

Current Department of Transportation Efforts Toward Digital Delivery Workflow for Seamless Data Exchange

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ABSTRACT: Digital Delivery has become a widely used term in the construction industry encompassing a wide movement towards digital technology implementation. This includes the adoption of e-construction technologies such as digital signatures and document management systems as well as Advanced Digital Construction Management Systems (ADCMS), both of which aim to integrate digital technologies across various project phases. In response, there are industry movements to transition towards digital data-oriented workflows and divert from paper-based and electronic-based processes that rely on PDFs and Excel exchanges. The Every Day Counts (EDC) initiative launched by the Federal Highway Administration (FHWA) aims to support the implementation of underutilized technologies, and the AID Demonstration grant by FHWA assists DOTs in expanding the implementation of innovative tools to enhance infrastructure projects' lifecycle. Nowadays, various funded and self-driven DOTs are implementing different strategies to gradually adapt digital delivery workflows. This paper aims to highlight current practices implemented in the design and construction phases and highlight the strategies used by DOTs to transition towards digitalized data exchanges and address the problem of data interoperability. Additionally, the paper identifies key challenges and lessons learned to help guide new and continuing organizations in implementing digital delivery. As the industry undergoes this transition, this paper aims to provide valuable insights into successful strategies toward project digitalization.

1- INTRODUCTION

Digital delivery is a term quickly prevailing in the construction industry. Digital technologies such as Building Information Modeling (BIM) and Geographic Information Systems (GIS) have been adopted for decades (Vararean-Cochisa & Crisan, 2025) and advanced construction management technologies, including intelligent compactors, e-ticketing, and infrared thermal pavers, have increasingly contributed to advancing project delivery (Subramanya et al., 2022). The term digitalization is associated with different nomenclatures such as e-construction, Advanced Digital Construction Management Systems (ADCMS), and digital project delivery. These terms are often used interchangeably and encompass a wide spectrum of technologies. E-construction, introduced in 2016, promotes paperless construction and digital document management to streamline project delivery. The technologies used in e-construction include electronic document management systems for project-related document storage, web-based platforms for managing bids, digital signature, and the use of mobile devices by field inspectors to input data digitally instead of using field books (Duval, 2017).

ADCMS is another term that refers to the integration of technologies across a project's life cycle to digitally create and exchange data across design, construction, and inspection activities to enhance workflow efficiency. The Federal Highway Administration (FHWA), on May 30th, 2024, released an ADCMS grant to support the DOTs' digital transformation efforts (FHWA, 2024b). One of the digital strategies implemented under ADCMS by Connecticut DOT is establishing a centralized system for project management where all project stakeholders can effectively access project information. The system aims to be a "one-stop shop"

holding various project information about project budgets, schedules, environmental permits, and document submittals (Slominski et al., 2024). Other ADCMS strategies include adopting construction technologies such as unmanned aircraft systems, e-ticketing and implementing 3D-engineered models, and digital as-builts (FHWA, 2024c). E-construction and ADCMS vision align with the digital project delivery objectives, emphasizing digital workflows and data exchanges. Digital delivery often involves digital data exchanges and closely connects with BIM and GIS technologies, for providing essential asset attributes and location data through the project stages. BIM and GIS have various use cases across the asset lifecycle. For example, BIM can provide a comprehensive asset management approach by generating 3D models and enriching them with data through the project phases to evolve into digital as-built models or even digital twins with real-time asset data (Lu et al., 2020).

With the shift towards digitalization comes many benefits for decarbonization through promoting paperless workflows and electronic exchanges. With e-construction in 2016, Michigan approximately evaluated that six million papers per year were eliminated from their projects' cycle, saving \$12 million and shifting to 99% paperless. Florida Department of Transportation reported that 20,000 pieces of paper were replaced in four projects due to paperless document management systems (Zaharewicz, 2018). These shifts save on paper utilization and reduce the project footprint embedded in paper-based exchange, saving on carbon and greenhouse gas emissions (Zaharewicz, 2018). Bortoli et al. (2023) study aimed to quantify the impact of BIM implementation on pavement project lifecycle. BIM integration in maintenance stages enables real-time monitoring, which reduces unnecessary maintenance tasks. Using data-driven decisions during the maintenance stage has led to a 3% reduction in greenhouse gas emissions. Furthermore, 3D visualization in parametric modeling allows designers to refine designs and construction sequences before execution, reducing design errors and potential clashes, which minimizes embodied carbon (De Bortoli et al., 2023; Manifold et al., 2024). Thus, digitalization plays a significant role in reducing carbon footprints and promoting decarbonization.

In light of the above, this paper aims to summarize the digital delivery strategies implemented by various DOTs to promote digital data creation and digital exchanges across project phases and examine the challenges faced, and strategies used to overcome them. The paper presents information from publicly available online sources such as case studies and tech brief reports published in the FHWA digital as-builts library, published standards in DOT websites, and webinars about digital delivery efforts. The scope of this study is limited to four DOTs: Minnesota DOT (MnDOT), Pennsylvania DOT (PennDOT), Utah DOT (UDOT), and Iowa DOT. Based on this demographic scope, the author screened each DOT's digital delivery web portals to collect relevant documents such as published standards and guidelines, deployment plans, digital delivery road maps, and recorded outreach webinars. In addition, the FHWA digital as-built library and newsletter were reviewed to identify and filter relevant case studies and tech briefs specifically related to the efforts of the four selected DOTs. Together, these sources provide the most recent insights into each agency's internal strategies and initiatives, offering an in-depth understanding of their approaches toward digital delivery.

2- DEPARTMENT OF TRANSPORTATION'S CURRENT EFFORTS TOWARDS DIGITAL DELIVERY

Previous research studies have explored the implementation of digital technologies across various project phases and activities. Nassereddine et al. (2022) study analyzed the extent of 3D digital model implementation across DOTs for highway construction projects. Among the 41 responses, 5 DOTs use 3D models as contract documents and for information purposes, 21 DOTs provide 3D design models for information only, and 15 DOTs do not use 3D design models. Another study by Costine et al. (2021) explored data interoperability in digital delivery, focusing on two major projects: 1) TPF-5(372), a transportation pooled fund aiming to test IFC schema as an information exchange in design-to-fabrication and design-to-construction use cases for bridge projects and 2) TG1/TG15, a task group which has developed a process map for the design to fabrication phase of a steel bridge, identified 11 key exchange model requirements (ERMs), and utilized the bridge information modeling data dictionary to develop exchange requirements for each ERM. Dadi et al. (2022) assessed the implementation of 16 ADCMS technologies across DOTs. The most widely implemented technologies were electronic bidding, digital signature, electronic construction documents management systems, mobile devices, and construction

administration software such as AASHTOWare Project Construction & Materials. However, implementing new technologies has faced various challenges. Key obstacles are attributed to the absence of standardized processes for developing legal models, ambiguity in the process of 3D design reviews, the need for training for design and construction staff, a lack of understanding of the contractual liabilities associated with 3D legal models, “isolation of project phases, incompatibility of project technologies” and high investment cost (Nassereddine et al., 2022; Guo et al., 2021; Dadi et.al, 2022). Based on these challenges, various DOTs in recent years have taken further steps to overcome the challenge of data interoperability and lack of standards to approach digital delivery effectively. The following section highlights the ongoing initiative aimed to advance digitalization and mitigate interoperability barriers.

2.1. Minnesota Department of Transportation (MnDOT)

Since 2011, MnDOT approached project digital delivery by implementing digital as-builts (DAB) and advancing its Asset Management System (AMS). MnDOT outsourced the collection of DABs to contractors with these requirements provided in special provisions. They launched a website offering downloadable DAB templates and contact personnel for each asset class. Contractors are required to submit digital as-builts as well as marked changes on plans during construction and send these files to a centralized email system for review and approval by district and central office personnel. As-built data passes through quality control checks before approving as-built information and importing that to the AMS (Unkefer et al., 2024b). MNDOT AMS includes a Transportation Asset Management System (TAMS), which holds data for ancillary assets such as signals, signs, culverts, etc. Data for Tier 1 as pavement and bridge asset classes are captured in the Pavement Management System (PMS) and Bridge Management System (BMS) (Mallela et al., 2024). Despite the advancement in DAB implementation, a cost analysis conducted by MnDOT showed that the cost of collecting and reconciling asset data from DAB is twice that if captured by sensors and LiDAR. As a result, a state-wide post-construction LiDAR data collection project is proposed for future development (Mallela et al., 2024; Unkefer et al. 2024).

MnDOT also implemented model-based Digital As-Builts (DABs) in two pilot projects, TH 169 Redefine Elk River and 11th Street Underpass, utilizing 3D and 4D modeling tools with a CM/GC delivery approach to produce data-rich models for project design. A cloud-based design review was implemented which facilitated real-time sharing of design comments between stakeholders. This helped in mitigating construction risks early in the project and saved up to \$15 million (Unkefer et al., 2024a). During the design stage, separate 3D models were developed for each discipline, such as roadway design, earthwork, bridge drainage, and utilities, and later incorporated into a federated model to create a comprehensive project view (Unkefer et al., 2024a).

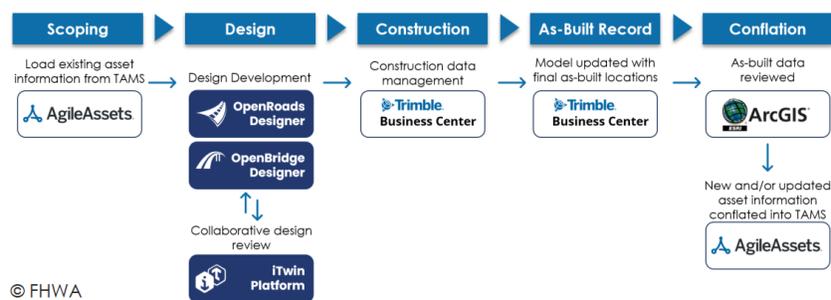


Figure 1 MnDOT Digital Workflow for asset data adopted for 11th Street Underpass Project (Adapted from Unkefer et al., 2024a)

To improve data interoperability, MnDOT collaborated with software providers for efficient data flow. Figure 1 illustrates the workflow developed on one of the pilot projects. Existing asset data flows from AgileAssets software (a TAMS platform) into Bentley software solutions for design development, such as OpenRoads Designer, then to Trimble Business Center (TBC) construction software for viewing and updating asset data during construction. Changes in asset location are captured using surveying tools and updated to TBC. After quality control checks, as-built data migrate to AgileAssets. In addition, ArcGIS is used for field data collection, where new and updated information is integrated into TAMS platform (Unkefer et al., 2024a).

2.2. Pennsylvania Department of Transportation (PennDOT)

PennDOT started in 2020 with the vision of achieving paperless project delivery by 2025. Their digital strategies for the design phase include 3D modeling, DAB, model as a legal document, roll plans, and testing new technology for the construction phase. Pilot projects are being conducted in several disciplines, such as bridges, drainage systems, and roadway sectors (PennDOT, 2017). They also expanded in 2024 to drainage and utility 3D modeling to capture their complexities. PennDOT plans to introduce digital delivery to each district and move towards open data standards using IFC as a file deliverable (PennDOT, 2024).

Like MnDOT, PennDOT has developed digital as-builts requirements, which mandate contractors to collect digital-as-builts by submitting designated asset data. This data is required in spreadsheet formats and encompass information about “assets location, installation details, asset identification and properties and inspection details” (PennDOT, 2025). Once collected, the information is submitted to the agency maintaining the asset for approval and payment. In 2023, PennDOT piloted the use of 3D models as a legal document (PennDOT, 2017). To support this initiative, the agency developed modeling standards and a model review checklist to facilitate stated-wide digital implementation (HDR, 2023, 2024) .

Besides 3D modeling endeavors, pilot projects were initiated to implement the Roll Plan requirements. The purpose is to deliver a 2D project model in a single PDF form, which contains all information required in plans, specifications, and estimates (PS&E) submittals (HDR, 2024). However, typical sections, details, and summary tabulations were delivered in traditional 22 by 34-inch formats (HDR, 2024). In the utility sector, the agency developed a centralized geodatabase and open GIS map service to capture features of existing assets (PennDOT, 2024). The centralized respiratory is based on the ASCE 75 standard to capture utility attributes like location, positional accuracy, material, depth, and feature dimensions. PennDOT has been adapting and experimenting with different software and technologies for data generation and exchange through the project phases. Figure 2 shows PennDOT-adapted digital workflow for capturing utility records, and Table 1 shows technologies tested in different pilot projects (PennDOT, 2024).

Table 1: Surveying and Visualization Technologies tested by PennDOT in Pilot Projects, (PennDOT, 2024)

Technology	Functionality	Implementation
Trimble Business Center (TBC)	Surveying and data management tool	Used by PennDOT as the main survey workflow manager to process and manage survey data
Trimble Access	Surveying data collection tool	A field software for data collection
ArcGIS Online	Data management	A cloud-based mapping and geographic information system (GIS) platform to store and analyze spatial data. PennDOT integrated ArcGIS with TBC to ensure seamless data exchange and real-time mapping.
Trimble SiteVision	Visualization	Augmented reality solution that allows users to see digital plans overlaid on the real site using a tablet equipped with a GNSS antenna. It supports real-time measurements such as distance and volumes.
PointMan	Surveying data collection tool	Field data collector application used to collect precise utility location data through a mobile application connected with GPS devices. It has a virtual online data portal and can be integrated with asset collection and Google Street View.
Pix4D Catch Pro	Visualization	A mobile-based application for reality capture that allows users to capture and process 3D point clouds and compute volumes and depths.

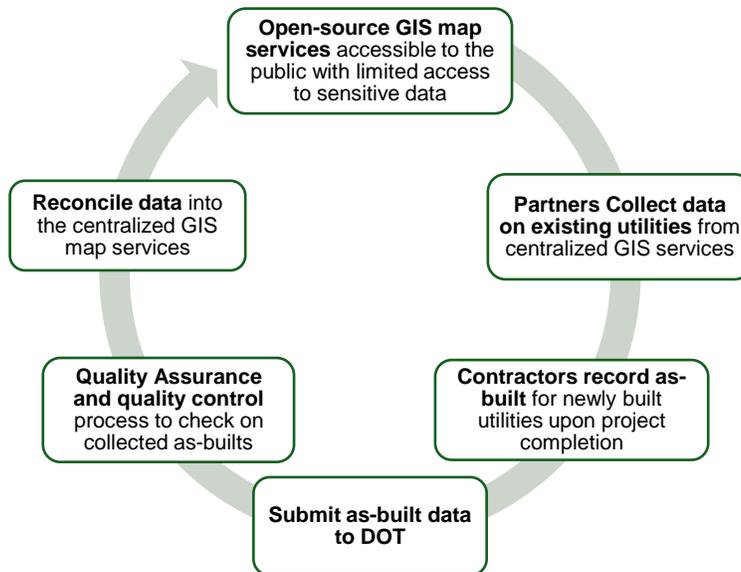


Figure 2: Utility Sector Digital Workflow Capturing records for existing and new utilities, (PennDOT, 2024)

2.3. Utah Department of Transportation (UDOT)

Utah Department of Transportation (UDOT) has long pursued the journey of digital delivery to enhance data management and workflow efficiency. Their efforts support the industry shift towards 3D modeling in the design phase and adoption of digital tools for construction and inspection. UDOT's digital delivery roadmap incorporated various strategies, ranging from the full model-based design to hybrid projects with both 3D models and PDF plans and the adoption of Scroll plots to substitute plan sheets (UDOT, 2019). Like PennDOT, the department's established standards for model development which defines the Level of Development (LOD) for various design elements, item type requirements, and model use cases, and developed a 3D workspace to improve consistency in drafting (UDOT, 2021, 2025b). The target assets for digital delivery where roadway, utility, structure, and drainage assets (UDOT, 2021).

Additionally, UDOT has developed in-house tools to support BIM-to-GIS integration and transfer pay item attributes from design models to construction tools (UDOT, 2024). BIM has become the legal record for design and construction, substituting 2D paper-based drawings with 3D models and advanced visualization and inspection technologies. Meanwhile, GIS adds spatial attributes to help track asset location and monitor construction progress. Figure 3 illustrates UDOT data workflow from design development to construction and GIS enterprise. Moving beyond 3D models, UDOT has advanced towards digital twins, which will store 3D models of existing assets and provide real-time asset information (Bills, 2024).

Initially, UDOT implemented the Construction Manager/General Contractor (CM/GC) procurement method, allowing early involvement of contractors in the design phase. This approach provided insights into how the contractors use 3D models for estimation and construction to identify the data needed for a contractual 3D model. Lessons learned from CM/GC delivery helped UDOT to expand Model-Based Design and Construction (MBDC) into design-build (DB) and Design-Bid-Build (DBB) procurement methods while ensuring that parties can fully utilize the 3D legal model (UDOT, 2019).

To address the barriers to digital adaptation, UDOT fostered a partnership approach with software vendors and project stakeholders, specifically contractors, to resolve technical and interoperability issues (Bills, 2024). UDOT developed a scoring sheet to assess project complexity and determine the most suitable partnering strategy (FHWA, 2019). The three levels of partnership adopted by UDOT were: formal partnering, where a certified facilitator leads discussions, which is crucial for complex projects with high risk; semi-partnering, which requires moderate technical assistance but does not involve a certified leader; and informal partnering, used for low-risk, low-complexity projects where issues can be resolved internally.

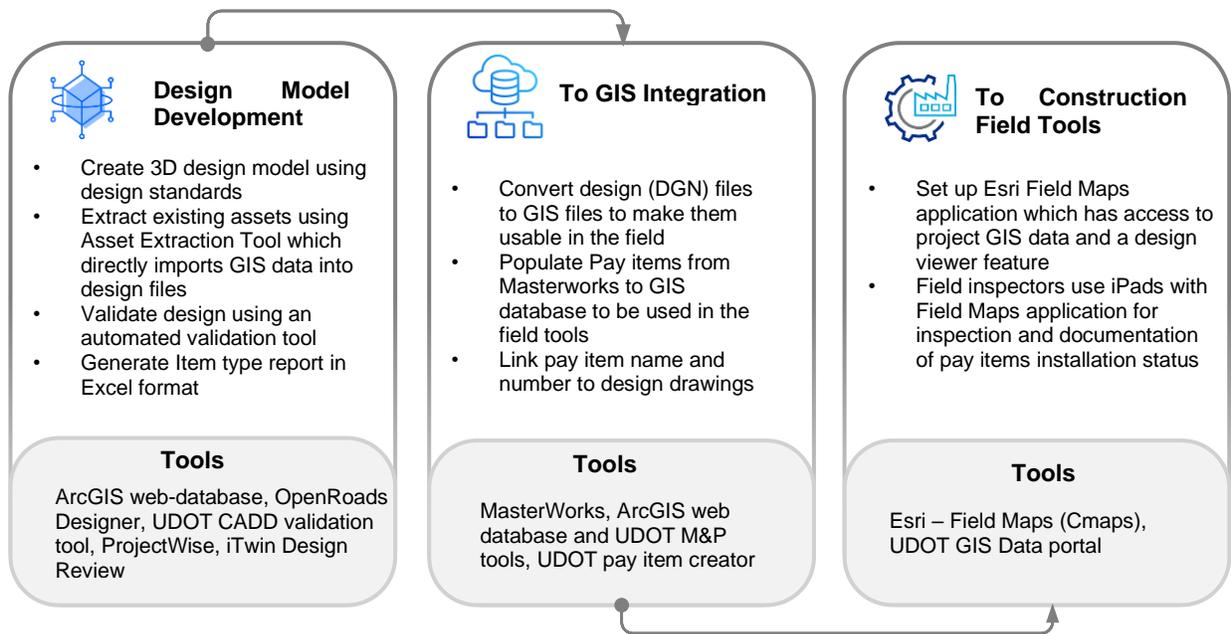


Figure 3: UDOT Data Flows and Transformation through Project Phases (UDOT, 2025a)

2.4. Iowa Department of Transportation (Iowa DOT)

Iowa DOT recognizes the benefits of digital data delivery in enhancing data management and eliminating inefficiencies in the current data flow process. To achieve this goal, IowaDOT defined the main focus areas based on current ongoing initiatives to advance digital workflows, as shown in Figure 4 (Iowa DOT, 2022b). In 2011, Iowa piloted collecting digital as-built records (DABs) for culverts, signs, and traffic barriers. In 2018, Iowa DOT piloted a 3D bridge model as a legal document in the I-80/I-380 interchange reconstruction project. The agency, in 2022, focused on understanding the data requirements, facilitating data collection and extraction, and technological advancements (FHWA, 2024a).

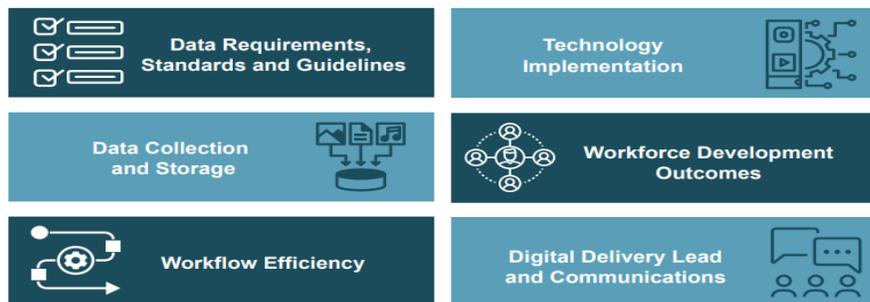


Figure 4: Six Focus Areas of Iowa DOT Roadmap (Iowa DOT, 2022b)

Digital tools like OpenRoads Designer and ProjectWise are currently used in the design phase. However, data downstream is often exchanged in electronic formats during construction, causing it to lose its digital characteristics (FHWA, 2024a). Furthermore, traditional 2D drawings are not interoperable with GIS software, which is commonly used from construction through operation and maintenance stages. Likewise, GIS data is not seamlessly linked with drafting software, creating inefficiencies. To overcome these challenges, the DOT, through a 2023 Digital AID grant, has introduced georeferencing as a norm within the design development to facilitate data integration. Also, they started developing in-house tools to achieve interoperability between design software and their GIS enterprise as well as an automated drawing verification tool to ensure compliance with agency design standards (Iowa DOT, 2022a). For 3D modeling, Iowa DOT is standardizing 3D cells for key assets (i.e. signs, barriers, and electric utilities) to facilitate model creation and ensure consistency. Additionally, IowaDOT is implementing LiDAR equipment for as-

built documentation while implementing their recent developmental specs, which require contractors to collect 3D DABs per ASCE 75 (Iowa DOT, 2023).

Pilot projects such as the reconstruction works of I-80/I-380 tested 3D BIM and 2D traditional plans in a hybrid environment. A 3D BIM model was provided as a legal document for one of the bridge ramps. During construction, Bentley View and SYNCHRO were tested for model viewing and navigation, while OpenRoads Designer and ProjectWise are the workspaces for design and 3D as-built development (FHWA, 2024a).

To ensure a smooth transition to digital delivery, IowaDOT organized a digital delivery day to inform its internal staff members from various districts about the ongoing transition. During this event, the department introduced several technologies, including, Pix4D, drones integrated with Propeller, and DirtMate software for mapping and real-time tracking solutions. OnStation is a mobile tool that allows inspectors to access project alignment using their smart devices and provides real-time project location information. SYNCHRO, another field tool being tested, provides read-only 3D models, has daily logs, and observation input features, and can track site changes. Finally, ArcGIS Field Maps, a mobile data collection tool used by inspectors, has been implemented in the operation and maintenance phase.

3- KEY CHALLENGES AND LESSONS LEARNT FROM CURRENT DOT EFFORTS

In recent years, the industry has made significant strides towards the digitalization of information, which aims to enhance data collection, exchange, and reliability. The ultimate goal is to establish a single source of truth for data collection. However, the process continues to face challenges in its implementation. This section outlines key challenges faced by DOTs, along with possible mitigation strategies for new adaptors and organizations progressing in this path. The main challenges addressed in this section are the following:

- 1- **Siloed and proprietary nature of asset data:** The tools utilized, such as design authoring software and asset inventory databases, store data models in isolated formats with limited interoperability between these tools across project phases (FHWA, 2024).
- 2- **A lack of standardization to support 3D models as legal documents:** DOTs face challenges in achieving consistency in digital design development. The lack of standards and guidelines highlighted the need to define 3D modeling requirements for different assets (FHWA, 2024).
- 3- **Limited technical skills to effectively utilize emerging technologies:** Training efforts and investments are required to equip CAD and non-CAD users with the necessary technical skills to adapt to evolving digital workflows (UDOT, 2019).
- 4- **Resistance to change from internal and external stakeholders:** Internal and external traditional processes are being changed which may face resistance from internal or external parties such as contractors or other bureaus when obtaining environmental and permitting approvals (PennDOT, 2024).

Based on these challenges, Table 2 highlights some of the ongoing mitigation efforts toward advancing digital delivery, drawing on some efforts made by MnDOT, PennDOT, UDOT, and Iowa DOT.

Table 2 Challenges and Examples of Implementation Strategies

Challenges	Examples of Implementation Strategies
Siloed and proprietary nature of asset data	<p>PennDOT partnered with software vendors to test proof of concept workflows, evaluating different technologies in terms of budget constraints, ease of use, positional accuracy, ability to communicate material attribution, and integration with other solutions.</p> <p>UDOT partnered with vendors and other stakeholders, such as contractors, to understand different parties' needs and developed its tool map digital delivery workflow (FHWA, 2019).</p> <p>MnDOT, PennDOT, UDOT, and IowaDOT, assigned dedicated staff to oversee digital delivery efforts and coordinate across internal and external</p>

	agencies to identify and address data exchange challenges in digital delivery implementation. (FHWA, 2024a; UDOT, 2021).
lack of standardization to support 3D models	PennDOT and UDOT, developed model design standards and advanced their workspace to include standard 3D cells to enhance consistency and accelerate 3D model production. Also, design validation tools were developed in-house to check submitted models against the agency design standard (HDR, 2023; UDOT, 2025b).
Limited technical skills to effectively utilize emerging technologies	UDOT provides digital delivery training to educate users about the evolving shifts in delivery formats and introduces new tools required to adapt to the industry change (UDOT, 2019).
Resistance to change from internal and external stakeholders	PennDOT hosted external meetings, such as the Contractor’s summits and online webinars, to increase awareness about the new digital delivery process. Additionally, external processes such as permitting and environmental approvals still require 2D traditional plan sets as a deliverable (FHWA, 2024a; PennDOT, 2024). Thus, PennDOT integrated stakeholder requirements into their digital delivery workflows. Actions taken include using 3D models to extract standard permit plans and using iPads to capture images from the site and tag them to 3D models to develop environmental reports (PennDOT, 2024).

4- CONCLUSION

To conclude, this paper summarizes the ongoing efforts by DOTs toward digital project delivery. Key efforts include establishing a centralized asset management system, developing standards and guidelines for producing 3D design models as a legal document, defining digital as-built (DAB) specifications for data collection, and addressing data interoperability between design software and GIS to facilitate data migration from design to construction and asset management. These initiatives serve as the foundation for developing 3D digital twins for existing assets, and various DOTs have adopted these strategies to advance toward digital twin implementation. Collectively, these efforts play a crucial role in decarbonizing the construction industry for infrastructure assets.

While this study presents various tools and practices, its scope of work is limited to publicly announced efforts of four DOTs, specifically MnDOT, PennDOT, UDOT, and IowaDOT. As a future recommendation, the authors suggest expanding this review to include other DOTs moving towards digital delivery and conducting state-wide surveys to gather more insight into different ongoing efforts and related barriers. By identifying state-wide practices, future research can focus on comparing different technologies in terms of ease of use and cost-effectiveness for digital delivery based on broader implementation experiences.

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