape or Paint)			✓
		Type (Solid, Skip, Dotted)			✓
		Width			✓
		Color			✓
		Taper Rate, Where Applicable			✓
Utilities (Junction Boxes, Cabinets, Pedestals, Existing Power	3D Geometry	Assumptions Used for the Utility	✓		✓
		Utility Type			✓
		Utility Owner			✓
		Shape			✓

Poles and Power Lines)			Size				✓
			Material				✓
			Pay Item Name				✓
			Pay Item Number				✓
Signals and Lighting	Point	3D Geometry	Poles (All)	✓			✓
			Foundations				✓
			Mast Arms				✓
			Function Boxes				✓
			Cabinets				✓
ATMs (Foundations, Junction Boxes, and Cabinets)		3D Geometry	Pay Item Name				✓
			Pay Item Number				✓
ADA	Point		Type	✓			
Bridge Deck	Line			✓		✓	
Retain Wall	Point		Type		✓		
			Dimension Characteristics				

APPENDIX B. QUALITATIVE INTERVIEW FOR DESIGNERS OF RECORD

Part 1. Descriptive Information of Participants and Projects

1. Please specify your current position/role: _____

2. Please indicate how long you have worked in this position: ___ Year ___ Month

3. Please indicate the range of contract value in dollars for the majority of projects that you have been involved in: _____

4. What are the typical delivery methods of the projects you have been involved in and could you please outline the contract relationship of key stakeholders under each delivery method?

_____
_____
_____

Part 2. Design: Business Process Related Questions

5. What is the general process to complete design for INDOT, such as do you follow the Indiana Design Manual?

_____
_____
_____

6. What are the typical stakeholders in INDOT projects? We assume there will be owner (INDOT), designers of record, contractors, and subcontractors. Are there anyone else that we miss? We can discuss it based on the type of project and phase of the project.

_____
_____
_____

7. What key staff or offices in INDOT do you need to communicate with to complete design? And what are the specific responsibilities or roles of the key staff or offices in INDOT?

_____
_____
_____

8. What type of responsibilities do designers of record have for INDOT projects?

_____
_____
_____

9. When are the key staff or offices in INDOT getting involved in the project?

10. Questions about the work between designers of record and contractors
    a. What information (e.g., drawings, etc.) do you usually **deliver to contractors**? And what is the typical format?

    b. What information/documents cannot designers of record provide when contractors need, and what is the challenge?

    c. Are designers of record responsible for the information/documents they provided to contractors?

11. Questions about the work between designers of record and INDOT
    a. What information/documents does INDOT usually require from designers of record? And what is the typical format?

    b. What information/documents cannot designers of record provide when INDOT needs, and what is the challenge?

    c. What are the mistakes that usually happen during the design phase on the designer's side?

    d. What types of change are usually requested by INDOT during design?

e. What problems do you usually encounter with INDOT?

f. What information (e.g., drawings, etc.) do you usually obtain from INDOT?

g. What are the typical formats of information/documents designers of record obtain from INDOT?

h. How do you prefer to obtain information from INDOT?

i. Is INDOT responsible for the information/documents they provided to designers of record?

j. What information is usually missing when you obtain information from INDOT?

k. What information do you usually need from INDOT, but they cannot provide?

l. What information do you need to create when you cannot obtain from INDOT?

m. What are the challenges if INDOT cannot provide the needed information?

n. What information (e.g., drawings, etc.) do you usually deliver to INDOT?

o. How do you prefer to deliver information to INDOT?

p. Are designers of record responsible for the information/documents they delivered to INDOT?

q. Will you be okay if a data schema is provided for you to fill in asset and attributes data?

r. What risks would designers of record be concerned with if they were liable for the digital as-builts?

s. Do you have any issues when using INDOT's Collector to supplement INDOT GIS asset inventories. For example, consultants are using collector to capture new assets placed in the field and to recommend the retirement of assets (in INDOT asset inventory) as they are removed from service.

t. Would designers of record be willing to accept the following language if added to the contract between INDOT and designers of record for requiring designers of record to provide and be responsible for digital as-builts of assets? Because designers of record

are using collector to capture new assets placed in the field and to recommend the retirement of assets (in INDOT asset inventory) as they are removed from service.

Legal Document: Digital files of as-builts that are required to be delivered to INDOT. Designers of record shall take responsibilities for any mistakes identified in the documents provided. Legal Document and required format(s) to be delivered are as follows: (File types to be filled by INDOT).

Designers of record shall provide and be responsible for digital as built files which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT to fill in required info and formats

12. Models related questions

a. Would designers of record be willing to provide digital models if digital files of models are requested in the contract without disclaimer, which means designers of record are liable for the documents provided?

b. What compensation do you need to have if designers of record are liable for the digital models provided?

c. Would designers of record be willing to accept the following language if added to the contract between INDOT and designers of record for requiring designers of record to provide and be responsible for digital models?
Legal Document: Digital models that are required to be delivered to INDOT. Designers of record shall take responsibilities for any mistakes identified in the documents provided. Legal Document and required format(s) to be delivered are as follows: (File types to be filled by INDOT).

Designers of record shall provide and be responsible for digital models which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT to fill in required info and formats

d. Would designers of record be okay if digital files of as-builts are requested in the contract with disclaimer, which means designers of record are NOT liable for the documents provided?

e. Would designers of record be okay if the following is added to the contract between INDOT and designers of record for requiring designers of record to share digital files with INDOT and not to be liable for the digital files shared?
   - *For Information Only: Additional helpful files, some are required, and some are not required, to be delivered to INDOT from designers of record . For Information Only files and required format(s) to be delivered are as follows: (File types to be filled by INDOT).*
   - *3D model digital design files meeting (INDOT standards to be determined) will be delivered to INDOT from designers of record.*

f. Would designers of record be okay if the following is added to the contract between INDOT and designers of record for requiring designers of record to share digital files with INDOT during the bidding process?
   For Information Only: Additional helpful files, some are required and some are not required, to be delivered to INDOT from designers of record. For Information Only files and required format(s) to be delivered are as follows: (File types to be filled by INDOT).

g. Would you be okay to share 3D design files such as XML with INDOT/contractors with disclaimer/without disclaimer?

13. Will contractors be okay if the following is added to the contract between INDOT and designers of record for requiring designers of record to sign electronically?
    Electronically signing and submitting this contract is the legal equivalent of having placed my handwritten signature on the submitted contract and this affirmation.

Part 3. Design: Technology Related Questions

14. Does INDOT require you to use any software for design?

_____
_____
_____

15. What software do you use to deliver 3D models?

_____
_____
_____

16. What software do you use to deliver geographic data?

_____
_____
_____

17. Will designers of record be okay if the following is added to the contract between INDOT and designers of record for requiring designers of record to use one of the software vendors specified by INDOT?
"One of the following software (software decided by INDOT) should be used for design and completion of the final digital models."

_____
_____
_____

18. Would designers of record be okay if the following is added to the contract with designers of record for requiring designers of record to use the specific version of software specified by INDOT?
"(Software version decided by INDOT) should be used for design."

_____
_____
_____

19. Current practices and issues of data interoperability
    a. What is the data extension of design files during the design phase? (Please select all that apply.)
        A. DGN
        B. ALG
        C. DTM
        D. FGB
        E. SDB
        F. ITL
        G. SHP
        H. IPS

I. XML
J. PDF
K. DWG
L. DXF
M. CityGML
N. KML
O. Others (please specify) _____

b. What software do you use for transportation design? (Please select all that apply.)
A. MicroStation
B. OpenRoad Designer
C. InRoads SS2
D. InRoads SS3
E. InRoads SS4
F. OpenCities
G. ProjectWise Interplot
H. AutoCAD
I. Civil3D
J. Others (please specify) _____

c. What geospatial referencing system is used in design? (Please select all that apply.)
A. Local coordinate system
B. Latitude and longitude
C. Project station and offset
D. State plane coordinate system
E. Indiana Geospatial Coordinate System (InGCS)
F. Others (please specify) _____

d. Do you need to convert 3D models and geographic data between different formats 1) within designers of record, 2) between designers of record and INDOT offices, and 3) between designers of record and contractors?

_____
_____
_____

e. How often do you need the conversion you mentioned above?

_____
_____
_____

f. How do you perform the conversion you mentioned above?

_____
_____
_____

g. Are you satisfied with the method(s) you mentioned above with respect to **quality** of conversion? (1: Strongly unsatisfied 2: unsatisfied 3: Neither satisfied nor unsatisfied 4: satisfied 5: Strongly satisfied)

h. Does (do) the method(s) you mentioned above have missing data or data inconsistency issues? Please give examples.

20. INDOT CAD software workspace

a. Do you use CAD software workspace provided by INDOT in design phase? (INDOT CAD standard https://www.in.gov/indot/design_manual/files/INDOT_CAD_Standards.pdf, https://www.in.gov/indot/div/cad/v8i_downloads.htm)

b. Which software do you use to implement INDOT CAD workplace?

c. Do you think CAD software workspace provided by INDOT should have more standards?

d. Do you think CAD software workspace provided by INDOT should have less standards?

21. Opinions on developing new data interoperability process

a. Will you be okay if the standardized data interoperability process is developed based on IFC schema?

b. Do you have any suggestions to solve data interoperability issues 1) within designers of record, 2) between designers of record and INDOT offices, and 3) between designers of record and contractors?

_____

_____

_____

APPENDIX C. QUALITATIVE INTERVIEW FOR CONTRACTORS

Part 1. Descriptive Information of Participants and Projects

1. Please specify your current position/role: _____

2. Please indicate how long you have worked in this position: ___ Year ___ Month

3. Please indicate the range of contract value in dollars for the majority of projects that you have been involved in: _____

4. What are the typical delivery methods of the projects you have been involved in and could you please outline the contract relationship of key stakeholders under each delivery method?

_____
_____
_____

Part 2. Construction: Business Process Related Questions

5. Questions about the work between contractors and designers of record
    a. What information (e.g., drawings, etc.) do you usually obtain from designers of record at bid time and after biding?

_____
_____
_____

    b. What is the typical format of information/documents contractors obtain from designers of record at bid time and after bidding, and are there any issues?

_____
_____
_____

    c. How do you prefer to obtain information from designers of record at bid time and after bidding?

_____
_____
_____

    d. Are designers of record responsible for the information/documents they provided to contractors at bid time / after bidding?

_____
_____
_____

e. What information is usually missing when you obtain information from designers of record?

f. What information do you usually need from designers of record, but they are not required to provide?

g. What information do you usually need to create when you cannot obtain from designers of record? And what are the challenges for you?

6. Questions about the work between contractors and INDOT
   a. What information/documents does INDOT usually need from contractors? And what is the typical format?

   b. What type of responsibilities do contractors have for INDOT projects (e.g., construction engineering, as-built drawings, etc.)?

   c. What information/documents do you find difficult to provide when INDOT needs, and what is the challenge?

   d. What are the mistakes that usually happen during the construction phase on the contractor side?

e. What types of change are usually requested by INDOT during construction?

f. What information (e.g., drawings, etc.) do you usually obtain from INDOT?

g. What is the typical format of information/documents contractors obtain from INDOT, and are there any issues?

h. How do you prefer to obtain information from INDOT?

i. Is INDOT responsible for the information/documents they provided to contractors?

j. What information is usually missing when you obtain information from INDOT?

k. What information do you usually need from INDOT, but they do not provide?

l. What information do you need to create when you cannot obtain from INDOT?

m. What are the challenges if INDOT cannot provide the needed information?

n. What information (e.g., change orders, material certifications, etc.) do you usually deliver to INDOT during a project and at the completion of a project?

o. How do you prefer to deliver information (e.g., change orders, material certifications, etc.) to INDOT during a project and at the completion of a project?

p. Are contractors responsible for the information/documents (e.g., change orders, material certifications, etc.) they delivered to INDOT?

7. As-built drawings related questions

a. Who currently creates as-builts? (For example, designers of record create the initial plan/drawings, then contractors mark on those plan/drawings?)

b. What type of assets do contractors currently provide as-builts to INDOT?

c. What other as-builts can contractors provide to INDOT if requested by INDOT?

d. Currently, are contractors responsible for the hard-copy as-builts provided to INDOT?

e. If NO to question above, would contractors be interested in taking responsibility for hard-copy as-builts for INDOT?

f. Will contractors be willing to take responsibility for digital files of as-builts if requested in the contract without disclaimer, which means contractors are liable for the documents provided?

_____
_____
_____

g. What risks would contractors be concerned with if they were liable for the digital as-builts?

_____
_____
_____

h. Would contractors be willing to accept the following language if added to the contract between INDOT and contractors for requiring contractors to be responsible for digital as-builts of assets?

Legal Document: Digital files of as-builts that are required to be delivered to INDOT. Contractors shall take responsibilities for any mistakes identified in the documents provided. Legal Document and required format(s) to be delivered are as follows: (File types to be filled by INDOT)
Contractors shall provide and be responsible for digital as built files which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT to fill in required info and formats.

_____
_____
_____

i. Would contractors be willing to submit digital as built files if requested in the contract with disclaimer, which means contractors are NOT liable for the documents provided?

_____
_____
_____

j. Would contractors be willing to accept the following language if added to the contract between INDOT and contractors for requiring contractors to **sign electronically**?

Electronically signing and submitting this contract is the legal equivalent of having placed my handwritten signature on the submitted contract and this affirmation.

_____
_____
_____

Part 3. Construction: Technology Related Questions

8. Does INDOT require you to use any software for construction?

_____
_____
_____

9. What software do you use to view 3D models?

_____
_____
_____

10. What do you primarily use 3D models for in construction?

_____
_____
_____

11. What software do you use to view geographic data?

_____
_____
_____

12. What do you primarily use geographic data for in construction?

_____
_____
_____

13. Would contractors be willing to accept the following language if added to the contract between INDOT and contractors for requiring contractors to use one of the software vendors specified by INDOT?

"One of the following software (software decided by INDOT) should be used for BIM modeling during construction and completion of the final as built digital file."

_____
_____
_____

14. Current practices and issues of data interoperability
    a. What formats of design files are available to you to use in construction? (Please select all that apply.).
        A. CAD files
        B. Bentley files
        C. Revit files
        D. IFC files
        E. Others (please specify) _____

b. What is the data extension of construction files which are available to you to use in construction? (Please select all that apply.)
   A. DGN
   B. ALG
   C. DTM
   D. FGB
   E. SDB
   F. ITL
   G. SHP
   H. IPS
   I. XML
   J. PDF
   K. DWG
   L. DXF
   M. CityGML
   N. KML
   O. Others (please specify) _____

c. What software do you use for construction? (Please select all that apply.)
   A. Bentley
   B. Trimble
   C. Autodesk
   D. Others (please specify) _____

d. What geospatial referencing system is used in construction? (Please select all that apply.)
   A. Local coordinate system
   B. Latitude and longitude
   C. Project station and offset
   D. State plane coordinate system
   E. Indiana Geospatial Coordinate System (InGCS)
   F. Others (please specify) _____

e. How do you record your as-builts data?
   A. Redline of paper-based plans
   B. Redline of electronic plans
   C. Updated CAD files
   D. Laser scanning PCD files
   E. Others (please specify) _____

f. What is the standard data format for reporting and archiving your construction records?
   A. Paper copies
   B. Video
   C. CAD

D. Site Manager
E. Microsoft Office
F. PDF
G. Others (please specify) _____

g. Do you need to convert 3D models and geographic data between different formats 1) within contractors, 2) between contractors and INDOT offices, and 3) between contractors and designers of record?

_____
_____
_____

h. How often do you need the conversion you mentioned above?

_____
_____
_____

i. How do you perform the conversion you mentioned above?

_____
_____
_____

j. Are you satisfied with the method(s) you mentioned above with respect to **quality** of conversion? (1: Strongly unsatisfied 2: unsatisfied 3: Neither satisfied nor unsatisfied 4: satisfied 5: Strongly satisfied)

_____
_____
_____

k. Does (do) the method(s) you mentioned above have missing data or data inconsistency issues? Please give examples.

_____
_____
_____

15. Opinions on developing new data interoperability process

a. Will you be okay if the standardized data interoperability process is developed based on IFC schema?

_____
_____
_____

b. Do you have any suggestions to solve data interoperability issues 1) within contractors, 2) between contractors and INDOT offices, and 3) between contractors and designers of record?

_____

_____

_____

APPENDIX D. QUALITATIVE INTERVIEW FOR SOFTWARE VENDOR

Part 1. Descriptive Information of Participants and Projects

1. Please specify your current position/role: _____

2. Please indicate how long you have worked in this position: ___ Year ___ Month

3. Please indicate the range of contract value in dollars for the majority of projects that you have been involved in: _____

Part 2. Software Vendors

4. What key staff or offices in INDOT do you need to communicate with?

_____
_____
_____

5. What software do you currently provide for project management?

_____
_____
_____

6. What software do you currently provide for design?

_____
_____
_____

7. What software do you currently provide for construction?

_____
_____
_____

8. What software do you currently provide for asset management?

_____
_____
_____

9. What are some common issues / data interoperability issues you are asked to resolve by the DOT with the software of design?

_____
_____
_____

10. What are some common issues / data interoperability issues you are asked to resolve by the DOT with the software of construction?

_____
_____
_____

11. What are some common issues / data interoperability issues you are asked to resolve by the DOT with the software of asset management?

_____
_____
_____

12. What kind of problems occur when software is upgraded from an old version to a newer version?

_____
_____
_____

13. What file types does your software support? (DGN, DWG, XML, etc.)

_____
_____
_____

14. What changes/improvements to your software are usually requested from contractors, if any?

_____
_____
_____

15. What changes/improvements to your software are usually requested from designers of record, if any?

_____
_____
_____

16. What changes/improvements to your software are usually requested from INDOT office (design, construction, and asset management teams), if any?

_____
_____
_____

17. What challenges do you have when you work with contractors, if any?

_____
_____
_____

18. What challenges do you have when you work with designers of record, if any?

_____
_____
_____

19. What challenges do you have when you work with owners (design, construction, and asset management teams), if any?

_____
_____
_____

20. What geospatial reference system does your software support?

_____
_____
_____

21. How does your software handle any data interoperability issues and/or conversions between 3D models and geographic data files?

_____
_____
_____

22. Is your software planning to have capability to resolve any security concerns with having digital files become legal contract documents by signing in and out users, tracking changes, etc.?

_____
_____
_____

23. Plan for developing new data interoperability process.
    a. Are you planning to integrate your software with 3D models from multiple vendors based on IFC data schema?

_____
_____
_____

    b. Do you have any other plans to solve data interoperability issues: 1) between different DOT offices, 2) between DOT offices and designers of record, and 3) between DOT offices and contractors?

_____
_____
_____

APPENDIX E. QUALITATIVE INTERVIEW FOR INDOT

Part 1. Descriptive Information of Participants and Projects

1. Please specify your current position/role: _____

2. Please indicate how long you have worked in this position: ___ Year ___ Month

3. Please indicate the range of contract value in dollars for the majority of projects that you have been involved in: _____

4. What are the typical delivery methods of the projects you have been involved in? Could you please outline the contract relationship of key stakeholders under each delivery method?

_____
_____
_____

Part 2. General Questions

5. What is the general process to complete design, construction (e.g., construction engineering, preparing as-builts, etc.), or asset management for INDOT?

_____
_____
_____

6. What is the respective organization structure within the design office, within the construction office, and within asset management office, and what is the information channel (e.g., who you need to talk within INDOT and outside INDOT for INDOT projects)? And what are the key staff or offices and their responsibilities in INDOT for construction (e.g., communicating with contractors), design (e.g., communicating with designers of record), or asset management?

_____
_____
_____

7. What type of responsibilities do designers of record or contractors (e.g., construction engineering, preparing as-builts, etc.) have for INDOT projects?

_____
_____
_____

8. What does INDOT need?

8.1 What information/documents do INDOT design office, construction office, and asset management office need from **designers of record and contractors**, and do you have it now? What is the typical format of those information/documents, and do you have it now?

_____
_____
_____

8.2 What information do **designers of record/contractors** need to be responsible for?

_____
_____
_____

8.3 Are designers of record or contractors responsible for the information/documents they provided to INDOT?

What information is provided?	When is it provided?	Are they responsible for it?

_____
_____
_____

8.4 How does INDOT prefer to obtain information from designers of record or contractors, if INDOT is currently not satisfied with the way they provide information?

_____
_____
_____

9. What problems does INDOT design office, construction office, and asset management office usually encounter with **designers of record/contractors**, such as 1) information/documents that are often a challenge to produce or 2) changes happened during design or construction?

_____
_____
_____

10. What information is usually missing when you obtain information from designers of record or contractors?

_____
_____
_____

11. What information do you usually require from designers of record or contractors, but they find difficult to provide?

_____
_____
_____

12. What information do you need to create which you cannot obtain from designers of record or contractors? And what are the challenges for you?

_____
_____
_____

13. What information (e.g., drawings, etc.) does INDOT usually provide to designers of record or contractors and what is the format/file type? And what is INDOT's level of responsibility for the information/documents that INDOT provides to designers of record or contractors?

_____
_____
_____

14. How do you prefer to deliver information to designers of record or contractors?

_____
_____
_____

Part 3. Business Process Related Questions for INDOT Design Office

15. Questions about the work between INDOT and designers of record

15.1 Do you think it is okay to provide a data schema to designers of record for them to fill in asset and attributes data?

_____
_____
_____

15.2 Do you think it is okay to add the following language to the contract between INDOT and designers of record for requiring designers of record to provide and be responsible for digital as-builts of assets? Because consultants are using collector to capture new assets placed in the field and to recommend the retirement of assets (in INDOT asset inventory) as they are removed from service.

Legal Document: Digital files of as-builts that are required to be delivered to INDOT. Designers of record shall take responsibilities for any mistakes identified in the documents provided. Legal Document and required format(s) to be delivered are as follows: (File types to be filled by INDOT).

Designers of record shall provide and be responsible for digital as built files which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT to fill in required info and formats.

_____
_____
_____

16. Design models related questions

16.1 Will designers of record be okay if digital files of models are requested in the contract **without disclaimer**, which means designers of record **are liable** for the documents provided?

_____
_____
_____

16.2 Do you think it is okay to add the following language to the contract between INDOT and designers for requiring designers to provide and be responsible for digital models?
Legal Document: Digital models that are required to be delivered to INDOT. Designers of record shall take responsibilities for any mistakes identified in the documents provided. Legal Document and required format(s) to be delivered are as follows: (File types to be filled by INDOT)
Designers of record shall provide and be responsible for digital models which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT to fill in required info and formats

_____
_____
_____

16.3 Would INDOT be willing to offer compensation if designers of record are liable for the digital models provided without disclaimer?

_____
_____
_____

16.4 Would designers of record be okay if digital files of as-builts are requested in the contract **with disclaimer**, which means designers of record **are NOT liable** for the documents provided?

_____
_____
_____

16.5 Do you think it is okay to add the following to the contract between INDOT and designers of record for requiring designers of record to share digital files with INDOT and not to be liable for the digital files shared?

- *For Information Only: Additional helpful files, some are required, and some are not required, to be delivered to INDOT from designers of record. For Information Only files and required format(s) to be delivered are as follows: (File types to be filled by INDOT)*
- *3D model digital design files meeting (INDOT standards to be determined) will be delivered to INDOT from designers of record.*

_____
_____
_____

16.6 Do you think it is okay to add the following to the contract between INDOT and designers of record for requiring designers of record to share digital files with INDOT during the bidding process?

- *For Information Only: Additional helpful files, some are required and some are not required, to be delivered to INDOT from designers of record. For Information Only files and required format(s) to be delivered are as follows: (File types to be filled by INDOT)*
- *3D model digital design files meeting (INDOT standards to be determined) will be delivered to INDOT from designers of record.*

_____
_____
_____

16.7 Would INDOT be okay to share 3D design files such as XML (obtained from designers of record) with contractors?

_____
_____
_____

17. Do you think it is okay to add the following to the contract between INDOT and designers of record for requiring designers of record to **sign electronically**?
Electronically signing and submitting this contract is the legal equivalent of having placed my handwritten signature on the submitted contract and this affirmation.

_____
_____
_____

Part 4. Business Process Related Questions for INDOT Construction Office

18. As-built drawings related questions.

18.1 How are as-builts (traffic signals and other assets) drawings created for different types of assets (traffic signals and other assets)?

What types of assets	Who	How	Format	Responsibility

18.2 What are contractors liable for currently? How long are contractors liable for the quality of construction currently?

18.3 Do contractors need to be responsible for the as-builts they provided during the first few years?

18.4 Should INDOT take full responsibility for as-builts since 1) the original drawings/plans are created by designers of record with 2) the markups by contractors?

18.5 Should the party who creates the as-builts be responsible for it?

18.6 Do you think it would not be acceptable to have contractors take on the risk of as-built deliverables?

18.7 If contractors take full responsibility of as-built deliverables, would the as-builts be more accurate and therefore lower the risk to INDOT, or do you have any concerns on this?

18.8 Why are as-builts of traffic signals the only one required of contractors for now? And how are as-built drawings of traffic signals used currently (e.g., for asset management or only for

documentation)? Does INDOT currently use the hard-copy as-builts of traffic signals for asset management or only require it for documentation?

_____

_____

_____

18.9 What other as-builts would INDOT like to receive from contractors, besides Traffic Signals, and in what format?

_____

_____

_____

18.10 Currently, are contractors legally responsible for the **hard-copy as-builts** provided to INDOT? If NO to the question above, do you think it is okay to ask contractors to be legally responsible for the **hard-copy as-builts** provided to INDOT?

_____

_____

_____

18.11 Currently, who exactly at INDOT needs to be responsible for the as-builts received? Is it project engineer?

_____

_____

_____

18.12 Would you think it is okay to move responsibility of as-builts from INDOT to the Contractor under Construction Engineering? For example, a licensed surveyor can be hired by contractor to document and create the as-builts.

_____

_____

_____

18.13 Do you think it is okay to ask contractors to deliver digital files of as-builts if requested in the contract **without disclaimer**, which means contractors **are liable** for the documents provided?

_____

_____

_____

18.14 What risks do you think contractors would be concerned with if they were liable for the digital as-builts?

_____

_____

_____

18.15 Would you be willing to offer compensation if contractors are liable for the digital as-builts provided without disclaimer?

_____
_____
_____

18.16 Would contractors be willing to accept the following language if added to the contract between INDOT and contractors for requiring contractors to provide and be responsible for as-builts of assets?

Legal Document: Digital files of as-builts that are required to be delivered to INDOT. Contractors shall take responsibilities for any mistakes identified in the documents provided. Legal Document and required format(s) to be delivered are as follows: (File types to be filled by INDOT)

Contractors shall provide digital as built files which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT to fill in required info and formats

_____
_____
_____

18.17 Would contractors be willing to submit digital as built files if requested in the contract **with disclaimer**, which means contractors **are NOT liable** for the documents provided?

_____
_____
_____

19. Would contractors be willing to accept the following language if added to the contract between INDOT and contractors for requiring contractors to **sign electronically**?

Electronically signing and submitting this contract is the legal equivalent of having placed my handwritten signature on the submitted contract and this affirmation.

_____
_____
_____

Part 5. Business Process Related Questions for INDOT Asset Management Office

20. Digital as-built drawings related questions

20.1 What digital as-built drawings are currently provided to INDOT asset management and who is responsible for the as-built drawings provided?

_____
_____
_____

20.2 What other digital as-built drawings does INDOT asset management need?

_____
_____
_____

20.3 How do you use the currently available as-built drawings of traffic signals?

_____
_____
_____

20.4 Who is currently responsible for creating as-built drawings of traffic signals for INDOT asset management?

_____
_____
_____

20.5 What is the current file format of as-built drawings of traffic signals that provided to INDOT asset management?

_____
_____
_____

20.6 What is the desired file format of as-built drawings of traffic signals that are provided to INDOT asset management?

_____
_____
_____

20.7 Who is currently responsible for creating as-built drawings of other assets (please be specific) for INDOT asset management?

_____
_____
_____

20.8 What is the current file format of as-built drawings of other assets (please be specific) that are provided to INDOT asset management?

_____
_____
_____

20.9 What is the desired file format of as-built drawings of other assets (please be specific) that are provided to INDOT asset management?

_____
_____
_____

20.10 Where do you currently receive as-built drawings (traffic signals and other assets) from, and do you have any issues with this?

_____
_____
_____

20.11 How do you currently receive as-built drawings (traffic signals and other assets), and do you have any issues with this?

_____
_____
_____

20.12 If yes to the above question, what is your desired way to receive as-built drawings (traffic signals and other assets)?

_____
_____
_____

20.13 How exactly is the data of digital as-built drawings processed for asset inventory?

_____
_____
_____

20.14 Besides the requirement of file format, is there any other requirement for using digital as-built drawings to provide input for asset inventory?

_____
_____
_____

20.15 How do you currently measure the changes between what the inventories defined before construction and after construction?

_____
_____
_____

20.16 How do you currently identify the **removed from service, moved but still in service, and changed** assets?

_____
_____
_____

20.17 What is your desired way to identify the **removed from service, moved but still in service, and changed** assets?

_____
_____
_____

20.18 Who is currently responsible for doing the above two tasks?

_____
_____
_____

20.19 What technology do you use for the above two tasks?

_____
_____
_____

20.20 When (what phases of a project) do you do the above two tasks?

_____
_____
_____

20.21 When are the designers of record collecting the asset info, and if this could be any designer/consultant hired later as a separate service?

_____
_____
_____

21. Field data collection technology related questions

21.1 What is the process to use the current field data collection technology for traffic signals?

_____
_____
_____

21.2 What is the process to use the current field data collection technology for other assets?

_____
_____
_____

21.3 Who is responsible for data produced by using the field data collection technology regarding traffic signals?

_____
_____
_____

21.4 Who is responsible for data produced by using the field data collection technology regarding other assets?

_____
_____
_____

21.5 What are included in the field data collection technology?

_____
_____
_____

21.6 Are there any issues when using the current field data collection technology?

_____
_____
_____

21.7 Are there any things you wish to improve about the current field data collection technology?

_____
_____
_____

21.8 **Increased responsibility for INDOT**: Would INDOT be willing to accept the following language if added to the contract between INDOT and contractors for requiring INDOT to **share digital files of as-builts of the locations of the existing underground utilities**?
For Information Only: Additional existing underground utilities files to be delivered to contractors from INDOT or designers of record. For Information Only files and required format(s) to be delivered are as follows: (File types to be filled by INDOT)

_____
_____
_____

21.9 Do you think your rating of an asset is consistent with others (subjective scale of 1-9)? If not, how do you wish to make it consistent?

_____
_____
_____

22. Database related questions
22.1 What is the current process for inspectors to update information in the database?

_____
_____
_____

22.2 What are the issues regarding the current process for inspectors to update information in the database?

_____
_____
_____

22.3 What is the current process for INDOT to be notified by Federal Highway Administration regarding the changes they made to the inventory database?

_____
_____
_____

22.4 How do you input information in different databases (e.g., event editor, road inventory, etc.)?

Databases	Definition	What information	How to input information?	Responsible parties
Event Editor				
BIAS				
GeoDatabase				
National bridge inventory				
Road analyzer				
Roadway inventory				
Roadway characteristics editor				

_____
_____
_____

22.5 Who do you ask to use the collector application to collect asset inventory data, and do you have any issues?

_____
_____
_____

23. How is the warranty that contractors currently provide to INDOT, and do you have any concerns?

_____
_____
_____

Part 6. Technical Part: General Questions

24. What software/platform does INDOT prefer to receive/send 3D model deliveries? (Please provide answers for different senders and different recipients respectively)

_____
_____
_____

25. What software/platform does INDOT prefer to receive / send geographic data? (Please provide answers for different senders and different recipients respectively)

_____
_____
_____

26. What software/platform does INDOT usually require contractors and designers of record to use?

_____
_____
_____

Part 7. Technical Part: INDOT Design Office

27. Do you think it is okay to add the following to the contract between INDOT and designers of record for requiring contractors to use one of the software vendors specified by INDOT? "*One of the following software (software decided by INDOT) should be used for design and completion of the final digital models*."

_____
_____
_____

28. Current practices and issues of data interoperability

28.1 Do you need to convert 3D models and geographic data between different formats 1) within INDOT design office, 2) for other INDOT offices, and 3) for designers of record?

_____
_____
_____

28.2 How often do you need the conversion as you mentioned above?

_____
_____
_____

28.3 How do you perform the conversion as you mentioned above?

_____
_____
_____

28.4 Are you satisfied with the method(s) you mentioned above with respect to **quality** of conversion? (1: Strongly unsatisfied 2: unsatisfied 3: Neither satisfied nor unsatisfied 4: satisfied 5: Strongly satisfied)

_____
_____
_____

28.5 Does (do) the method(s) you mentioned above have missing data or data inconsistency issues? Please give examples.

_____
_____
_____

29. Opinions on developing new data interoperability process

29.1 Will you be okay if the standardized data interoperability process is developed based on IFC schema?

_____
_____
_____

29.2 Do you have any suggestions to solve data interoperability issues 1) within INDOT design office, 2) between INDOT design office and other offices in INDOT, and 3) between INDOT design office and designers of record?

_____
_____
_____

Part 8. Technical Part: INDOT Construction Office

30. Do you think it is okay to add the following to the contract between INDOT and contractors for requiring contractors to use one of the software vendors specified by INDOT?

One of the following software (software decided by INDOT) should be used for BIM modeling during construction and completion of the final as-built digital file

_____
_____
_____

31. What do you primarily use 3D models for in construction?

_____
_____
_____

32. What do you primarily use geographic data for in construction?

_____
_____
_____

33. Current practices and issues of data interoperability

33.1 Do you need to convert 3D models and geographic data between different formats 1) within INDOT construction office 2) for other offices in INDOT 3) for contractors?

_____
_____
_____

33.2 How often do you need the conversion as you mentioned above?

_____
_____
_____

33.3 How do you perform the conversion as you mentioned above?

_____
_____
_____

33.4 Are you satisfied with the method(s) you mentioned above with respect to **quality** of conversion? (1: Strongly unsatisfied 2: unsatisfied 3: Neither satisfied nor unsatisfied 4: satisfied 5: Strongly satisfied)

_____
_____
_____

33.5 Does (do) the method(s) you mentioned above have missing data or data inconsistency issues? Please give examples.

_____
_____
_____

34. Opinions on developing new data interoperability process

34.1 Will you be okay if the standardized data interoperability process is developed based on IFC schema?

_____
_____
_____

34.2 Do you have any suggestions to solve data interoperability issues 1) within INDOT construction office, 2) between INDOT construction office and other offices in INDOT, and 3) between INDOT construction office and contractors?

_____
_____
_____

Part 9. Technical Part: INDOT Asset Management Office

35. Current practices in bridge or culvert inspection

35.1 Besides condition rating, what other data are required in bridge or culvert inspection?

_____
_____
_____

35.2 Besides, deck, superstructure, substructure, what other objects are evaluated in bridge or culvert condition rating?

_____
_____
_____

35.3 What factors are considered when evaluating bridge or culvert conditions?

_____
_____
_____

35.4 What are key differences between condition rating 5 (fair), and 4 (poor)? (The difference between 4 and 5 is important because according to the national performance management measures, a structurally deficient bridge or culvert is one with any component condition rating less than or equal to 4.)

_____
_____
_____

35.5 Who provide bridges or culverts condition rating data to INDOT?

_____
_____
_____

35.6 How are those people trained for bridge or culvert inspection work?

_____
_____
_____

35.7 Do you agree more efficient training should be provided before people start bridge or culvert inspection work? (1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly agree)

_____
_____
_____

35.8 Are you satisfied with quality of condition ratings data? (1: Strongly unsatisfied 2: Unsatisfied 3: Neither satisfied nor unsatisfied 4: Satisfied 5: Strongly satisfied)

_____
_____
_____

35.9 What are the challenges in current condition evaluation data?

_____
_____
_____

36. Current practices in pavement condition / mobility asset / safety asset inspection

36.1 Besides International Roughness Index (IRI), Rutting (RUT), Faulting, Cracking, what other data are required in pavement condition inspection?

_____
_____
_____

36.2 What data are required in mobility / safety asset inspection?

_____
_____
_____

36.3 Who provide pavement condition / mobility / safety asset inspection to INDOT?

_____
_____
_____

36.4 How are those people trained for pavement condition / mobility / safety asset inspection work?

_____
_____
_____

36.5 Do you agree more efficient training should be provided before people start pavement condition inspection mobility / safety asset inspection work? (1: Strongly disagree 2: Disagree 3: Neither agree nor disagree 4: Agree 5: Strongly agree)

_____
_____
_____

36.6 Are you satisfied with pavement condition / mobility / safety asset inspection data? (1: Strongly unsatisfied 2: Unsatisfied 3: Neither satisfied nor unsatisfied 4: Satisfied 5: Strongly satisfied)

_____
_____
_____

36.7 What are the challenges in current pavement condition / mobility / safety asset inspection data?

_____
_____
_____

37. What is the data format of asset management files?

_____
_____
_____

38. What software do you use for asset management?

_____
_____
_____

39. What geospatial referencing system is used in your construction projects for your O&M asset locations? (Please select all that apply.)
    A. Local coordinate system
    B. Latitude and longitude
    C. Project station and offset
    D. State plane coordinate system
    E. Indiana Geospatial Coordinate System (InGCS)
    F. Others (please specify) _____

40. Current practices and issues of data interoperability.

40.1 Do you need to convert 3D models and geographic data between different formats, 1) within INDOT asset management office, 2) for other offices in INDOT, 3) for designers of record, and 4) for contractors?

_____
_____
_____

40.2 How often do you need the conversion as you mentioned above?

_____
_____
_____

40.3 How do you perform the conversion as you mentioned above?

_____
_____
_____

40.4 Are you satisfied with the method(s) you mentioned above with respect to **quality** of conversion? (1: Strongly unsatisfied 2: Unsatisfied 3: Neither satisfied nor unsatisfied 4: Satisfied 5: Strongly satisfied)

_____
_____
_____

40.5 Does (do) the method(s) you mentioned above have missing data or data inconsistency issues? Please give examples.

_____
_____
_____

41. Opinions on developing new data interoperability process

41.1 Will you be okay if the standardized data interoperability process is developed based on IFC schema?

_____
_____
_____

41.2 Do you have any suggestions to solve data interoperability issues 1) within INDOT asset management office, 2) between INDOT asset management office and other offices in INDOT, 3) between INDOT asset management and designers of record, and 4) between INDOT asset management and contractors?

_____
_____
_____

APPENDIX F. QUANTITATIVE SURVEY FOR DESIGNERS OF RECORD

Part 1. Descriptive Information of Participants and Projects

1. What is your current position/role?
2. How long have you worked in this position? ___ year(s) ___ month(s)
3. What is the range of contract value in dollars for the majority of projects that you have been involved in? ___ millions to ___ millions
4. What infrastructure do you work on?
   a. Road
   b. Bridge
   c. Both road and bridge
   d. Others, please specify___
5. What are the typical delivery methods of the projects you have been involved in? (Please select all that apply.)
   a. Design Bid Build
   b. Design Build
   c. Alternative/Integrated Project Delivery
   d. Others, please specify___

Part 2. Design: Technology Related Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

1. How do you feel if INDOT asks designers of record to use a specific software for engineering calculation?
2. How do you feel if INDOT asks designers of record to use a specific software for CAD drawing development?
3. How do you feel about Bentley collaborative software (such as ProjectWise) that you currently use to deliver 3D models?
4. How do you feel about Autodesk collaborative software (such as BIM360) that you currently use to deliver 3D models?
5. How do you feel about software such as ERMS that you currently use to deliver geographic data?
6. How do you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers of record to use one of the software vendors specified by INDOT?
   - "One of the following software (software decided by INDOT) should be used for design and completion of the final digital models."
7. How do you feel if INDOT allows the designers of record to use any software they want, in the data format accepted by INDOT, such as DGN, DWG, XML, and IFC?
8. How do you feel about the conversion results of grouped data (i.e., grouping of model elements in one drawing)?
9. How do you feel about using InRoads to export PDF files for different sections of 3D models in terms of efficiency?

10. How do you feel about the current way to convert 3D models and geographic data between different formats 1) within designers of record, 2) between designers of record and INDOT offices, and 3) between designers of record and contractors?
11. How do you feel about the method(s) you mentioned above with respect to quality of conversion?
12. INDOT CAD software workspace

12.1 How do you feel about CAD software workspace provided by INDOT in design phase? (INDOT CAD standard https://www.in.gov/indot/design_manual/files/INDOT_CAD_Standards.pdf , https://www.in.gov/indot/div/cad/v8i_downloads.htm)

13. How do you feel if a standardized data interoperability process is developed based on files in IFC format?
14. How do you feel if a standardized data interoperability process is developed based on files in XML format?

Part 3. Design: Business Process Related Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

15. How do you feel about the current process to complete design for INDOT, such as following the Indiana Design Manual?
16. How do you feel about the current responsibilities that designers of record have for INDOT projects?
17. How do you feel about the process for obtaining historic plan information from (https://entapps.indot.in.gov/opsm/Dashboard/UserRequest)?
18. How do you feel about obtaining information from INDOT by email?
19. How do you feel about obtaining information from INDOT by website (i.e., INDOT posts it on website and then you download it.)? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*

19.1 Please specify what way to obtain information from INDOT that you prefer. ___

20. How do you feel about delivering information to INDOT by email?
21. How do you feel about delivering information to INDOT in the form of PDFs? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*

21.1 Please specify what form of information/documents that you prefer. ___

22. How do you feel when using the ERMS to submit documents to INDOT for review?
23. How will you feel if ERMS is equipped with a function to automatically populate the information from your submitted document and you just need to verify it instead of manually typing in everything?
24. Questions about the work between designers of record and contractors

24.1 How do you feel about the completeness of information/documents (e.g., drawings, etc.) that you usually deliver to contractors? (If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)

- Please specify what information is incomplete. ___

24.2 How do you feel about the accuracy of information/documents (e.g., drawings, etc.) that you usually deliver to contractors? (If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)

- Please specify what information is inaccurate. ___

24.3 How do you feel about your current responsibility for the information/documents?

24.4 How do you feel about using mobile apps (e.g., ESRI's Collector App as configured by INDOT) for data collection in the field to supplement INDOT GIS asset inventories?

25. Models related questions

25.1 How do you feel if digital files of models are requested in the contract with disclaimer, which means designers of record are NOT liable for the documents provided?

25.2 How do you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers of record to share digital files with INDOT with disclaimer?

- 3D model digital design files meeting (INDOT standards to be determined) will be delivered to INDOT from designers of record with disclaimer, for information only.

25.3 How do you feel if digital files of models are requested in the contract without disclaimer, which means designers of record are liable for the documents provided?

25.4 How do you feel about INDOT offering you compensation if you are liable for the digital as-builts provided without disclaimer?

25.5 What kind of compensation do you want in order to be liable for the digital as-builts provided without disclaimer? Please specify___

25.6 How do you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers of record to provide and be responsible for digital models?

- Legal Document: Digital models that are required to be delivered to INDOT without disclaimer. Designers of record shall provide and be responsible for digital models which include all the assets and asset information required by INDOT in the format required by INDOT. INDOT needs to fill in required information and formats.

25.7 How do you feel about sharing 3D design files such as XML with INDOT/contractors with disclaimer?

25.8 How do you feel about sharing 3D design files such as XML with INDOT/contractors without disclaimer?

26. How do you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers of record to sign electronically?
Electronically signing and submitting this contract is the legal equivalent of having placed my handwritten signature on the submitted contract.

27. Please provide additional comments regarding the above questions if any.

APPENDIX G. QUANTITATIVE SURVEY FOR CONTRACTORS

Part 1. Descriptive Information of Participants and Projects

1. What is your current position/role?2. How long have you worked in this position? ___ year(s) ___ month(s)
2. What is the range of contract value in dollars for the majority of projects that you have been involved in? ___ millions to ___ millions
3. What are the typical delivery methods of the projects you have been involved in? (Please select all that apply.)
   a. Design Bid Build
   b. Design Build
   c. Alternative/Integrated Project Delivery
   d. Others, please specify___

Part 2. Construction: Technology-Related Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

4. How do you feel if INDOT asks the contractors to use a specific software for 3D models?
5. How do you feel if INDOT asks the contractors to use a specific software for survey work?
6. How do you feel the following contract term is added to the contract between INDOT and contractors for requiring contractors to use one of the software vendors specified by INDOT?
   - "*One of the following software (software decided by INDOT) should be used for construction.*"
7. How do you feel if INDOT allows the contractors to use any software that they want, with the data format accepted by INDOT directly, such as DGN, DWG, XML, and IFC?
8. How do you feel if INDOT allows the contractors to use any software that they want, with the data format needed to be converted by INDOT?
9. How do you feel about the current software you use to view 3D models?
10. How do you feel about the software you use to view geographic data?
11. How do you feel about the current way to convert 3D models between different formats 1) within contractors, 2) between contractors and INDOT offices, and 3) between contractors and designers of record?
12. How do you feel about the current way to convert geographic data between different formats 1) within contractors, 2) between contractors and INDOT offices, and 3) between contractors and designers of record?
13. How do you feel about the method(s) you mentioned above with respect to **quality** of conversion?
14. How do you feel if the standardized data interoperability process is developed based on files in IFC format?
15. How do you feel if the standardized data interoperability process is developed based on files in XML format?

Part 3. Construction: Business Process Related Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

16. Questions about the work between contractors and designers of record
    a. How do you usually feel about the information/documents (e.g., drawings, etc.) from designers of record in terms of completeness? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*
        i. Please specify what information is incomplete. ___
    b. How do you usually feel about the information/documents (e.g., drawings, etc.) from designers of record in terms of accuracy? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*
        i. Please specify what information is inaccurate. ___
    c. How do you usually feel about the information/documents from designers of record in the form of PDFs?
    d. How do you usually feel about the information/documents from designers of record in the form of 3D models? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*
        i. Please specify what form of information/documents you prefer. ___
17. How do you feel about the way to obtain information from designers of record by email/SharePoint such as OneDrive?
18. How do you feel about the way to obtain information from INDOT by email/SharePoint such as OneDrive? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*
    a. Please specify what way to obtain information from INDOT you prefer.___
19. How do you feel if the existing underground utilities are provided to you with disclaimer?
20. How do you feel if additional documents are requested in the contract with disclaimer, which means you contractors are NOT liable for the documents provided?
21. How do you feel if the following contract term is added to the contract between you and INDOT for requiring you contractors to provide digital files of as-builts to INDOT **with disclaimer**?
    - *Digital files of as-builts (INDOT standards to be determined) will be delivered to INDOT from contractors with disclaimer, for information only.*
22. How do you feel about INDOT offering you compensation if you are liable for the digital as-builts provided without disclaimer?
23. What kind of compensation do you want to be liable for the digital as-builts provided without disclaimer? Please specify___
24. How do you feel about INDOT asking you contractors to submit digital as-builts if requested in the contract **without disclaimer**?
25. How do you feel if the following contract term is added to the contract between you contractors and INDOT for requiring contractors to provide and be responsible for as-builts of assets?
    - *Legal Document: Digital files of as-builts that are required to be delivered to INDOT without disclaimer. Contractors shall provide digital and be responsible*

for as built files which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT needs to fill in required information and formats.

26. How do you feel if the following contract term is added to the contract between INDOT and contractors for requiring contractors to **sign electronically**?
    - *Electronically signing and submitting this contract is the legal equivalent of having placed my handwritten signature on the submitted contract.*
27. Please provide additional comments regarding the above questions if any.

APPENDIX H. QUANTITATIVE SURVEY FOR SOFTWARE VENDORS

Part 1. Descriptive Information of Participants and Projects

1. What is your current position/role?
2. How long have you worked in this position: ___ year(s) ___ month(s)
3. What is the range of contract value in dollars for the majority of projects that you have been involved in?

Part 2. Software Vendors (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

4. How do you feel about your service with INDOT design?
5. How do you feel about your service with INDOT construction?
6. How do you feel about your service with INDOT asset management?
7. How do you feel about your software to support design work with INDOT if applicable?
8. How do you feel about your software to support construction work with INDOT if applicable?
9. How do you feel about your software to support asset management work with INDOT if applicable?
10. How do you feel about your software's ability to handle any data interoperability issues and/or conversions between 3D models and geographic data files?
11. How do you feel about integrating your software with 3D models from multiple vendors based on files in IFC format?
12. How do you feel about integrating your software with 3D models from multiple vendors based on files in XML format?
13. Please provide additional comments regarding the above questions if any.

APPENDIX I. QUANTITATIVE SURVEY FOR INDOT DESIGN OFFICE

Part 1. Descriptive Information of Participants and Projects

1. What is your current position? _____
2. How long have you worked in this position? ___ year(s) ___ month(s)
3. What is the range of contract value in dollars for the majority of projects that you have been involved in?
4. What are the typical delivery methods of the projects you have been involved in? (Please select all that apply.)
    a. Design Bid Build
    b. Design Build
    c. Alternative/Integrated Project Delivery
    d. Others, please specify___

Part 2. Technical Part: INDOT Design Office (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

5. How do you feel if INDOT asks designers of record to use a specific software for engineering calculation?
6. How do you feel if INDOT asks designers of record to use a specific software for CAD drawing development?
7. How do you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers to use one of the software vendors specified by INDOT?
    - "*One of the following software (software decided by INDOT) should be used for design and completion of the final digital models*."
8. How do you feel if INDOT allows designers of record to use any software that they want, but in the data format accepted by INDOT, such as DGN, DWG, XML, and IFC?
9. How do you feel about the conversion results of grouped data (i.e., grouping of multiple model elements in one drawing)?
10. How do you feel about using InRoads to export PDF files for different sections of 3D models in terms of efficiency?
11. Current practices and issues of data interoperability

11.1 How do you feel about the current way to convert 3D models and geographic data between different formats 1) within INDOT design office, 2) for other INDOT offices, and 3) for designers of record?

11.2 How do you feel about the method(s) you mentioned above with respect to **quality** of conversion?

12. Opinions on developing new data interoperability process

12.1 How do you feel if a standardized data interoperability process is developed based on industry foundation classes (IFC) schema (i.e., the ISO standard)?

12.2 How do you feel if a standardized data interoperability process is developed based on XML schema?

Part 3. Business Process Related Questions for INDOT Design Office (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

13. How do you feel if the designers of record can talk with the design review staff in the INDOT design office directly? Currently, a coordinator is required to transfer documents submitted by designers of record through ERMS.
14. Design models related questions

14.1 How do you feel about asking designers of record to submit **digital as-builts** if requested in the contract **with disclaimer**, which means contractors **are NOT liable** for the documents provided?

14.2 How do you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers of record to provide digital files of as-builts to INDOT **with disclaimer**?

- *Digital files of as-builts (INDOT standards to be determined) will be delivered to INDOT from designers of record with disclaimer, for information only.*

14.3 How do you feel about asking designers of record to submit **digital as-builts** if requested in the contract **without disclaimer**?

14.4 How do you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers of record to provide digital files of as-builts to INDOT **without disclaimer**?

- *Legal Document: Digital files of as-builts that are required to be delivered to INDOT without disclaimer.*
  Designers of record shall provide and be responsible for digital files of as-builts which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT needs to fill in required info and formats.

14.5 How do you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers of record to share **3D model digital files** with INDOT with disclaimer?

- *3D model digital files meeting (INDOT standards to be determined) will be delivered to INDOT from designers of record with disclaimer, for information only.*

14.6 How do you feel about offering compensation if designers of record are liable for the digital models provided by designers without disclaimer?

14.7 What kind of compensation do you want to offer to have designers of record liable for the digital models provided by designers without disclaimer? Please specify___

14.8 How do you feel if the following contract term is added to the contract between INDOT and designers for requiring designers to provide and be responsible for digital models?

- *Legal Document: Digital models that are required to be delivered to INDOT without disclaimer. Designers of record shall provide and be responsible for digital models which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT needs to fill in required info and formats.*

14.9 How do you feel about sharing 3D design files such as XML (obtained from designers of record) with contractors, with disclaimer?

14.10 How do you feel about sharing 3D design files such as XML (obtained from designers of record) with contractors, without disclaimer?

15. How do you feel if the following contract term is added to the contract between INDOT and designers of record for requiring designers of record to **sign electronically**?
    - *Electronically signing and submitting this contract is the legal equivalent of having placed my handwritten signature on the submitted contract.*

Part 4. Technical Part: General Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

16. How do you feel about the **Bentley collaborative software (such as ProjectWise)** to receive/send 3D model deliveries?
17. How do you feel about the **Autodesk collaborative software (such as BIM360)** to receive/send 3D model deliveries?
18. How do you feel about software/platform (such as ERMS) that INDOT uses to receive/send geographic data?

Part 5. Business Process: General Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

19. How do you feel about the current process to complete design, construction (e.g., construction engineering, preparing as-builts, etc.), or asset management for INDOT?
20. How do you feel about the current organization structure within the design office, within the construction office, or within asset management office?
21. How do you feel about the current arrangement of responsibility of key staff or offices in INDOT for design (e.g., communicating with designers of record), construction (e.g., communicating with contractors), or asset management?
22. How do you feel about the information/documents that INDOT design office, construction office, or asset management office obtain from **designers of record**? For example, you never have all the information that you need (very dissatisfied), or you always have all the information that you need (very satisfied).
23. How do you feel about the information/documents that INDOT design office, construction office, and asset management office obtain from **contractors**? For example, you never have all the information that you need (very dissatisfied), or you always have all the information that you need (very satisfied).
24. How do you feel that currently most information/documents are delivered in PDF, such as drawings, plans, etc.? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*

24.1 Please specify what form of information/documents that you prefer. ___

25. How do you feel that currently some information/documents are delivered in Word, such as special provisions? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*

25.1 Please specify what form of information/documents do you prefer. ___

26. How do you feel about the current responsibility of designers of record for INDOT?
27. How do you feel about the current responsibility of contractors for INDOT?
28. How do you feel about the current way that INDOT obtains information from designers of record by email?

29. How do you feel about the current way that INDOT obtains information from contractors by email?
30. How do you feel about the current way that INDOT obtains information from designers of record or contractors by ERMS?
31. How do you feel about the current way that INDOT obtains information from designers of record or contractors by OneDrive/Google Drive? (If participants indicate their dissatisfaction with 1 and 2 to any of the four questions above, the following question will be asked :)

31.1 Please specify what way to obtain information do you prefer. ___

32. How will you feel if dashboard, such as Power BI, is created where INDOT employees can customize the dashboard in one place to extract information from different systems to track the information important to them in the future?
33. How do you feel if more access in ERMS is granted so that INDOT employees do not have to submit the information request form to find historical data?
34. How do you feel if ERMS can let you search for documents without inputting the exact names, which means relevant information will show up by only searching a keyword?
35. How do you feel about standardizing the requirement for designers and contractors across different districts? Currently, the inconsistent requirement among different districts confuses the designers or contractors, sometimes.
36. Please provide additional comments regarding the above questions if any.

APPENDIX J. QUANTITATIVE SURVEY FOR INDOT CONSTRUCTION OFFICE

Part 1. Descriptive Information of Participants and Projects

1. What is your current position? _____
2. How long have you worked in this position? ___ year(s) ___ month(s)
3. What is the range of contract value in dollars for the majority of projects that you have been involved in?
4. What are the typical delivery methods of the projects you have been involved in? (Please select all that apply.)
    e. Design Bid Build
    f. Design Build
    g. Alternative/Integrated Project Delivery
    h. Others, please specify___

Part 2. Technical Part: INDOT Construction Office (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

5. How do you feel if INDOT asks contractors to use a specific software for 3D model?
6. How do you feel if INDOT asks contractors to use a specific software for surveying?
7. How do you feel if the following contract term is added to the contract between INDOT and contractors for requiring contractors to use one of the software vendors specified by INDOT?
    - *"One of the following software (software decided by INDOT) should be used for construction."*
8. How do you feel if INDOT allows contractors to use any software they want, in the data format accepted by INDOT, such as DGN, DWG, XML, and IFC?
9. How do you feel if INDOT asks project engineers (in some cases contractors) to collect digital as-builts, so the information can be automatically processed?
10. Current practices and issues of data interoperability
    a. How do you feel about the current way to convert 3D models between different formats 1) within INDOT construction office, 2) for other offices in INDOT, and 3) for contractors?
    b. How do you feel about the current way to convert geographic data between different formats 1) within INDOT construction office, 2) for other offices in INDOT, and 3) for contractors?
    c. How do you feel about the method(s) you mentioned above with respect to **quality** of conversion?
11. Opinions on developing new data interoperability process
    a. How do you feel if a standardized data interoperability process is developed based on files in IFC format?
    b. How do you feel if a standardized data interoperability process is developed based on files in XML format?

Part 3. Business Process Related Questions for INDOT Construction Office (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

12. As-built drawings related questions
    a. How do you feel about contractors' current liability?
    b. How do you feel about INDOT (project engineers) taking full responsibility for as-builts since 1) the original drawings/plans are created by designers of record with 2) the markups added by contractors?
    c. How do you feel about contractors being legally responsible for the **as-builts** provided to INDOT?
    d. How do you feel about moving responsibility of as-builts from INDOT to the Contractor under Construction Engineering? For example, a licensed surveyor can be hired by contractor to document and create the as-builts.
    e. How do you feel about asking contractors to submit digital as-builts if requested in the contract **with disclaimer**, which means contractors **are NOT liable** for the documents provided?
    f. How do you feel if the following contract term is added to the contract between INDOT and contractors for requiring contractors to provide digital files of as-builts to INDOT **with disclaimer**, which means contractors are NOT liable for the documents provided?
        - *Digital files of as-builts (INDOT standards to be determined) will be delivered to INDOT from contractors with disclaimer, for information only.*
    g. How do you feel about offering compensation if contractors are liable for the digital as-builts provided by contractors without disclaimer?
    h. What kind of compensation do you want to offer to have contractors liable for the digital as-builts provided by contractors without disclaimer? Please specify___
    i. How do you feel about asking contractors to submit digital as-builts if requested in the contract **without disclaimer**?
    j. How do you feel if the following contract term is added to the contract between INDOT and contractors for requiring contractors to provide and be responsible for as-builts of assets?
        - *Legal Document: Digital files of as-builts that are required to be delivered to INDOT without disclaimer. Contractors shall provide digital and be responsible for as built files which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT needs to fill in required information and formats.*
13. How do you feel if the following contract term is added to the contract between INDOT and contractors for requiring contractors to **sign electronically**?
        - *Electronically signing and submitting this contract is the legal equivalent of having placed my handwritten signature on the submitted contract.*

Part 4. Technical Part: General Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

14. How do you feel about the **Bentley collaborative software (such as ProjectWise)** to receive/send 3D model deliveries?
15. How do you feel about the **Autodesk collaborative software (such as BIM360)** to receive/send 3D model deliveries?
16. How do you feel about software/platform (such as ERMS) that INDOT uses to receive/send geographic data?

Part 5. Business Process: General Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

17. How do you feel about the current process to complete design, construction (e.g., construction engineering, preparing as-builts, etc.), or asset management for INDOT?
18. How do you feel about the current organization structure within the design office, within the construction office, or within asset management office?
19. How do you feel about the current arrangement of responsibility of key staff or offices in INDOT for design (e.g., communicating with designers of record), construction (e.g., communicating with contractors), or asset management?
20. How do you feel about the information/documents that INDOT design office, construction office, or asset management office obtain from **designers of record**? For example, you never have all the information that you need (very dissatisfied), or you always have all the information that you need (very satisfied).
21. How do you feel about the information/documents that INDOT design office, construction office, and asset management office obtain from **contractors**? For example, you never have all the information that you need (very dissatisfied), or you always have all the information that you need (very satisfied).
22. How do you feel that currently most information/documents are delivered in PDF, such as drawings, plans, etc.? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*
    a. Please specify what form of information/documents that you prefer. ___
23. How do you feel that currently some information/documents are delivered in Word, such as special provisions? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*
    a. Please specify what form of information/documents do you prefer. ___
24. How do you feel about the current responsibility of designers of record for INDOT?
25. How do you feel about the current responsibility of contractors for INDOT?
26. How do you feel about the current way that INDOT obtains information from designers of record by email?
27. How do you feel about the current way that INDOT obtains information from contractors by email?
28. How do you feel about the current way that INDOT obtains information from designers of record or contractors by ERMS?

29. How do you feel about the current way that INDOT obtains information from designers of record or contractors by OneDrive/Google Drive? *(If participants indicate their dissatisfaction with 1 and 2 to any of the four questions above, the following question will be asked.)*
    a. Please specify what way to obtain information do you prefer. ___
30. How will you feel if dashboard, such as Power BI, is created where INDOT employees can customize the dashboard in one place to extract information from different systems to track the information important to them in the future?
31. How do you feel if more access in ERMS is granted so that INDOT employees do not have to submit the information request form to find historical data?
32. How do you feel if ERMS can let you search for documents without inputting the exact names, which means relevant information will show up by only searching a keyword?
33. How do you feel about standardizing the requirement for designers and contractors across different districts? Currently, the inconsistent requirement among different districts confuses the designers or contractors, sometimes.
34. Please provide additional comments regarding the above questions if any.

APPENDIX K. QUANTITATIVE SURVEY FOR INDOT ASSET MANAGEMENT OFFICE

Part 1. Descriptive Information of Participants and Projects

1. What is your current position? _____
2. How long have you worked in this position? ___ year(s) ___ month(s)
3. What is the range of contract value in dollars for the majority of projects that you have been involved in? ___ millions to ___ millions
4. What are the typical delivery methods of the projects you have been involved in? (Please select all that apply.)
    i. Design Bid Build
    j. Design Build
    k. Alternative/Integrated Project Delivery
    l. Others, please specify___

Part 2. Technical Part: INDOT Asset Management Office (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

5. How do you feel about the information/documents (e.g., as-builts) delivered in the form of PDF?
    a. Please specify what form of information/documents do you prefer? ___
6. How do you feel about the asset location information currently provided, in terms of accuracy?
    a. Please specify what asset location information is inaccurate? ___
7. How do you feel about the asset location information currently provided, in terms of completeness?
    a. Please specify what asset location information is incomplete? ___
8. How do you feel about the asset performance information currently provided?
9. How do you feel about the collector application overall?
10. How do you feel about the collector application. For example, the terminology used may confuse users.
11. How do you feel about the pavement inspection work performed by Pathway?
12. How do you feel about the bridge inspection work performed by INDOT bridge inspection group?
13. How do you feel about the training you received for inspection work? For example, you may not feel very confident about what to inspect.
14. How do you feel about the updating cycle of asset?
15. Current practices in bridge, pavement, culvert, etc. inspection
    a. How do you feel about the current condition rating process in bridge inspection?
    b. How do you feel about the current condition rating process in pavement inspection?
    c. How do you feel about the current condition rating process in culvert inspection?
    d. How do you feel about the current condition rating result in bridge inspection?
    e. How do you feel about the current condition rating result in pavement inspection?
    f. How do you feel about the current condition rating result in culvert inspection?

g. How do you feel about the current bridge inspection frequency?
h. How do you feel about the current pavement inspection frequency?
i. How do you feel about the current culvert inspection frequency?
j. What frequency do you want to have for bridge inspection?
    i. Twice a year
    ii. Once a year
    iii. Once every two years
    iv. Once every three years
    v. Others, please specify___
k. What frequency do you want to have for pavement inspection?
    i. Twice a year
    ii. Once a year
    iii. Once every two years
    iv. Once every three years
    v. Others, please specify___
l. What frequency do you want to have for culvert inspection?
    i. Twice a year
    ii. Once a year
    iii. Once every two years
    iv. Once every three years
    v. Others, please specify___
m. How do you feel about the current way to train people for bridge inspection?
n. How do you feel about the current way to train people for pavement inspection?
o. How do you feel about the current way to train people for culvert inspection?
p. How do you feel if INDOT adopts virtual reality to train inspectors? So that you, as the inspector, can practice the inspection in an immersive environment.
q. What frequency do you think INDOT shall train inspectors?
    i. Once every year
    ii. Once every two years
    iii. Others, please specify___
r. How do you feel when inspection engineers need to perform a nightly check of the database for any missing information?
s. How will you feel if the nightly check for the database is performed by adopting the model view definition (MVD) method (an Industry Foundation Class view definition that defines a subset of the IFC schema) in the future?

16. Current practices and issues of data interoperability
    a. How do you feel about the current way to convert 3D models and geographic data between different formats 1) within INDOT asset management office, 2) for other offices in INDOT, and 3) for designers of record 4) for contractors?
    b. How do you feel the completeness of conversion as you mentioned above?
    c. How do you feel about the method(s) you mentioned above with respect to **quality** of conversion?
17. Opinions on developing new data interoperability process
    a. How do you feel if a standardized data interoperability process is developed based on files in IFC format?

b. How do you feel if a standardized data interoperability process is developed based on files in XML format?

Part 3. Business Process Related Questions for INDOT Asset Management Office (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

18. Digital as-built drawings related questions
    a. How do you feel about the quality of as-builts currently provided to INDOT asset management?
    b. How do you feel about the current file format (PDF) of as-builts?
        i. Please specify what form of as-builts you prefer. ___
    c. How do you feel about the current field data collection technology?
    d. **Increased responsibility for INDOT**: How do you feel if the following contract term is added to the contract between INDOT and contractors for requiring INDOT to **share digital files of as-builts of the locations of the existing underground utilities**?
    For Information Only: Additional existing underground utilities files to be delivered to contractors from INDOT or designers of record with disclaimer. For Information Only files and required format(s) to be delivered are as follows: (File types to be filled by INDOT)
    e. How do you feel about the consistency of your rating with others (subjective scale of 1-9)? For example, you may rate an asset condition of 4 (poor), while another inspector may rate the same asset condition of 5 (fair).
19. How do you feel about the current process for inspectors to update information in the database?

Part 4. Technical Part: General Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

20. How do you feel about the **Bentley collaborative software (such as ProjectWise)** to receive/send 3D model deliveries?
21. How do you feel about the **Autodesk collaborative software (such as BIM360)** to receive/send 3D model deliveries?
22. How do you feel about software/platform (such as ERMS) that INDOT uses to receive/send geographic data?

Part 5. Business Process: General Questions (Five-point Likert scale with 1 for very dissatisfied and 5 for very satisfied, and with an option of "not sure")

23. How do you feel about the current process to complete design, construction (e.g., construction engineering, preparing as-builts, etc.), or asset management for INDOT?
24. How do you feel about the current organization structure within the design office, within the construction office, or within asset management office?

25. How do you feel about the current arrangement of responsibility of key staff or offices in INDOT for design (e.g., communicating with designers of record), construction (e.g., communicating with contractors), or asset management?
26. How do you feel about the information/documents that INDOT design office, construction office, or asset management office obtain from **designers of record**? For example, you never have all the information that you need (very dissatisfied), or you always have all the information that you need (very satisfied).
27. How do you feel about the information/documents that INDOT design office, construction office, and asset management office obtain from **contractors**? For example, you never have all the information that you need (very dissatisfied), or you always have all the information that you need (very satisfied).
28. How do you feel that currently most information/documents are delivered in PDF, such as drawings, plans, etc.? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*
    a. Please specify what form of information/documents that you prefer. ___
29. How do you feel that currently some information/documents are delivered in Word, such as special provisions? *(If participants indicate their dissatisfaction with 1 and 2 to the question above, the following question will be asked.)*
    a. Please specify what form of information/documents you prefer. ___
30. How do you feel about the current responsibility of designers of record for INDOT?
31. How do you feel about the current responsibility of contractors for INDOT?
32. How do you feel about the current way that INDOT obtains information from designers of record by email?
33. How do you feel about the current way that INDOT obtains information from contractors by email?
34. How do you feel about the current way that INDOT obtains information from designers of record or contractors by ERMS?
35. How do you feel about the current way that INDOT obtains information from designers of record or contractors by OneDrive/Google Drive? *(If participants indicate their dissatisfaction with 1 and 2 to any of the four questions above, the following question will be asked.)*
    a. Please specify what way to obtain information you prefer. ___
36. How will you feel if dashboard, such as Power BI, is created where INDOT employees can customize the dashboard in one place to extract information from different systems to track the information important to them in the future?
37. How do you feel if more access in ERMS is granted so that INDOT employees do not have to submit the information request form to find historical data?
38. How do you feel if ERMS can let you search for documents without inputting the exact names, which means relevant information will show up by only searching a keyword?
39. How do you feel about standardizing the requirement for designers and contractors across different districts? Currently, the inconsistent requirement among different districts confuses the designers or contractors, sometimes.
40. Please provide additional comments regarding the above questions if any.

APPENDIX L. CONTRACT TERMS

Contract term 1: Legal Document: Digital models that are required to be delivered to INDOT without disclaimer. Designers of record shall provide and be responsible for digital models which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT to fill in required info and formats.

Contract term 2: Legal Document: Digital files of as-builts that are required to be delivered to INDOT without disclaimer. Contractors shall provide digital and be responsible for as built files which include all of the assets and asset information required by INDOT in the format required by INDOT. INDOT to fill in required info and formats.

Contract term 3: Electronically signing and submitting this contract is the legal equivalent of having placed my handwritten signature on the submitted contract and this affirmation (INDOT, 2017).

Contract term 4: 3D model digital files meeting (INDOT standards to be determined) will be delivered to INDOT from designers of record with disclaimer, for information only.

Contract term 5: One of the following software (software decided by INDOT) should be used for design or completion.

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 1,600 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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