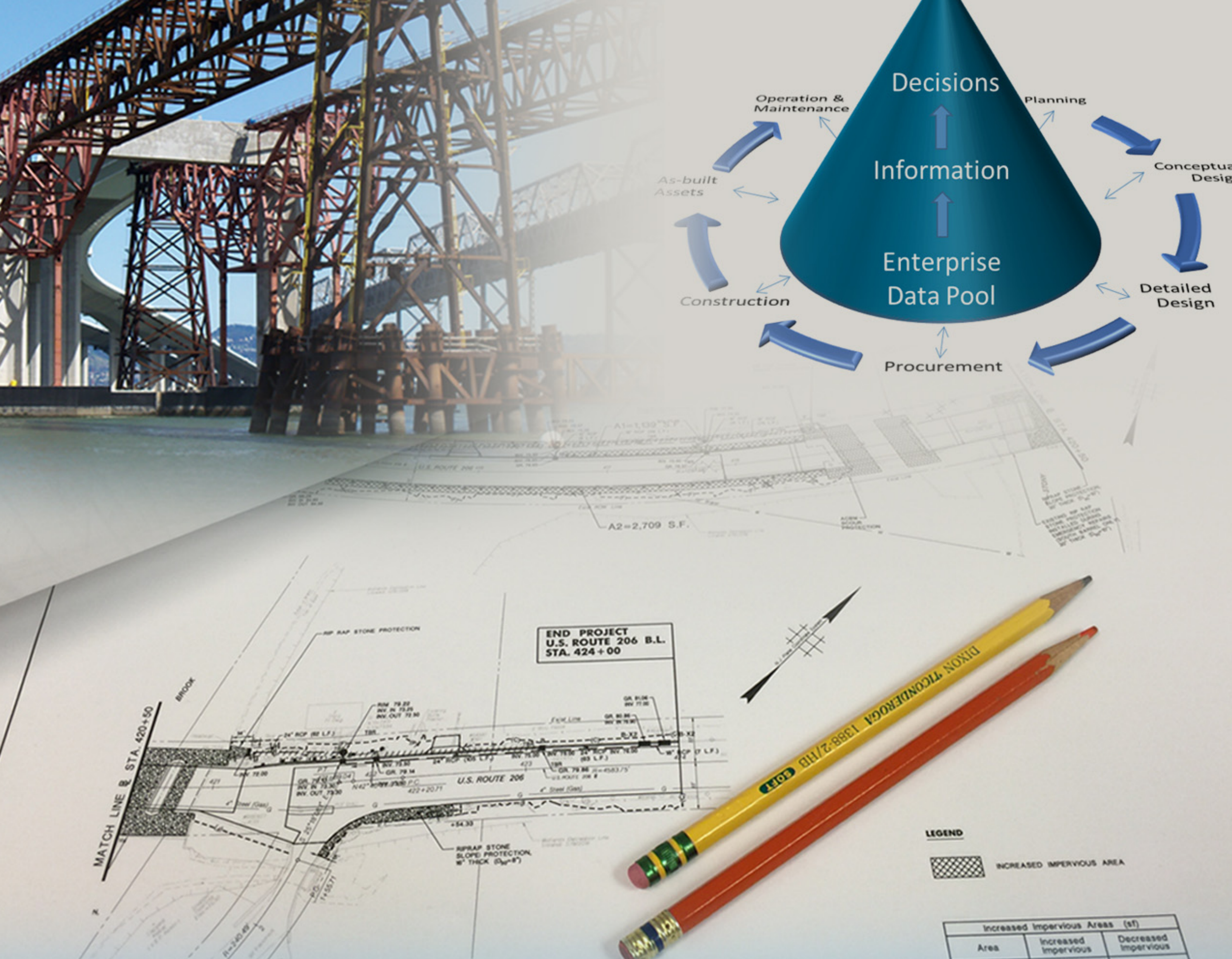


SCAN TEAM REPORT

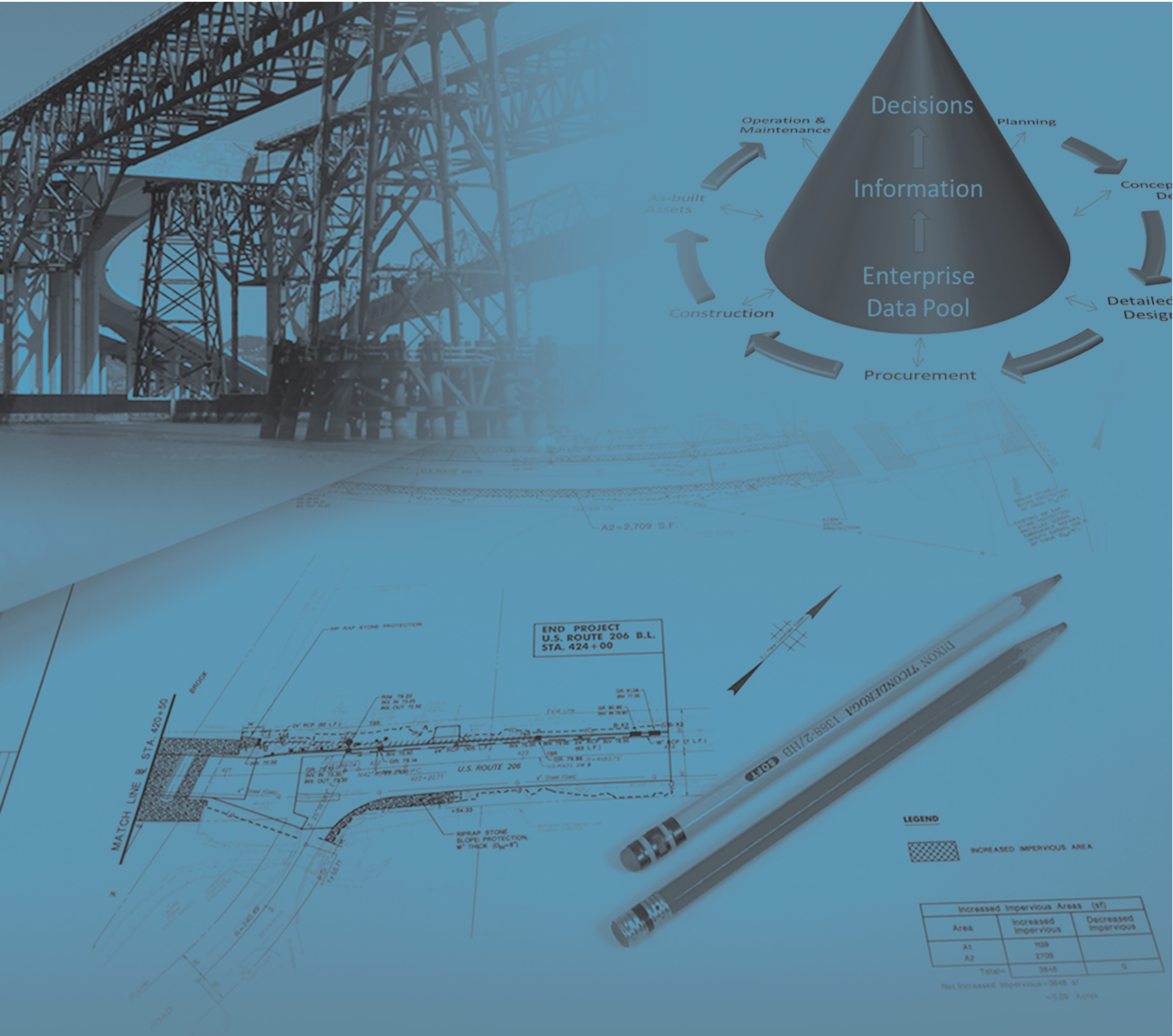
NCHRP Project 20-68A, Scan 13-02

ADVANCES IN CIVIL INTEGRATED MANAGEMENT

Supported by the

National Cooperative Highway Research Program

April 2015


Decisions
Information
Enterprise Data Pool
Planning
Operation & Maintenance
As-built Assets
Construction
Procurement
Detailed
END PROJECT
U.S. ROUTE 206 B.L.
STA. 424+00
U.S. ROUTE 206
LEGEND
INCREASED IMPERVIOUS AREA
Increased Impervious Areas (sf)

Acknowledgments

The work described in this document was conducted as part of NCHRP Project 20-68A, the U.S. Domestic Scan program. This program was requested by the American Association of State Highway and Transportation Officials (AASHTO), with funding provided through the National Cooperative Highway Research Program (NCHRP). The NCHRP is supported by annual voluntary contributions from the state Departments of Transportation. Additional support for selected scans is provided by the U.S. Federal Highway Administration and other agencies.

The purpose of each scan and of Project 20-68A as a whole is to accelerate beneficial innovation by facilitating information sharing and technology exchange among the states and other transportation agencies, and identifying actionable items of common interest. Experience has shown that personal contact with new ideas and their application is a particularly valuable means for such sharing and exchange. A scan entails peer-to-peer discussions between practitioners who have implemented new practices and others who are able to disseminate knowledge of these new practices and their possible benefits to a broad audience of other users. Each scan addresses a single technical topic selected by AASHTO and the NCHRP 20-68A Project Panel. Further information on the NCHRP 20-68A U.S. Domestic Scan program is available at http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1570.

This report was prepared by the scan team for Domestic Scan 13-02, Advances in Civil Integrated Management, whose members are listed below. Scan planning and logistics are managed by Arora and Associates, P.C. Harry Capers is the Principal Investigator. NCHRP Project 20-68A is guided by a technical project panel and managed by Andrew C. Lemer, PhD, NCHRP Senior Program Officer.

The scan team members include the following individuals:

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Disclaimer

Scan 13-02
Advances in Civil Integrated Management

REQUESTED BY THE

American Association of State Highway and Transportation Officials

PREPARED BY

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SCAN MANAGEMENT

Arora and Associates, P.C.
Lawrenceville, NJ

April 2015

The information contained in this report was prepared as part of NCHRP Project 20-68A U.S. Domestic Scan, National Cooperative Highway Research Program.

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Abbreviations and Acronyms

3D	Three-Dimensional
4D	Four-Dimensional (i.e., 3D engineered models + schedule)
5D	Five-Dimensional (i.e., 3D engineered models + schedule + cost elements)
AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
AGC	The Associated General Contractors of America
AMC	Automatic Machine Control
AMG	Automated Machine Guidance
ARTBA	American Road and Transportation Builders Association
CADD	Computer-Aided Design and Drafting
CIM	Civil Integrated Management
CMV	Compaction Meter Value
CORS	Continuously Operating Reference Stations
DFW	Dallas-Fort Worth
DOT	Department of Transportation
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HARN	High Accuracy Reference Network
HOT	High-Occupancy Toll
IC	Intelligent Compaction
ICST	Intelligent Construction Systems and Technologies
IFC	Industry Foundation Classes
IT	Information Technology
LiDAR	Light Detection and Ranging
MDOT	Michigan Department of Transportation
MDP	Machine Drive Power
NCHRP	National Cooperative Highway Research Program
NSRS	National Spatial Reference System
NYSDOT	New York State Department of Transportation
PennDOT	Pennsylvania Department of Transportation
PI	Public Information
PPP	Public-Private Partnership
RTK	Real-Time Kinematic
TRB	Transportation Research Board
UAV	Unmanned Aerial Vehicles
UDOT	Utah Department of Transportation
VDOT	Virginia Department of Transportation
WisDOT	Wisconsin Department of Transportation

Executive Summary

The rapid development of information technologies is transforming how construction project information is produced, exchanged and managed throughout a transportation project's life cycle. This transformative change is accelerating due to the availability of intelligent construction systems and technologies, and the pressing need for better, faster, and smarter ways of delivering projects. With ample evidence and success stories from the vertical construction industry and some promising case study results from the highway industry, a significant improvement in data sharing among project participants and across project development stages is possible with a model-based project delivery process and digital data transfer systems. In turn, this will translate into increased productivity, efficiency, and accountability.

The Federal Highway Administration (FHWA) and three other national associations: the American Association of State Highway and Transportation Officials (AASHTO), the American Road and Transportation Builders Association (ARTBA), and The Associated General Contractors of America (AGC) have quickly captured the concept of this new business paradigm, and they defined the term Civil Integrated Management (CIM) as follows:

> *"Civil Integrated Management (CIM) is the collection, organization, and managed accessibility to accurate data and information related to a highway facility. The concept may be used by all affected parties for a wide range of purposes, including planning, environmental assessment, surveying, construction, maintenance, asset management, and risk assessment."*

Based on the discussions during scan team meetings, the 13-02 scan team decided that addressing the importance of data usage throughout the entire life cycle of a transportation facility is desirable. Furthermore, the team acknowledged that design is an integral contributor and user of life cycle data so the scan team suggests that the original definition of CIM be modified to the following:

> *"Civil Integrated Management (CIM) is the technology-enabled collection, organization, managed accessibility, and use of accurate data and information throughout the life cycle of a transportation asset. The concept may be used by all affected parties for a wide range of purposes, including planning, environmental assessment, surveying, design, construction, maintenance, asset management, and risk assessment."*

To explore the concept of CIM and the potential implementation of CIM within transportation agencies further, the Scan 13-02 team devoted two weeks to the scan during the summer of 2014. The participating department of transportation included Iowa, Michigan, New York, Texas, Utah, Virginia, and Wisconsin. Each state DOT and its contractors presented their experiences and insights into the implementation of CIM-related practices and tools.

This scan's focus area included the following:

- Technical factors
- Organization factors
- Proven, efficient intelligent construction technologies
- Construction project performance measures
- Successful partnering techniques

- Digital data to provide the information and knowledge for planning, operation, and maintenance phases
- Opportunities that would benefit an entire transportation agency
- Opportunities for collecting and using geospatial data

CIM concepts can be categorized as foundational concepts, enabling technologies, and contributing technologies. Agencies might consider first starting with some foundational concepts that facilitate CIM implementation. Next, consider enabling technologies that are highly useful in a CIM system. Contributing technologies may not be necessary for initial CIM implementation; however, they have the potential to amplify the usefulness of a CIM system. The following is a list of foundational concepts, enabling technologies, and contributing technologies.

Foundational Concepts

- Establish a data warehouse or enterprise integration core that stores data, information, and knowledge on existing transportation assets and new or planned transportation projects
- Promote innovation within the whole agency
- Ensure that information technology arrangements are responsive to agency business needs
- Enable users to obtain needed data and improve decision making
- Employ model-based design as a starting point for CIM implementation
- Consider other possible areas to jump-start CIM
- Think beyond the next customer to ensure that data remains useful during the facility's entire life cycle and throughout the enterprise
- Establish a strong geospatial foundation and consider investments in the National Spatial Reference System (NSRS)
- Use common exchange formats to facilitate wide sharing of data
- Employ information modeling within the agency
- Make the required information technology (IT) investments to support a large concept
- Collaborate with contractors and utility trade groups to enhance the usefulness of CIM and enlist support.

Enabling Technologies

- Geographic information systems (GISs)
- Three-dimensional (3D) engineered models
- Light Detection and Ranging (LiDAR)
- Global positioning systems (GPSs)
- Automated machine guidance (AMG)/automatic machine control (AMC)

- Mobile devices
- Electronic document management systems

Contributing Technologies

- Intelligent compaction (IC)
- Electronic signatures
- 4D/5D models (adding schedule/schedule and cost dimensions to 3D engineered models)

Implementation plans or frameworks should be developed to serve as case studies and examples that would help agencies in their CIM development efforts. Peer exchange workshops should be held to demonstrate data pool development efforts, data governance approaches, data exchange formats, and workflow development.

The scan team identified and is pursuing outreach activities to disseminate their findings and support further adoption of CIM.

1 Introduction

Background

The rapid development of information technologies is transforming how construction project information is produced, exchanged and managed throughout a transportation project's life cycle. This transformative change is accelerating due to the availability of intelligent construction systems and technologies, and the pressing need for better, faster, and smarter ways of delivering projects. With ample evidence and success stories from the vertical construction industry and some promising case study results from the highway industry, a significant improvement in data sharing among project participants and across project development stages is possible with a model-based project delivery process and digital data transfer systems. In turn, this will translate into increased productivity, efficiency, and accountability.

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Project Description

The original problem statement submitted for this scan is as following:

> NCHRP 20-68A – US Domestic Scan Program
>
> Scan 13-02 Advances in Civil Integrated Management (CIM)
>
> Over the past 20 years there has occurred a dynamic evolution in the use of computers to assist in highway construction efforts. The application of computer driven total station, laser guidance systems, automated machine guidance systems, three-dimensional (3D), four-dimensional (4D), or five-dimensional (5D) modeling of complex construction strategies, or remote modeling of assembly of bridge elements, has resulted in more efficiency and accuracy than ever before. In addition, contract administration has evolved such that contract administration tools are being used that enhance partnering between owners, consultants, materials suppliers, and contractors to optimize just in time delivery of services and materials.

The purpose of this scan is to examine projects that utilize CIM technologies and partnering efforts between state DOTs, consultants, contractors, and materials suppliers. This scan considers organization factors (e.g., size of program, degree of centralization or decentralization, and outsourcing) that may influence a state DOT's, consultant's, materials suppliers', or contractors' ability to utilize CIM. The scan team identified and examined CIM type projects across the nation.

The team should meet with project management, design, materials suppliers, and construction staff to assess the effectiveness of the technology and partnering efforts currently being used by the state DOTs, consultants, materials suppliers, and contractors. Specifically, the scan team should document:

- Identified proven intelligent construction technologies
- Construction project performance measures being used
- Successful partnering techniques, including virtual meetings, wireless data sharing, and paperless communication, as applicable

The findings of this scan will assist agencies in identifying when and where to effectively employ intelligent construction technologies. The results will also identify successful partnering techniques being used by state DOTs, consultants, contractors, and materials suppliers in utilizing intelligent construction technology. Finally, the results of this scan will serve as a valuable precursor to a new research project approved by the AASHTO Standing Committee on Research for inclusion in NCHRP's FY2014 research program, problem statement D-12, "Civil Integrated Management: Benefits and Challenges."

Agencies will benefit from this scan by gaining knowledge of the use of CIM practices and tools in highway construction projects utilizing emerging intelligent construction technologies and partnering for the fast, efficient, and safe delivery of projects.

As the scan team planned and conducted the scan, the objectives of the investigation broadened to provide greater emphasis on opportunities that would benefit an entire transportation agency, rather than only those opportunities in the design and construction phases of a facility's life cycle. Greater emphasis was placed on encouraging the use of digital data to provide the information and knowledge necessary for decisions that are made during the planning, operation, and asset management (including maintenance) phases. Opportunities for the collection and use of geospatial data were also considered. This shift of emphasis resulted in a greater interest in enterprise-wide data, information, and knowledge pools; data governance and information technology infrastructure; and how to meet the goals of having greater data-use flexibility and structuring reports to transmit information and knowledge more effectively.

Team Membership and Assigned Responsibilities

Experts from across the nation and covering all AASHTO regions made up the scan team. Individuals were selected based on their experience and interest in working on the subject issue. Table 1.1 presents the list of scan team members along with their organization. Scan team biographical sketches and contact information are provided in Appendix A and Appendix B, respectively

Table 1.1 Scan team members

Team member	Organization
John Adam, AASHTO Co-Chair	Iowa Department of Transportation (DOT)
Bryan Cawley, FHWA Co-Chair	FHWA
Katherine Petros, FHWA Co-Chair	FHWA
Duane Brautigam	Florida DOT (FDOT)
Rebecca Burns	Pennsylvania DOT (PennDOT)
Stan Burns	Utah DOT (UDOT)
Julie Kliewer	Arizona DOT (ADOT)
John Lobbestael	Michigan DOT (MDOT)
Randall R. Park	Utah DOT
Charles T. Jahren, Subject Matter Expert	Consultant

Leadership in organizing the project, directing the team, setting up meetings, and publishing findings was provided by Arora and Associates, P.C. Harry Capers, PI and Melissa Jiang were Arora's primary representatives.

Methodology

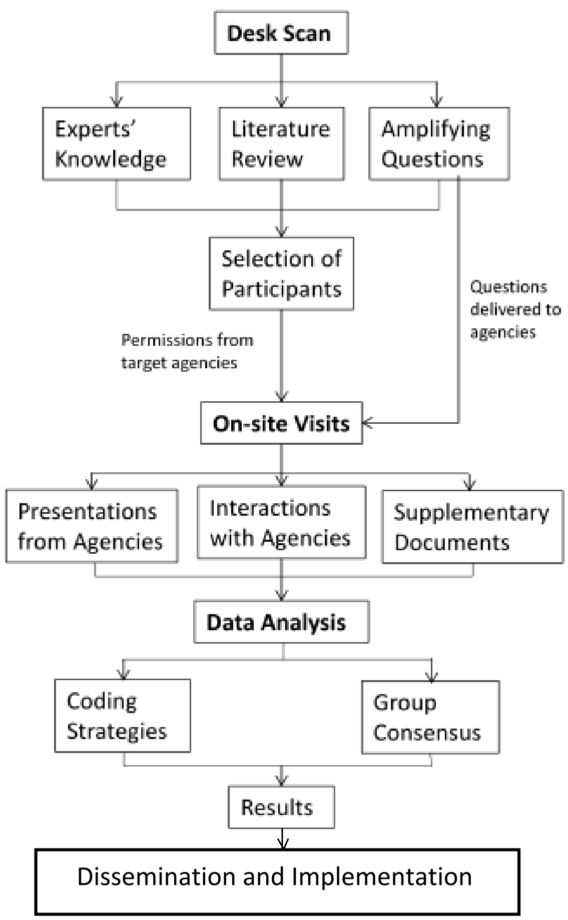

Figure 1.1 Scan project's methodology flowchart

Figure 1.1 shows the overall flowchart for the methodology adopted for this project. Initially, a desk scan was performed that included a literature review, personal contacts with experts, and internet searches, including visits to agency and project websites that use some CIM practices and tools. This effort identified CIM foundational components and CIM practices and tools used by projects and agencies. Based on the results of the desk scan, the scan team selected prospective host agencies to visit.

The scan team developed amplifying questions, and the subject matter expert combined and organized these questions within five categories to facilitate discussion and provide insights:

- Technical Considerations
- Organizational Considerations
- Performance Measures
- Legal Considerations
- Future Vision

Table 1.2 Places visited during the scan tour

State	Agency	Major Presentation Focus
Iowa	Iowa DOT central office	Implementation of CIM with initial emphasis on statewide use of three-dimnsional (3D) engineered models.
Michigan	Michigan DOT central office with project-based presenters	Implementation of CIM with initial emphasis on electronic document management for construction administration systems and 3D engineered models
New York	New York State DOT main office	Implementation of CIM based on mature 3D engineered models and document management system
Texas	Texas Horseshoe project office	Use of CIM tools in a large design-buld project
	Dallas-Fort Worth Connector Project office	Use of CIM tools in large design-build Public Private Partnership project that included post-construction maintenance expectations
	Beck Group-Dallas Kiewit Infrastructure South (a JV partner of Northgate Constructors)	
Utah	Utah DOT central office with regionally based presenters	Implementation of CIM with initial emphasis on bulk GIS data collection[1]
Virginia	Virginia DOT I-95, I-495 Express Lanes Mega Project office	Use of CIM tools in large design-build PPP project that included post-construction maintenance expectations
Wisconsin	Wisconsin DOT SE Freeway Program office (included statewide presenters)	Implementation of CIM with initial emphasis on use of 3D engineered models for urban freeway design and construction

Appendix C provides the categorized amplifying questions.

Arora and Associates, PC provided the amplifying questions to the host agencies and arranged for the team to visit host agencies listed in Table 1.2.

[1] UPlan UDOT Map Center, Utah Department of Transportation, http://uplan.maps.arcgis.com/home/

Appendix D provides host agency contact information.

Scan team members visited each host agency over a two-week period in July and August 2014. Local experts presented their organizations experiences and answered the amplifying questions. There was extensive interaction between team members and the hosting agencies during these presentations. Team members then met independently to develop the key findings presented in this report.

2 Overall Concept of Civil Integrated Management

CIM is deeply associated with data, the information derived from the data, and knowledgeable decisions that result from analysis of the information. The decision-making process for transportation projects is challenging because there are many stakeholders with varying perspectives and constraints. Decisions are made throughout a facility's entire life cycle: from planning, design, procurement, construction, as-built assets, operation, and maintenance to the planning of the next life cycle.

Data should be collected or created as early as possible during each phase of a facility and stored in an enterprise data pool so that it can be used for other purposes during other phases (Figure 2.1). An enterprise data pool is preferable over a project-centric data pool for CIM implementation because numerous parties need to access and use the data during multiple phases of the transportation asset's life cycle.

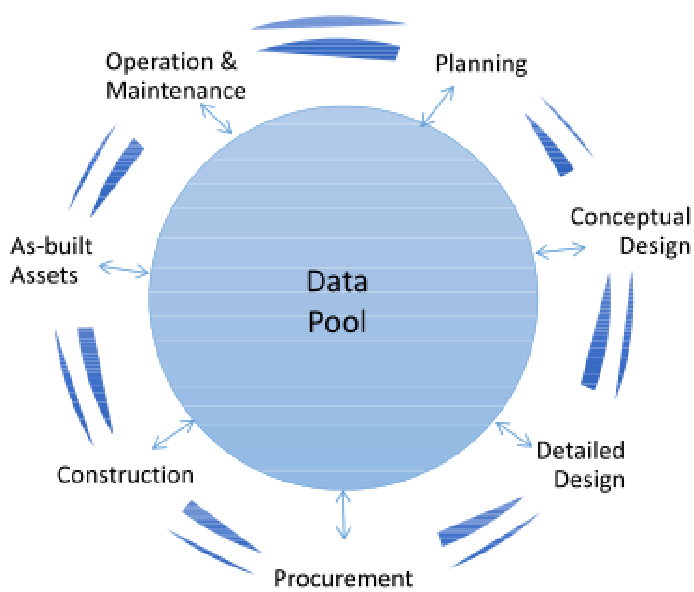

Figure 2.1 Enterprise data pool

To ensure objectivity and transparency, it is preferable that decision processes be data driven. Unfortunately, the data, information, and knowledge needed to make the decisions are often scattered and exist in a variety of formats, including hard copy, electronic files for PC business applications, and in mainframe databases that have serious interoperability challenges. It would be desirable to develop a system of practices and tools for CIM that would provide:

- A common data, information, and knowledge pool
- Standard processes for transforming data into information and information into knowledge
- Electronic data transfer protocols
- Long-term data storage and accessibility

The core building blocks of CIM are geo-located asset data, including 3D engineered models, which are compatible with Intelligent Construction Systems and Technologies (ICST) technologies, such as:[2,3]

- LiDAR (light detecting and ranging for surveying and establishing data points for physical features)
- Subsurface geophysics (location of the water table or underground conflicts)
- Automated machine guidance (AMG)
- Intelligent construction technology

The departure from traditional document-based project delivery and management to a system based on models requires redefined workflow processes, creates digital data storage and data interoperability issues, and raises legal issues such as the ownership of digital data and models. Prominent CIM practices and tools that were explored in this scan are shown in Figure 2.2.

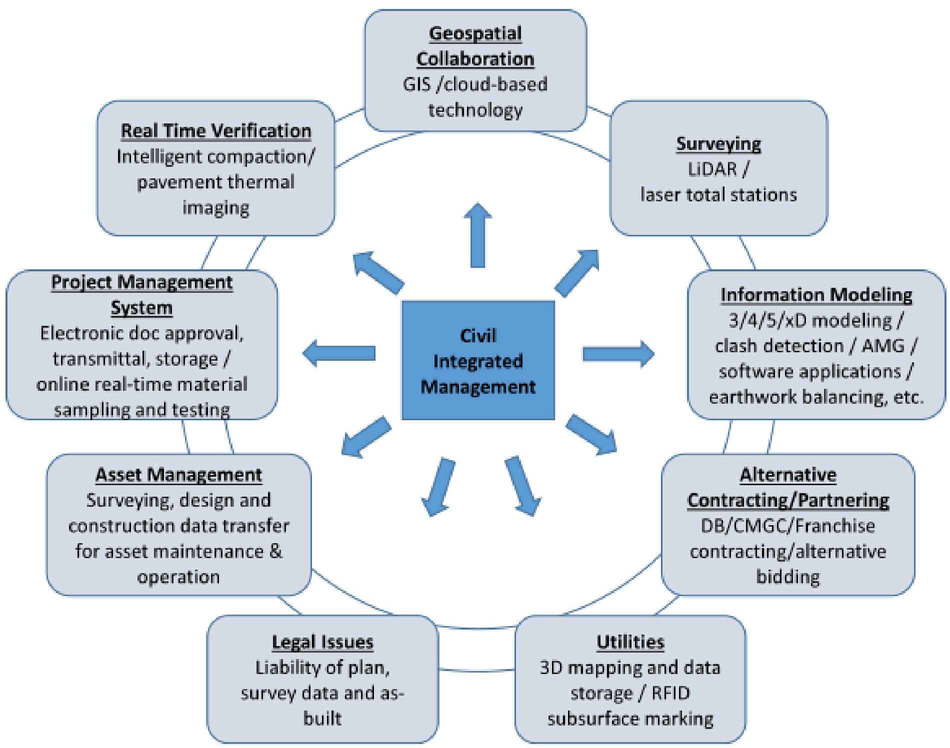

Figure 2.2 CIM practices and tools (adapted and modified from Intelligent Compaction, FHWA, 2013)

Civil Integrated Management Building Blocks

Geospatial Collaboration

Geospatial data collaboration is important to consider so that the project team and external parties can make effective decisions that result in the successful delivery of the project. For example, a geographic information system (GIS) allows the project team to perform spatial analyses and create an augmented

2 FHWA EDC. (2013). "3D Engineered Models for Construction Implementation Plan." Every Day Counts. 1-20.

3 Ralls, M. L., (2013), The Second Letter Report of the Transportation Research Board's (TRB's) Committee for Intelligent Construction Systems and Technologies: Program Review, Letter addressed to the Administrator of Federal Highway Administration by the chair of TRB Committee for Intelligent Construction Systems and Technologies, November 26, 2013

reality environment with object-oriented spatial data, which are especially useful during planning phases. The FHWA is now promoting cloud-based technology that enables GIS data sharing between parties to facilitate geospatial collaboration. Data accessibility could facilitate better collaboration among team members and external partners, which could enable more effective decisions. Data sharing can also save some information technology (IT) personnel effort and the cost of external web maps.

Surveying

CIM facilitates the collection of high-grade spatial data by using technologies such as LiDAR, robotic total stations and real-time kinematic (RTK) global positioning system (GPS) devices. LiDAR refers to an active sensor system that uses laser light to rapidly measure distances between the sensor and points on the ground, hard surfaces, buildings and vegetation to collect and generate densely spaced and highly accurate position data.[4] RTK GPS involves the use of at least two GPS receivers, where "at least one receiver is set up over a known (reference) point and remains stationary, while another (rover) receiver is moved from point to point."[5] Additional information regarding the application of LiDAR and RTK GPS is available in Chapter 5 of FHWA's Project Development and Design Manual.[6]

The collected spatial data could be used to generate maps and other intermediate electronic data products (e.g., digital terrain models, 3D models, cost estimates, and schedules). Such intermediate electronic data products are developed as data is transformed into knowledge. Construction, maintenance, and operation personnel can access the retained original data as necessary to address the needs of these downstream functions. The initial data collection effort should be done carefully to ensure sufficient reliability and accuracy. The data should be able to tie to a robust datum for it to be useful for downstream users. Steps must be taken to preserve the originally collected data in sufficient detail during processing.

Information Modeling

Spatially organized information is especially useful for planning, designing, constructing, operating, and maintaining transportation facilities. Most stakeholders are focused on and need to understand how the components of a transportation facility are located in the real world or the proposed real world. Three-dimensional engineered models provide an excellent electronic visual representation that is intuitive. Data, information, and knowledge are linked to locations and can be efficiently retrieved. It is important that the model be sufficiently accurate and tied to a robust datum so that it can serve the intended purposes. Some models that are developed for planning or stakeholder involvement purposes may not have the desired traits. The advantages of the file sharing and organization that CIM provides will be a key requirement to provide the necessary "infrastructure" so that such models reach their full potential. Standardized exchange languages (e.g., LandXML[7], TransXML[8], or Industry Foundation Classes[9] [IFC]) can be used to avoid data loss or damage when files are transferred from one software platform to another.

Alternative Contracting and Partnering

CIM will require the support of new layers of communication and trust between not only contractual

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4 Project Development and Design Manual, Chapter 5: Surveying and Mapping, p 5-24, Federal Highway Administration, December 17, 2014, http://flh.fhwa.dot.gov/business/resources/design/pddm/Chapter_05.pdf

5 Project Development and Design Manual, Chapter 5: Surveying and Mapping, p 5-21, Federal Highway Administration, December 17, 2014, http://flh.fhwa.dot.gov/business/resources/design/pddm/Chapter_05.pdf

6 Project Development and Design Manual, Chapter 5: Surveying and Mapping, Federal Highway Administration, December 17, 2014, http://flh.fhwa.dot.gov/business/resources/design/pddm/Chapter_05.pdf

7 LandXML.org, http://www.landxml.org/

8 TransXML, Cambridge Systematics, Inc., http://www.transxml.org/

9 IFC - Industry Foundation Classes, http://www.ifcwiki.org/index.php/Main_Page

stakeholders, but also individuals from different functional areas within the agency. As of this writing, parts of a full CIM system have been implemented on a project level where alternative contracting methods, the design-bid-build delivery system, and partnering arrangements have been in use. Contracting methods typically address the cooperation among organizations (i.e., contract stakeholders), while partnering attempts to emphasize cooperation among participants at the project team level, which may or may not be associated with the same stakeholder organization. Legal issues may be mitigated when alternative contracting methods and partnering are used because they may reduce adversarial relationships among stakeholders.

Utilities

Accurately knowing the location of subsurface utilities is an important consideration across the entire life cycle of a facility. CIM supports the use of 3D models that can spatially document the location of utilities and connect them with a database that will provide other necessary information. Considerable effort has recently been invested in locating utilities and including them in designs and construction plans. CIM can amplify the benefits of this investment by providing the data in a format that is easy to understand and share.

Legal Issues

Because CIM allows and promotes relatively effortless sharing of electronic engineered data, issues of ownership and licensure may need to be resolved in some cases. Alternative contracting methods and effective partnering may mitigate such issues. However, it will be important to document the involvement and supervision of unlicensed individuals in the creation of electronic engineering data and to arrange to preserve the integrity of the products of their efforts. Model sharing and version control by several stakeholders may present implied warranty and design challenges as CIM moves forward. The National Cooperative Highway Research Program[10] (NCHRP) Legal Research Digest 58[11] discusses the legal issues related to model ownership, authorization of model updates, model distributors, interoperability for software developers, participants' liabilities, digital intellectual property, copy right, and other issues.

Asset Management

Within a facility's full life cycle, considerable effort is required to preserve and maintain the facility as an asset. All of the data, information, and knowledge that is generated in its design and construction can potentially be available to enhance the operation, maintenance, and planning for future rehabilitation or rebuilding. Furthermore, CIM can act as a repository for additional data, information, and knowledge that is generated during operation and maintenance by linking to pavement management systems, bridge management systems, and similar knowledge bases. Seamlessly using electronic engineered files generated during planning, design, and construction, can save effort as assets are managed, providing superior results.

Project Management System

Planning, designing, constructing, operating, and maintaining transportation facilities are truly a team effort that requires the participation of many stakeholders. Each stakeholder requires shared access to data, information, and knowledge that could be electronically accessed from a CIM system.

A project management system gives all stakeholders controlled access to electronic files that they are authorized to access at various levels of functionality (e.g., view, edit, create, and delete). Transparency

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10 National Cooperative Highway Research Program, Transportation Research Board, http://www.trb.org/NCHRP/NCHRP.aspx

11 Legal Issues Surrounding the Use of Digital Intellectual Property on Design and Construction Projects, Legal Research Digest 58, March 2013, National Cooperative Highway Research Program, http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_lrd_58.pdf

is maintained by time-stamping events such as the addition and modification of files. It is critical that this part of the system be properly operated for CIM to operate properly. For example, this part of the system will make original survey data files that were collected during the planning phase available to construction personnel or ultimately to design personnel several years in the future when a decision is made to rehabilitate a facility near the end of its service life. If a maintenance issue surfaces, the results of quality control tests performed during construction can be retrieved to assist with troubleshooting. Issues of data storage, data transfer, and interoperability must be addressed when this CIM system component is developed.

Real-Time Verification

Real-time verification systems, coupled with geospatial data-collection capabilities such as intelligent compaction (IC) and pavement thermal imaging database (similar to survey and LiDAR data), require considerable file storage capability. Furthermore, considerable computer processing and, in some cases, human judgment are necessary to transform this data into information and, ultimately, to use this data and information to make decisions. These are examples of files that a project management system can retain and asset managers can use, in addition to construction quality control and contract administration.

Facilitating Effective Decision-Making

In general, a CIM system can potentially facilitate a more effective decision-making process by using and integrating various advanced tools or technologies throughout the transportation facility's life cycle. The scan tours, which were held over two weeks, were conducted to study the application of CIM-related practices within transportation agencies and contracting firms across seven states. The results and major findings are presented in the following sections.

3 Introduction to CIM-Related Technologies

The implementation of advanced technologies is very important for a CIM system, because they assist transportation agencies in making better decisions and increasing their overall productivity. The agencies visited have adopted a wide range of advanced technologies, which were found to be very beneficial. This section describes these technologies, the benefits and lessons learned by using these technologies, and various technical issues that should be considered during CIM implementation.

Table 3.1 summarizes CIM-related technologies implemented by the visited agencies and companies.

Table 3.1 Technologies implemented by visited agencies and companies

Agencies/ Projects	GIS	GPS	3D models	4D/5D models	LiDAR	AMG	Mobile Devices	IC	EDM	Digital Signatures
Utah DOT	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔
Texas Horseshoe	—	—	✔	✘	—	✘	✔	✘	✔	✘
DFW Connector	✔	✔	✔	✔	✔	✔	✔	✔	✔	—
I-95 HOT Lanes	✔	✔	✔	✘	✔	—	—	✘	✔	✘
Iowa DOT	✔	✔	✔	✘	✔	✔	✔	✔	✔	✔
Wisconsin DOT	✔	✔	✔	✔	✔	✔	✔	✘	✔	✘
Michigan DOT	✔	✔	✔	✘	✔	✔	✔	✘	✔	✔
NYSDOT	✔	✔	✔	✔	✔	✔		✘	✔	✘

✔ = The visited agency/company has implemented the technology.
✘ = The visited agency/company has not implemented the technology.
— = The technology was not discussed during the visit.

GIS is widely used for spatial data analysis and management. UPlan, developed by Utah DOT, is a good example of a statewide GIS-based platform. The use of GPS for surveying is in common use by the visited agencies as well as by AMG by contractors. AMG is mostly used for excavation, grading, and paving work. Contractors and subcontractors choose to use AMG to shorten their schedule and to stay competitive in the market. LiDAR is extensively used in UDOT, Iowa DOT, WisDOT, and NYSDOT for surveying tasks. The implementation of 3D engineered models is relatively mature for Iowa DOT, Wisconsin DOT, and NYSDOT. 3D models are mostly used during the design and construction phases to improve visualization, design quality, and communication and to provide input for automatic machine guidance. WisDOT uses 4D models to help personnel better visualize construction sequences and improve estimate accuracy. WisDOT and Michigan DOT use mobile devices extensively. Field tablets are used to obtain or verify field data and communicate with others.

IC technology is not widely used in any of the states the team visited; however, pilot projects have been implemented in UDOT, Michigan DOT, and the DFW Connector Project. IC technology is mostly used for ensuring more uniform compaction efforts.

Iowa DOT implemented thermal imaging to assist with paving inspections. All of the agencies that the team visited used EDM; however, its implementation was relatively more mature for UDOT, Michigan DOT, and NYSDOT. MDOT, WisDOT, Northgate Constructors at the DFW Connector Project, and NYSDOT are using commercially available products, while UDOT had developed its own program (Interchange using a SharePoint[12] platform). Iowa DOT collaborated with software developer Info Tech to develop a solution (Doc Express[13]) for its electronic file storage and exchange, which was in an early stage of adoption. Digital signatures are used in UDOT, Iowa DOT, and Michigan DOT. NorthGate Constructors and TxDOT at the DFW Connector Project reported electronically sealing plans.

Geographic Information Systems (GIS)

One example of a GIS system that is useful as a foundation for developing a statewide platform is UPlan[14], which UDOT has implemented. UPlan allows users to upload, manage, and share geospatial data using its own mapping platform. Recently, UDOT has made a major effort to transition from data collection and display to data analysis for various stakeholders. As a result, communications among stakeholders has greatly improved. UPlan can perform spatial analysis on the fly, which can aid in making informed decisions. It can also cross–reference data from various sources in one view, such as transportation plans, travel demand models, and others.

UPlan gives relevant and insightful information to UDOT and to other stakeholders, such as utility companies (e.g., utility companies can now anticipate the advantages in planning alignments of future transmission lines). UPlan also has capability to use various predictive models with the stored data (e.g., congestion predictions, pavement deficiency predictions, and others). The introduction of the ArcGIS-based UPlan allowed UDOT to easily create and manage users, generate reports quickly, and use UPlan as a development tool by integrating it with other services and sites.

Initial data collection for the UPlan system involved collecting LiDAR point clouds for the highway network and then extracting the location of features and attaching metadata. The list of extracted features is extensive and includes pavements, shoulders, signs, pavement markings, guardrails, and most other elements that would be required for maintenance planning; asset inventorying; or cost estimating for resurfacing, rehabilitation, and/or reconstruction. An outstanding example of the benefits of this system is that UDOT can develop conceptual estimates for approximately 10 miles of highway reconstruction in less than an hour by querying the asset inventory for a of highway segment and matching the inventory with current construction unit prices. Such quick estimates have proven quite effective in answering state legislators' questions regarding costs for proposed projects.

Additional and unexpected uses have been found for the UPlan system, including:

- The development of a spatial database that located threatened plants so that construction could

12 What is SharePoint? Microsoft, http://support.office.com/en-us/article/What-is-SharePoint-97b915e6-651b-43b2-827d-fb25777f446f

13 Doc Express, Info Tech Inc., https://www.infotechfl.com/doc_express

14 Webcast 13: UPlan, An Interactive, Web-Based GIS Tool Developed by the Utah Department of Transportation (UDOT), February 22, 2012, Summary of the Federal Highway Administration's Quarterly Webcast on Applications of Geospatial Technologies to Transportation, Federal Highway Administration, http://www.gis.fhwa.dot.gov/webcast13_uplan.asp

avoid them and UDOT could coordinate easily with stakeholders outside the agency to make decisions regarding the extent of protection

- The efficient location of utilities so coordination could be accomplished early in the design and construction of projects
- Tools to manage renewal of leases for materials pits
- Tools to manage right-of-way, including right-of-way documented on legacy plan sets, and right-of-way markers and section corners

In planning for a GIS system such as UPlan, it is important to provide survey control that is sufficiently accurate so that the features can be located accurately. Accurate control points should be placed before the LiDAR survey is performed so that the point cloud can be tied into the survey and features located accurately so the information can be used for design and construction, UDOT plans to refresh the LiDAR surveys regularly for new construction and other changes.

Iowa DOT reported that it is cross-referencing its linear referencing system with latitude and longitude coordinates in preparation for a more robust use of GIS systems. The I-95 HOT Lanes Project in Virginia reported developing a GIS inventory of assets that requiring maintenance under the concession agreement. MDOT reported plans to develop a spatially enabled data warehouse where data could be referenced using GIS techniques.

GIS technology has been found to be beneficial for project scoping, preliminary studies, and during a project's maintenance phase. In the project's planning phase, GIS can be used to provide a broad overview of a site or to generate maps to illustrate important data or features related to project. In the project's operation and maintenance phase, GIS can be used to remind personnel about timing, location, and other maintenance task details. Standardized templates should be provided to help ensure consistency in creating and managing GIS files. In addition, when developing a customized GIS product, it is helpful to have one person from each stakeholder group (e.g., designers, surveyors, traffic safety engineers, and project managers) to discuss the possible uses so that the final product will meet the agency's needs.

Global Positioning Systems (GPS)

During the predesign survey, GPS equipment can be used to collect the original ground survey data (including topography, tie-ins, drainage, and utilities,), which can be integrated into a rough model at the beginning of a project. The underground data (e.g., drainage and utilities) can then be updated as construction proceeds. The collected data can be used to create accurate as-built plans.

GPS technology is very helpful in earthmoving and road construction. RTK GPS is used to guide earthmoving equipment when combined with wireless communication and a computer system to provide AMG. When using AMG, operators know when the ground-engaging equipment (e.g., a bulldozer blade or an excavator bucket) has reached the desired grade[15]. When the ground is sufficiently close to the desired grade, it is often possible to place bulldozers and motor graders in an automatic mode, where the blade automatically adjusts to the proper grade without human intervention.

Proper survey control is required to provide the most accuracy for RTK GPS. High-accuracy control should be provided in areas where GPS surveying for construction is being used; locations should be crosschecked

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15 El-Rabbany A, GPS for Civil Engineering Applications, from Introduction to GPS: The Global Positioning System, HIS Engineering 360, 2002 (September 15, 2014), http://www.globalspec.com/reference/66261/203279/10-4-gps-for-civil-engineering-applications

regularly between GPS equipment and control points. Preferably, the survey control should tie into the National Spatial Reference System (NSRS). Michigan DOT, WisDOT, and NYSDOT have worked closely with the National Geodetic Survey to update and increase the accuracy of the NSRS in their jurisdictions. Iowa DOT, MDOT, and NYSDOT have cooperated with the National Geodetic Survey to develop a network of Continuously Operating Reference Stations (CORS) that provide spatial corrections over a cell phone signal that can be used to increase the accuracy of GPS locations. Michigan DOT reported that agricultural and industrial interests have also found the CORS corrections to be useful, which has engendered additional public support for deploying GPS technology.

3D Engineered Models

By creating all of a project's components in a 3D model, the spatial relationship among the various elements can be checked easily so that detected conflicts can be resolved early in the process[16]. In particular, clashes between underground utilities in horizontal civil projects can be detected within a virtual environment that is similar to how "clash detection" is applied to resolve conflicts among HVAC, electrical, plumbing and structural systems in building projects. Early detection and resolution would greatly reduce the amount of rework and change orders. Using 3D models can make quantity take-off and project cost estimates more accurate. For example, , estimators using a 3D trench model could easily and accurately estimate the amount of cut and fill from existing surface elevations, trench depths, and proposed slopes[17].

Iowa and Wisconsin are both leaders in the use of 3D engineered models in design and construction; however, they came to their position of leadership in different ways. WisDOT has been systematically rebuilding all of its freeway corridors in the southeast part of the state. The program's size was so overwhelming that the management team responsible for the program realized a business-as-usual approach would not be successful. Therefore, the team launched several elements of civil integrated management with 3D modeling serving as a centerpiece of the effort. The 3D modeling effort was considered central to the program's success because it serves as a hub for other CIM elements. Most of the original data collection is by LiDAR. 3D models can accommodate the resulting processed point clouds with relative ease. The 3D model provides an excellent platform for coordinating design activities, including resolving underground utility conflicts. The models also are a basis for 4D construction simulations and traffic visualizations.

WisDOT personnel reported that choosing an appropriate level of realism when the models are rendered for viewing is important. Enough realism should be incorporated so that viewers can recognize important features; however, too much detail and realism require expensive effort that may not be necessary for the model's purposes. For example, trees might be rendered to indicate the extent of the root ball to avoid utility interference and with a simple spherical top to indicate the location of trees for members of the public who wish to understand how the proposed project will affect their neighborhood.

WisDOT's contractors use the 3D model to develop machine control files for automatic machine guidance. Ruggedized tablets are used to visualize the 3D model in the field and report issues in real time. WisDOT is also developing as-built utility plans to aid with maintenance efforts after construction is complete.

Although the Southeast Freeways Program led WisDOT in the use of 3D engineered models, the rest of the agency is systematically implementing the use this innovation statewide. The process involves training

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16 O'Brien WJ, P Gau, C Schmeits, J Goyat, and N Khwaja, Benefits of Three- and Four-Dimensional Computer-Aided Design Model Applications for Review of Constructability, Transportation Research Record, Transportation Research Board, 2012, No. 2268, 18-25, http://trrjournalonline.trb.org/doi/abs/10.3141/2268-03

17 Cylwik E and K Dwyer, Virtual Design and Construction in Horizontal Infrastructure Projects, Engineering News-Record, 2012

experienced 2D designers to design in 3D, purchasing hardware and software, coordinating with consultants, developing data exchange standards, and revising construction specifications.

Iowa DOT developed its 3D modeling program based on the willingness of its designers to accommodate contractors who wished to implement AMG earthmoving. In particular, McAninch Corporation was a leader in AMG based on its experience in the land development industry. The designers who were parties in McAninch's design-build contracts were readily willing to share their 3D engineered models so that McAninch could use them to develop machine control files. Because McAninch also executed Iowa DOT projects, company personnel approached Iowa DOT designers about the possibility of transferring 3D models in a process that was similar to that used in the land development industry. At the time, most designs were developed in 2D; however, Iowa DOT designers were interested in designing in 3D, so steps were taken to develop that ability. Upper management supported the effort and was encouraged by the highway contractor trade association, which traditionally has a good relationship with Iowa DOT. Pilot projects were let that allowed or required contractors were to use AMG and 3D engineering models. The models were transferred to contractors "for information only" with the 2D drawings serving as the contract documents. Gradually, the use of 3D models has expanded to most earth moving and concrete paving projects. . This will provide opportunities to contractors to use AMG for stringless paving. (The traditional string line that guides the paving machine is eliminated.)

These examples demonstrate that 3D engineered models can be introduced either as part of a large program or by gradual rollout using typical highway construction projects. Both agencies and contractors can lead during the implementation process.

All other visited agencies used 3D modeling to some extent. NYSDOT has a well-developed program of using 3D engineered models and is the only agency the team visited that is developing detailed 3D models for bridge construction. This was limited to the substructures because they potentially conflict with buried utilities. Superstructure designs are still produced in 2D, but the agency is investigating the use of 3D modeling for superstructures and an XML schema to facilitate the 3D modeling efforts of fabricating shops. NYSDOT also has a well-developed library of specifications and other documentation for 3D engineered models.

At the time of the team's visit, UDOT was in the process of converting to 3D modeling. Their plan is to share the model with contractors at advertising and have contractors return an as-built model when the project is completed. As plans are being developed to integrate the use of 3D engineered models into UDOT processes, consideration is being given to issues such as file transfer, model ownership, development of QC/QA procedures for models, more stringent requirements for initial surveying data collection, incorporation of utility locations, and extensions to 4D and 5D modeling. An ultimate goal would be to have the model become the record of the design. However, it was noted that 2D output was still useful, especially for documenting right-of-way transactions.

While the previously described agencies developed their 3D engineered models mostly as part of a design-bid-build project delivery system, the two projects that were visited in Texas involved alternative project delivery systems: design-build and a public-private partnership (PPP). 3D models were used to some extent in both projects. The Horseshoe project used the design-build project delivery system. 3D engineered models were used to vet the conceptual design and ensure that project participants understood the spatial relationships for the many bridges involved in the complicated interchanges that were an important part of this project. After this general understanding was established, the designer elected to complete the detailed plans using a 2D approach because it was the most efficient method from the designer's point of view.

The DFW connector project was a PPP known as a comprehensive development agreement[18]. It was created to build the project at the north entrance to the DFW Airport and manage express lanes that are free for high-occupancy vehicles and tolled for others. In addition to typical design-build services, the concessionaire provides financing and maintenance for a period after construction in exchange for being allowed to collect tolls for low-occupancy vehicles that choose to use the managed lanes. The concessionaire is a joint venture with the moniker NorthGate Constructors. Again, the designer for the concessionaire initially elected to produce 2D plans. However, the constructor elected to develop a 3D engineered model based on the 2D project plans to better visualize the design during planning (including 4D modeling) and to use of automatic machine guidance during construction. Based on this experience, Northgate Constructors reported a preference for starting earlier with the development of 3D models for future projects.

NorthGate Constructors reported the following quality control/quality assurance process for 3D models in its response to the amplifying questions:

- For 30/60/90 percent drawings:
    - Project's professional services quality control manager (a registered Texas PE) verifies that the design drawings at each stage meet the requirements of the Design Quality Management Plan.
    - Project's design/build coordinator approves.
    - Design package goes to project disciplines and to TxDOT for review and comment.
    - NorthGate Constructors receives comments, provides comments to designer, and schedules a formal review meeting for all commenting parties.
    - Formal review meeting is held, and comment resolutions are discussed.
    - TxDOT receives and approves official comment resolutions.
- For 100% ready-for-construction drawings:
    - Project's professional services quality control manager attaches a certificate of compliance that the completed drawings meet the requirements of the design quality management plan.
    - Project's design/build coordinator approves drawings for transmittal to TxDOT.
    - TxDOT reviews and approves.
    - Project releases drawings for construction.

VDOT also used a PPP to develop the I-95 HOT Lanes Project. AMG was used for some of the paving so an engineered 3D model was developed to implement the AMG.

From the standpoint of construction entities, the following are benefits of implementing the use of 3D engineered models:[19]

- 3D models convey greater clarity of design intent in comparison to traditional 2D plans.
- Time and effort are saved when contractors develop 3D construction design models because the models are a better starting point compared to 2D plans.

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18 Schexnayder, C. J., Texas Build 'EM, *Engineering News-Record*, December 30, 2013, 40-43

19 Arneson E and R Larson, Wisconsin DOT: Adopting a Model-Based Approach to Roadway Design and Construction, Autodesk University 2011, http://aucache.autodesk.com/au2011/sessions/4707/class_handouts/v1_CI4707_Arneson.pdf

- Earthwork activities are easier to plan with 3D models.
- Less staking is required when 3D plans facilitate AMG construction.
- There is less need for a contractor to execute a preliminary site survey.
- Risk is mitigated when existing surface conditions are visualized using a 3D model.

Note that most of the benefits involve the facilitation of AMG by providing 3D engineered models.

In summary, 3D engineered models are particularly important for the project design phase, as they ensure the quality of the design by providing intuitive visualization opportunities and clash detection functions. Deficiencies can be detected sufficiently early to reduce rework substantially during a project's construction phase. Moreover, these models improve communication among partners.

The team found that standard file organization rules should be developed... File formats, naming conventions and other rules should be defined and followed throughout the entire organization. When providing 3D models to contractors, providing a variety of useful uniform formats appears to be most beneficial. In addition, templates and tools that are developed in house should be shared with other participants.

4D/5D Models

4D (3D engineered models + schedule) and 5D (3D engineered models + schedule + cost elements) models would likely be beneficial to many transportation agencies. Four-dimensional models animate the construction process that shows the order in which items are installed and provides improved visualization of the construction process. This helps project managers increase the effectiveness of the planning and decision-making process. When modifications are made to the design, the 4D model animation can evaluate the effect of these changes on the construction schedule. Additionally, 4D models can help simulate traffic phasing and detour scheduling. With additional built-in cost elements, 5D models could make the estimating process much more intuitive and accurate.

WisDOT and Northgate Constructors on the DFW connector project in Texas reported using 4D models to review construction sequences. In Texas, the software application Synchro used input from MicroStation (3D modeling software application) and Primavera P6 (scheduling software application) to provide animations that illustrated proposed construction sequences. NYSDOT requires 4D models in proposals for some design-build projects. Other agencies the team visited did not report currently using 4D or 5D models; however, UDOT and Iowa DOT hope to develop such models in the future.

Light Detection and Ranging (LiDAR)

With proper sensors, LiDAR technology can capture highly accurate spatial data. Ground-based and airborne LiDAR are becoming more commonly used in the transportation industry. The 3D mesh generated from LiDAR data can be imported into other 3D modeling software applications for further model development. A model generated from LiDAR data is often more complete and accurate compared to one created using traditional surveys. Airborne LiDAR, together with aerial photography, can help detect the existing terrain conditions, especially in complex mountainous areas, to create 3D terrain models or contour maps[20]. LiDAR point clouds require considerable file storage space, so cloud data storage and high-speed data transfer that are often associated with CIM implementation can be helpful for this technology.

As reported in the Geographic Information Systems (GIS) section, UDOT has made considerable use of

[20] The Uses of LiDAR, LiDAR-UK, http://www.lidar-uk.com/usage-of-lidar/

LiDAR technology in developing its UPlan system. WisDOT has also made extensive use of LiDAR to obtain measurements of existing conditions as design input for the Southeast Freeways Program. This was especially useful for measuring overhead clearances of overhead wires and bridges. An increased safety was a particular advantage given the high-speed, high-traffic volumes in the locations where measurements were required. Another advantage was that designers could return to the point cloud and obtain additional measurements without returning to the field when additional measurements were needed. Although WisDOT has its own static LiDAR equipment, mobile LiDAR is contracted; therefore, some lead-time is required for contracts to be set before the point clouds become available. Planning is required to accommodate such lead times.

NYSDOT reported using terrestrial, mobile, and airborne LiDAR. The agency owns equipment for the first two and contracts out the last. LiDAR is especially useful in time-sensitive situations, where large areas are covered, and where traffic safety is an issue. Examples of situations where LiDAR is particularly helpful for NYSDOT include:

- Overhead-line clearance measurements
- Forensics for bridge strikes
- Bridge mapping
- Monitoring retaining wall movement
- Archeological investigations
- Corridor mapping for asset management
- Bridge drainage pipe location
- Pavement settlement measurements

With regard to asset management, NYSDOT was just starting to extract sign data out of point clouds at the time of the team's visit. Personnel expressed caution about quality control and accuracy. Airborne LiDAR is generally less accurate than terrestrial LiDAR; data should be tagged to indicate expected accuracy. In some cases, elevations may be +/- 0.3 foot on the ground and 0.2 to 0.1 foot on hard surfaces. LiDAR location output from vendors should be crosschecked against ground surveys for elevations and photogrammetry for horizontal positions. LiDAR is used for topographic surveys and breaklines, grid points, and features in traffic are extracted for design purposes.

An example of LiDAR being particularly helpful for NYSDOT was in designing a remedy for a rockslide quickly. Survey control was provided by referencing the CORS network, which saved time compared to referencing the High Accuracy Reference Network (HARN). Since HARN references to physical monuments rather than a cell phone signal, ground surveying would be needed to provide control to the rockslide area. This would typically require two or three days. Using the CORS reference, a two-person crew was able to establish control in one day and then finish the LiDAR scans in a day and a half.

NYSDOT personnel listed several advantages to using LiDAR, including that it provides reasonably accurate measurement and that considerable information can be extracted from the point cloud. After the point cloud has been captured, measurements can be taken in the office without regard to weather, and the point cloud can be revisited without returning to the field. LiDAR scanning can also be accomplished at night. The disadvantages are scanning cannot be accomplished when it is windy or precipitating; data processing is challenging especially feature extraction; and the point cloud files require massive data storage capabilities.

Iowa DOT uses mobile LiDAR for interstate highway projects and terrestrial LiDAR for data collection in smaller areas, such as Americans with Disabilities Act improvements during urban reconstruction projects. Iowa DOT personnel cautioned that some of the Iowa DOT LiDAR files were obtained from low-accuracy airborne scanning to document drainage areas, and may only have an accuracy of +/- 1.5 feet and repeated that it is important to check on the accuracy of LiDAR data before it is used.

VDOT reported LiDAR being used on the I-495 Express Lanes Project and the I-95 HOT Lanes Project. LiDAR was particularly useful for collecting data in a railroad area where the safety of a survey crew working on the ground was important. The original control for one of LiDAR collection effort was provided by GPS surveying; however, this did not provide sufficient accuracy. Subsequently, six pairs of control monuments were provided over the 30 mile length of the I-95 HOT Lanes Project using static where the control points were occupied longer and position measurements were averaged over that time to provide better accuracy. Then construction control points were set from those monuments. These control points were not considered reliable for more than a year, because their accuracy was degraded by accidental strikes, vandalism, and weather- and age-related degradation.

Michigan DOT briefly reported on its use of LiDAR on 25 trunk highway projects and the DFW Connector Project in Texas also briefly acknowledged the use of LiDAR.

LiDAR technology has been found beneficial for quickly obtaining accurate survey data and is a potential solution for as-built data collection. The accuracy of LiDAR is sufficient for most of the surveying tasks transportation agencies require. LiDAR point clouds of the actual project site could also be used to create rough 3D design models, which save time in comparison to creating the design from conventionally. When as-built data needs to be collected, LiDAR could be a good tool to document the constructed facility and its site. As-built data is important because it gives personnel a clear understanding about the actual construction result and it can be used for future construction projects. LiDAR scanners can be operated outside danger zones, yet still scan within the danger zone, thus increasing personnel safety.

Automatic Machine Guidance (AMG)

Three-dimensional models can be uploaded to the computers installed on heavy equipment (e.g., bulldozers, excavators, and road graders) to assist operators in producing work at the proper grade and alignment. Adoption of AMG improves the productivity and quality of the work performed and reduces the time and labor required in the field. AMG was used at all locations the scan team visited, except for the Horseshoe Project in Texas. Personnel explained that the Horseshoe Project consisted mostly of bridges and AMG adds less to the efficiency of such a project in comparison to earthmoving and paving projects. Most agencies reported having several meetings with contractor trade association groups and obtaining consensus from the contractors for procedures to transfer 3D engineered models and other changes necessary to facilitate AMG construction. One exception to this was NYSDOT, which reported that, the agency has implemented a compromise of procedures that appears to have been satisfactory because no consensus was reached among the four trade associations that represent the highway construction industry in New York,

As mentioned previously, certain Iowa contractors were national leaders in AMG, so the technology is relatively mature at this location. AMG construction started with earthmoving where RTK GPS provided adequate accuracy for positioning. Iowa DOT also encourages the use of AMG for concrete paving projects. RTK GPS does not provide sufficient accuracy for concrete paving, so total stations automatically track paving equipment on which prism targets are mounted. The total stations are set at convenient locations and measurements are taken to locate the total stations in a process known as resectioning. In this process,

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[21] Peyret, F et al., "The Computer Integrated Road Construction Project." *Automation in Construction*, 2000, 9, 447-461

the distance and elevation are measured from two control points and a mathematical solution provides the location of the total station. Kirk Reicks of Herold-Reicks Surveying reported that control points are required at 250-foot intervals and that the control points are marked by 30 x ½ inch rebar with plastic caps. These markers will not hold elevation over the winter. The monuments that they use for primary control are ¾ inch in diameter and about 40 inches long with anchorages that curl out at the bottom, thus securing the monument. These are sold under the trade name Feno. To obtain proper accuracy for control points for paving projects, high-accuracy level circuits must be executed using three-wire leveling and Invar rods.

Unlike the triangulated irregular network that is commonly used for earthmoving, a D45 rectangular format is used for concrete paving. Tim Tometich of Iowa paving contractor Manatts reported that templates should be spaced at 5-foot intervals or more frequently to provide sufficient accuracy. He reported that when AMG is used for concrete overlays, material overruns are reduced from the usual 15 to 20% to 5 to 6%. He also mentioned that in preparation for paving, it is good practice to operate trimmers and pavement profilers using the surveying 3D engineered model and the surveying set up that will be used for the paving operation to obtain a pre paving quality control check. Tometich listed several benefits of using AMG including not having to wait for stakes, being able to find problems before construction by viewing the 3D engineered model, being able to implement changes faster, increased safety because fewer people are on the ground near the equipment, and the absence of trip-hazard string lines. There are also many unintended benefits. For example, contractors are able to grade temporary mobile concrete plant sites more quickly using AMG.

The DFW Connector Project in Texas and the I-95 HOT Lanes Project in Virginia also reported using AMG for concrete paving.

AMG has been found to increase the overall productivity, accuracy, and safety of construction. Design changes can be quickly integrated into the design models that are prepared for AMG use, and design problems can be easily understood by viewing the design models with 3D visualizations prior to construction. It was found that the incentives for contractors might be helpful during the initial implementation stage of AMG. Agencies should coordinate with contractor to find out how to encourage the use of AMG.

Mobile Devices

The use of hand-held electronic tablets in the field has become more common on road construction projects. The tablets allow field personnel to view electronic documents (e.g., plans, instructions, manual, and standards) and other online information (e.g., training materials). Field personnel can have real-time communication with office personnel to discuss any field issues and solutions. In addition, the mobile devices can assist in collecting data (e.g., pictures and coordinates), when necessary.

Mobile devices are fully integrated into the workflow of the MDOT e-construction initiative. Mobile devices are used especially by the construction staff, who use tablet computers in several different ways.

- Almost all reference documents and project plans and specifications that used to be carried as hard copy in vehicles are now digitized and available to mobile users.
- Wireless data is transferred using cell phone signals; thus, mobile e-mail and web browsing are supported.
- Still and video cameras are used to document construction progress and issues.
- All construction reports are processed on mobile devices. Users have full access to the electronic document management system.
- Video conferencing is supported, allowing field personnel a wide range of office support.
- Electronic signatures are supported so that approvals can be made if personnel are in the field.

Field personnel report greater efficiency in construction inspection because relatively more tasks can be accomplished in the field, resulting in less time being spent in offices away from inspection duties.

WisDOT is testing the use of ruggedized heavy-duty tablets for viewing 3D models in the field. Autodesk BIM 360 Glue is used as the model viewing software application on the tablets, which are connected wirelessly to the cloud. The tablets also have GPS positioning that is accurate to within 0.10 foot, so that issues found in the field can be noted at their proper location on the model. The model can be edited in the field and drawings can be extracted to expedite contract change requests. The system is expected to tie into WisDOT's document management system to facilitate communication and workflows. It is expected that users will be able to document as-built data in the field. Tablet PCs with 32-bit processors are required to have reasonable battery life while executing these tasks.

Iowa DOT has coordinated the purchase of tablet computers for construction inspectors with the rollout of its electronic document management system. Tablet computers will also be used for maintenance inspections for facilities such as culverts. Contractor construction personnel used tablet computers on the Texas Horseshoe Project to reference project plans, among other things. In particular, it was found to be surprisingly useful to have an unofficial overall 2D site map based on Google Earth of the project showing the approximate location of new construction elements.

On the DFW Connector Project, in addition to tablet computers, the project used a number of vehicle-based mobile devices to track locations and activities and to facilitate data gathering and data display of equipment and personnel. Several real-time verification technologies were included, including telematics (a blending of computers and wireless telecommunications technologies) and a custom-developed computer software application (XacTrac). Telematics allows the manager to track equipment use (i.e., operation hours, fuel consumption, and current location). The custom software application helps managers monitor equipment and operator status with a real-time electronic map. The software can also produce reports and notices for service checkups on the usage and routing of equipment.

Intelligent Compaction (IC)

IC is the compaction of road materials, such as soils, aggregate bases, or asphalt paving materials, using modern vibratory rollers equipped with an integrated measurement system, GPS-based mapping, onboard computer reporting system, and (optionally) a feedback control. With IC mapping capability, it is easy to identify locations where supporting layers are weak before and during compaction by observing a computer display on the compaction machine. The entire construction site can be compacted to a reasonably uniform stiffness, and the rolling pattern and machine-measured stiffness can be documented. For asphalt construction, the system can also document contractor efforts to maintain a desirable range of surface temperatures during each step of the compaction process[22]. In general, an IC system can facilitate high compaction quality, especially consistency and uniformity, while minimizing the number of rolling passes. The requirement for traditional lab tests will likely be reduced in many cases[23]. IC activities generate large data files that can be stored and moved with cloud storage and high-speed data transfer, which are often associated with CIM implementation.

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22 Chang G, Q Xu, J Rutledge, B Horan, L Michael, DJ White, and P Vennapusa, Accelerated Implementation of Intelligent Compaction Technology for Embankment Subgrade Soils, Aggregate Base, and Asphalt Pavement Materials, Publication No. FHWA –IF-12,-002, Federal Highway Administration, http://www.fhwa.dot.gov/pavement/ic/pubs/hif12002.pdf

23 Anderegg R and K Kaufmann, Intelligent Compaction with Vibratory Rollers: Feedback Control Systems in Automatic Compaction and Compaction Control, Transportation Research Record, Transportation Research Board, 1868(1), 124-134, http://trrjournalonline.trb.org/doi/abs/10.3141/1868-13

The DFW connector concessionaire, Northgate Constructors, has made extensive use of IC on its project. Joint venture partner Kiewit Construction Company has a development and innovation agreement with equipment manufacturer Caterpillar to provide two types of measurements for IC: compaction meter value (CMV) and machine drive power (MDP). After initial testing, the project personnel chose to use the MDP approach because it measured mostly to depth of a 12-inch lift thickness rather than to a 39-inch depth involved with CMV measurements. The process commences by calibrating the machine on a test strip, which is gradually compacted during an extensive testing regime involving nuclear density gauges, dynamic cone penetrometers, lightweight deflectometers, and plate load tests. MDP values are noted when the other tests indicate satisfactory compaction for the test strip. The computer display output is adjusted on the compactor to indicate green areas on maps of the project where the desired MDP value is exceeded. This allows the operator to monitor the part of the fill where the MDP index value predicts that satisfactory compaction has not been achieved. The resulting documentation is stored in Caterpillar's proprietary Accugrade™ Grade Control System software from where it can be shared as necessary.

UDOT hosted some IC trials for both soil and asphalt compaction and reported mixed results during the visit. For soil compaction, contractors expressed concern regarding the amount of time required to set up the previously described test strip and being able to isolate the compaction values for the current lift. (A CMV measurement was being used in this case.) It was noted that retrofitting existing machines might cost as much as $80,000 and that the each retrofitting was custom and depended of the particular machine's make and model.

The asphalt compaction trials received reviews that are more positive. Some care was required to ensure the proper operation of thermal sensors. The Vetasoftware application was used to analyze and document the results. Pass counts and, in the case of asphalt construction, thermal stiffness was documented during the analysis. In general, being able to keep accurate track of the number of roller passes was considered the most promising function of the system. Survey-grade GPS control was required provide positions that had sufficient accuracy to monitor roller passes GPS data was lost under bridges. Contractors reported that the roller operators have little interest in using output from the displays. Requested improvements include more-robust sensors, larger displays with a more intuitive user interface, and data processing that provides real-time results earlier in the construction process. A large payoff was possible if the system were to be further developed. The greatest interest was in using IC for asphalt paving.

Michigan DOT performed an IC pilot project on a site with homogeneous soils that were well suited for the process. CMV measurements were taken. During the project it was found important that work progress systematically, data should be downloaded daily, and state plane coordinates should be used for locations. Fast data transfer to cloud storage was necessary because of the large size of the files.

Electronic Document Management (EDM) Systems

The use of EDM systems has become more common and beneficial for transportation agencies and their partners, especially for design and construction processes. Some agencies choose to use existing commercial products while some use in-house, customized software. With an EDM system, designers can upload design models and other documents to the system and share them with other parties. Contractors can also upload or download documents or models. In general, EDM systems greatly facilitate the electronic engineered data exchange and communication process among project stakeholders throughout the project life cycle.

An EDM system has been an important part of Michigan DOT's paperless job site initiative. ProjectWise, which MDOT had used for 12 years at the time of the scan team's visit, serves as the platform for this EDM system. The EDM system operation began as an electronic filing cabinet, but has since been upgraded to provide automated document routing that include up to seven people in a workflow. ProjectWise Mobile

Explorer is used to interface with mobile devices such as tablet computers. Security arrangements have been developed so that contractors can also have access to the EDM system.

Recently, UDOT hosted several high-profile design-build projects, each of which used an EDM system. Officials were impressed with the usefulness of these systems and wanted to develop an enterprise-wide system rather than project systems. They developed a system on a SharePoint platform and named it Interchange. UDOT believes the system will be useful for purposes beyond design and construction document control, when it is more fully implemented. It is expected that the system will facilitate design reviews and dissemination of meeting minutes, provide individuals and teams with coordination spaces, and allow contractors to participate in workflows during construction. Interchange was custom-developed for UDOT and required three consultant programmers more than a year to complete the application. This was in addition to UDOT employees who provided the business needs and conducted interviews to establish requirements for more than 20 document workflows. UDOT noted that this application could facilitate interoperability between other applications by transferring data through tables that are internal to the application. Because the application is unsuitable for the storage of large files, such as 3D engineered models and LiDAR point clouds, UDOT uses ProjectWise for this purpose. ProjectWise is also used for archiving files from Interchange after a project is completed.

SharePoint is used as a document management platform at other locations. The Texas Horseshoe Project had a project-specific EDM system that was provided by one of the design-build project participants. The EDM system had been custom-designed for the participant and successfully used for other projects and was performing well for the Horseshoe Project. Most of the materials testing results were kept on a legacy system that participants found more challenging to use. Most of the companies that participated in the project had their own EDM systems and kept backup copies of most documents in their systems.

VDOT also used a SharePoint platform for its EDM on the I-95 HOT Lanes Project. The agency noted that it had invested some effort in customizing the system and that a few automated workflows had been established. As with the Horseshoe Project, VDOT noted that participants retained copies of most documentation in their own EDM systems. In addition, design files were stored in ProjectWise, which was considered a better solution for storing large files.

For some projects, NYSDOT was using an EDM system that was associated with the scheduling software application Primavera P6 by Oracle. At the time of the visit, the EDM system was not configured to roll up to the enterprise level. The agency placed considerable emphasis on schedule control in its approach to contract administration. The approach WisDOT took to EDM was similar to that of NYSDOT.

Iowa DOT has collaborated with Info Tech to develop an initial development site for an EDM system called Doc Express. The system has been specifically developed to address the needs of the transportation construction industry. Documents are stored in virtual file drawers and workflows can be established for approvals. For the Iowa DOT application, the electronic files are stored outside the Iowa DOT firewall and can be accessed by contractors, suppliers, and designers. Operating the system has proven to be relatively intuitive, so only a modest amount of training has been required. Doc Express is accessible from mobile computing devices, which has increased flexibility. A process has been developed to collect the documents from Doc Express and archive them within the Iowa DOT firewall when the project is completed.

For the DFW Connector Project in Texas, Centric Project has served as the EDM system and ProjectWise provides storage for design files. Northgate Constructors joint venture partner Kiewit Construction Company plans to develop a SharePoint platform for future EDM purposes on future projects that are similar to the DFW Connector Project.

Northgate Constructors is also using an EDM system for material management that is a custom-developed software application. The application is now commercially available under the trade name FiveCubits. This system monitors usage and stockpiles and orders the materials needed for a project electronically through project suppliers that are connected to the cloud. The material availability and cost are visible to the contractor. Once the order is placed, the delivery process, including trucks' cycle time, number of loads, and routes, is transparent to all parties. The contractor completes payment after verifying that the correct materials have been delivered to the job site. The system can automatically generate a monthly report of material quantities and costs.

IEDM systems were found to be good tools for storing and sharing data or electronic documents and are effective for organizing and managing electronic documents. The scan team found that transportation agencies should encourage software developers to develop systems that are responsive to agency needs. A system that is intuitive for users and taking proper measures to maintain data security are important.

Digital Signatures

Some of the agencies have adopted the use of digital signatures, which are implemented in various ways. MDOT uses a portable document format (PDF) reading/writing software application. Iowa DOT uses the Doc Express EDM software application. UDOT uses digital signatures to sign off on 3D model QCs/QAs that are verified by IdenTrust. During discussion with DFW Connector concessionaire Northgate Constructors, it was noted that electronic design files have been digitally sealed. The existing standards and/or rules for managing digital signatures do need careful consideration; however, once the process is set up, the signature process (and, in some jurisdictions, even profession sealing processes) becomes more efficient. Personnel can sign the plans or documents at their convenience anytime and anywhere they have an Internet connection. For some agencies, legislation enabling the use of digital signatures may be necessary and policies may have to be changed. For example, digital signatures were not available to NYSDOT.

4 Technical Considerations

The most basic element of a CIM system is data. With all data stored in a central database, a project team or other parties involved can obtain more information and knowledge that are useful from an existing data pool, and decision-makers can make more-effective decisions using that information and knowledge. Operation of a CIM system is enabled with seamless data flow. To ensure that data flows seamlessly throughout the entire project life cycle, consideration should be given to data-related issues, such as data interoperability, accessibility, governance, storage, and management.

Data Interoperability and Accessibility

Data interoperability refers to the ability of IT systems/hardware/software from different vendors to communicate. Data interoperability is an important issue that the agency needs to address early in the process. The parties involved in a project might use various software applications and hardware types. Data transfer among the different software and hardware might cause issues such as data loss or damage. However, developing a uniform data format that works for all software and hardware and can be used throughout the facility's entire life cycle is challenging. Currently, some agencies have their own standards that specify the type of data formats, software, and hardware required for a project, which seems to be effective in avoiding issues during data transfer.

Data accessibility needs to be properly determined before the job starts. Personnel involved in the project should have appropriate access to the project-related data throughout the entire project life cycle. The proper level of authorization (e.g., read only or read and write) should be given to individuals or groups based on their responsibilities. Authorization level can be changed when circumstances change, such as when a person leaves an organization or a design or construction contract is completed.

Data Governance

Proper data governance is necessary for the implementation of CIM. This ensures that the data is stored in the right place in the right format so that it will become useful legacy data for the entire agency well into the future. The host agencies have adopted various electronic document management systems. For example, MDOT requires its contractors to submit documents or models to a commercially developed electronic file management system called ProjectWise that was specifically designed to retain design files. MDOT applies digital signatures and provides access to project stakeholders.

Some agencies use software applications they developed in house. Some use general-purpose commercial file-storage and workflow-facilitating software applications that they have customized to store and manage their electronic documents. One example is Utah Interchange, which was developed based on a Microsoft SharePoint platform. Before the system was developed, the agency gathered internal personnel and contractors to discuss the workflow and processes. Programmers then developed the system based on the stakeholders' consensus. The resulting product therefore satisfied both the agency's and their contractors' needs. Utah Interchange supports document submission, task management, meeting minute development, review and distribution, and design review. It has other capabilities, as well. Design groups or contractors can submit documents or models to this program and specify which discipline should review the uploaded files. When changes are made to the file, the person responsible for reviewing the changes is notified immediately. Through this program, the agency can assign tasks to individuals or groups, as appropriate. Once finished, the task is closed.

The usefulness of meeting minutes might be enhance by directly passing meeting time, location, attendees, and other notes directly to the participants calendar and task list software or web applications. UDOT attempted this; however, data integration issues between the Utah Interchange and the calendaring and task list applications made the attempt unsuccessful.

Utah Interchange supports the design review process by efficiently tracking comments and responses. Usually, responses to the comments are addressed in the next design review/milestone meeting, and project managers have intermediate meetings to track the design progress.

Data Storage and Management

Data sets with large file sizes (e.g., LiDAR point clouds and 3D models) should be carefully considered because they require large storage space with potentially significant annual costs. In some of the agencies the scan team visited, data storage and management are performed under contract. Outsourcing enables agencies to focus more on the project instead of managing its data. However, it is hard to know what will happen to the data at the end of the contract period if responsibility is shifted to a different entity.

Use of Mobile Devices

Data needs to be stored and managed wisely, and to be accessible and used effectively. On construction sites, the use of mobile devices is becoming increasingly popular. With a tablet computer, craft workers can view 3D project models or other electronic documents (e.g., instructions, manuals, and standards) on the job site and make real-time notes about the constructed components. Digital geo-located photographs of construction can be taken and inserted into the electronic documents. These real-time notes and photographs can be synchronized with other devices and be viewed by personnel other places. In addition, tablets and smart phones allow real-time communication between the field personnel and people in other places, which enables quick response to identified field issues. WisDOT and MDOT have extensive experience using mobile devices in the field. In general, the use of mobile devices has the potential to increase the flexibility and productivity of the construction process greatly.

LiDAR for Data Collection

One of the important data collection options in a CIM system is LiDAR. LiDAR technology enables surveying data to be collected efficiently and with an adequate level of accuracy. Compared to traditional surveying methods, LiDAR provides better efficiency and improved safety. Technologies like LiDAR, 3D mapping, and unmanned aerial vehicles (UAVs) provide good quality results without adding extra work for surveyors, as long as the right sensors and platforms are selected for the job. In addition, LiDAR can be used to collect as-built data of transportation assets, which can be used for asset management.

Currently, most agencies are not systematically and consistently collecting as-built data due to extra time required and difficulty in storing and integrating this data in their current workflows. For example, little as-built data is collected on utilities. When a road is reconstructed, agencies spend considerable time and effort finding utility locations and sizes. If a utility is not identified correctly during this initial surveying phase, it may be damaged later in the construction phase, resulting in delays and additional cost. Systematically including as-built data in an agency database would help improve asset management practices and rehabilitation of transportation facilities.

Value of Spatial Data

CIM data should be geospatially located with coordinates of known precision and accuracy because the collection and curation of good quality spatial data has a definite payoff. Geospatial information can be easily imported into a GIS or similar platform, and the project team can better use the information (i.e. to conduct a traffic study expediently) and visualize project-related features (i.e. to identify places with steep slopes). A summary report for a preliminary study can be developed and linked with the GIS map before a kickoff meeting, enabling the project team and the public to understand the project better.

GIS is a communication tool that can display both aboveground and underground features. UDOT's UPlan is a good example. UPlan includes attributes for geospatially located features. For example, road alignments with mileposts are displayed on a GIS map. By clicking the milepost, the public can view the relevant road properties and even view a virtual display of the road as it was configured when the data was collected.

Geospatial data may potentially be beneficial for enterprise-level management. Projects in various geospatial locations could be better managed through one platform. This would allow upper managers to obtain up-to-date project information (e.g., schedule, cost, and quality). Moreover, the electronic documents could be linked based on their geospatial parameters.

5 Organizational Considerations

Communication Among Stakeholders

Stakeholders should create a culture of open communication and information sharing so that data and information can flow smoothly throughout the transportation facility's life cycle. However, most stakeholders are used to storing, retaining, and modifying their own copies of the information, which makes information sharing challenging in some cases, especially when modifications are made to the copies and the originals files are not updated too. Communication needs to occur across departments within agencies, and between external stakeholders and organizations.

Agency should develop rules or standards to facilitate formal and informal communications among project stakeholders. In one of the projects the scan team examined, a joint venture contractor (design-builder) had several suppliers tied into its material management system. The contractor ordered sand, rock, cement, and concrete online through an electronic portal for material management. To facilitate construction material transactions within the project, its subcontracts and material contracts require subcontractors and suppliers to use the same electronic system. The contractor also tried to collaborate with its subcontractors and suppliers as much as possible, including using tracking and management systems and holding weekly meetings to discuss job-related issues. The contractor has observed significant benefits by using this enhanced and efficient communication method.

Communication for Public Information Activities

Communication with the public is important, and project stakeholders should work together to ensure that the public is informed about project updates. When CIM or CIM-related practices are involved, extensive amounts of digital data usually have been created by the intelligent technologies or tools. Portions of this digital data could be modified and repurposed for communicating with the public. The adoption of emerging digital communication tools would make communication process more efficient. Currently, a significant amount of public information on many road construction projects is disseminated through project websites, mobile apps and social media.

On the joint venture project mentioned above, the contractor was responsible for creating and distributing information to the public on behalf of the DOT and under the DOT's supervision. The contractor adopted various methods such as portable, changeable message boards, a project website, a weekly e-mail alert, social media, and mobile applications. The project implemented procedures to minimize the impact on the public. First, the project was phased to reduce the number of traffic switches and closures needed to build the project. Second, per the contract, full highway closures were only performed during off-peak hours (i.e., weeknights and weekends). Most importantly, the PI team informed the public and stakeholders about upcoming traffic impacts so they could plan their travel accordingly.

Upper Management Support

Upper management should learn how CIM supports the big picture. An organizational goal should be to develop CIM and implement by moving forward with applications. At the same time, upper management should encourage innovation and allow for risk and unexpected outcomes. Appropriate levels of investment should be allocated to support innovative ideas that advance the agency's objectives. Some setbacks and failures may occur, but good outcomes will also occur during the experimentation and implementation process. Additionally, passionate people should be involved during development so that they can motivate other team members to persevere.

Information Technology Support

Engineers should work closely with IT professionals to implement IT technology and develop customized applications and processes for the agency. Engineers and other business staff should develop concepts based on agency business needs and present those concepts to IT. Then, IT and business staff should negotiate and consider feasibility, security, and other issues before IT develops the system.

To develop CIM capabilities effectively, agencies should consider embedding IT professionals within the DOT's organizational structure and possibly within the design, construction, or asset management groups. This enables IT to collaborate with the application users and set priorities to accommodate CIM initiatives. Iowa DOT embedded IT professionals, which enabled the agency to respond quickly and support the IT needs of business units. In some cases, engineers and others have been able to develop sufficient expertise to be effective. In some cases, IT personnel are deployed to a particular business unit, while remaining part of a statewide IT organization.

Champion for 3D Engineered Models

During the development of 3D engineered models, an upper management champion who has a clear understanding of the capabilities of a model and its intended use and purpose should lead and coordinate the development process. Having the support of a champion in upper management can facilitate implementing 3D engineered models or CIM concepts and can help motivate team members to implement CIM enthusiastically. However, the champion may need to adjust the organization structure and allocate necessary resources for CIM development.

Impact of Project Delivery Methods

The team visited agencies and projects that used the design-bid-build, design-build, and PPP project delivery methods and found examples of advanced CIM implementation within each delivery system. However, the time required for coordination by stakeholders outside of the agency varied depending on which system was used. When the design-bid-build method is used, coordination is required between the agency and a contractor trade association regarding how contractors will use the CIM technology and how the data will be shared. This is especially true for 3D engineered models, AMG, and EDM. Organizations should consider how contractors might return as-built 3D models to the agency. For design-build and PPPs, the designer and construction contractor are within the same legal entity from the agency's standpoint. Thus, the designer and constructor can work out design and construction coordination together. It will still be necessary to coordinate how owner design reviews will proceed, how QC/QA data will be coordinated, and how as-built models and other electronic data will be exchanged.

6 Recommended Procedures for Successful Implementation

Consideration needs to be given while planning the CIM system for what data is useful and relevant for retention and then only that data should be stored in the database. Agencies should decide the value of data during the development of their CIM system, especially with regard to the data storage and management mechanisms. This requires the business staff exploring enterprise data architecture to decide what is valuable to whom, and is the best place where in the process to harvest the data. Consideration should be given to the data's immediate use and to its downstream, future uses.

Start with Model-Centric Design and Pilot Projects

Initial success is important to provide the necessary momentum to continue CIM implementation. Conducting one or two pilot tests on CIM components will enable them to demonstrate the benefits and challenges of using these technologies. Agencies that want to implement CIM could consider starting with model centric design.

When the Iowa DOT initially started 3D modeling, it met with hardware manufacturers like Trimble, Leica, and CAT to predict future directions for construction hardware and software, and then planned future direction for the agency accordingly. For the first pilot project, decision-makers planned a construction project that would require using AMG, making development of a 3D model necessary. Iowa DOT found that being able to view the model in 3D helped facilitate communication. Project stakeholders and the public found the design easier to understand because they could be visualize it in 3D. The agency realized other benefits of using 3D design, such as reduced costs, better verification, and the possibility of AMG with less effort. As agency personnel adopted 3D modeling and became more proficient in the modeling process, they learned the following lessons:

- Agencies should select goals first and then decide how to achieve those goals.
- During the initial implementation stage, the agency should engage industry personnel to decide the exchange format of electronic files, and then provide files in that format (e.g., LandXML, TransXML, or others). This is not a project-level decision, but rather agency-level policy.
- A standardized file-naming convention is beneficial for both file organization and sharing.
- Agencies should engage contractor trade associations to establish standards and procedures for model sharing and continue communications as improvements in hardware and software are made. Annual meetings seem to be appropriate.

Challenges associated with 3D modeling were observed during the implementation process:

- Designers might lack sufficient skills for 3D model development.
- Conflicts existed in electronic files or models delivered to contractors.
- The proper level of detail necessary for the design to meet the contractors' needs was difficult to determine.
- Whether the design model was compatible with contractors' software or tools was hard to predict

So far, agencies have overcome these challenges by providing training, manuals and websites, ensuring better quality control, and having workshops with contractors to find out what they need.

AMG is another important technology that has been identified as beneficial to transportation agencies. Models can be directly uploaded to the on-board computer installed on heavy construction equipment. An operator can supervise the machine operation through a computer screen and adjust the machine's movement. The field staff can bring to the field the design model on a tablet coupled with a modern survey instrument to verify that the as-built facility matches the proposed design.

Using AMG in paving has reduced the number of survey stakes and string lines and made workers safer when working on the ground near machinery. Using modern software applications and experienced staff, Iowa DOT claims that it produces 3D models with no more effort than what was formerly required to produce 2D plans.

Contractors have to transition from traditional grading to machine control; otherwise, they may not be competitive in the market. From contractors' perspectives, machine control can provide the following benefits:

- Increased productivity
- Increased accuracy
- Improved safety
- Faster integration of design changes
- More satisfied owners
- Fewer errors because problems can be detected before the job starts by reviewing the 3D models

Switch from 2D to 3D

Agencies can benefit from switching from 2D plans to 3D intelligent models. In one case, NYSDOT began by providing GPS equipment to construction field staff and adopted a software application that allowed its field staff to view designs in 3D. The agency trained its construction staff to use GPS equipment and computer-aided design and drafting (CADD) software. Once the staff became skilled with the equipment and software, and the agency began realizing benefits (e.g., timesaving gained from using the new technology), use of related tools was accepted.

Motivate Team Members and Think Forward

Agencies should provide employees considerable latitude to experiment with the CIM concept and prove its value. Upper management support and engaging team members who are convinced of CIM's value increases the chances that CIM would be implemented at a larger scale, which can result in several benefits for transportation agencies.

During the development of UPlan in UDOT Region 4, designers, surveyors, traffic safety engineers, and project managers were asked to identify possible applications of UPlan. Their ideas exceeded expectations. During the implementation of CIM, agencies should carefully consider the priority of tasks and investment areas. It is important to incorporate the needs of later maintenance, operations and asset management during the project's planning, design, and construction.

Share Lessons Learned with Other Agencies

As CIM develops, agencies should share ideas, best practices, and lessons learned with each other to enable CIM concepts to become more mature and beneficial to the entire transportation industry. Although the CIM development path for each agency will be unique, it would be beneficial to develop a general guideline or framework for CIM implementation. The need for software and data interoperability crosses state lines, and coordination helps avoid a patchwork of different requirements. Shared policies will encourage a larger pool of designers and contractors to grow that have abilities to address these opportunities.

7 Recommended Philosophy for Success

Data Used Throughout a Facility's Life cycle

CIM is a broad concept with more than one way of defining the concept. The principle of CIM is to be able to use data from throughout the life cycle of a facility including planning, design, construction, operation, maintenance, and returning to planning when the facility is rebuilt. In addition to being useful on individual projects, the data needs to be useful enterprise wide so it is useful in all phases of all facilities.

In Figure 2.1, data collected or created at each phase can be stored in an enterprise data pool that would be a primary resource for other phases of the facility's life cycle. When using the data pool, agency personnel will spend less time and effort finding and collecting data as compared to traditional methods.

NYSDOT has collected and stored some as-built data. This electronic as-built data, along with design files, could produce useful information for asset management or for planning a subsequent rehabilitation project. However, this practice has had limited implementation.

Higher accuracy utility data is seldom currently included in as-built plans. Developing a utility database that contains all as-built utility information would be beneficial. Ultimately, it might be possible to develop a database for all existing transportation systems. This would require that all as-built utility information be updated as they are installed or shortly thereafter. Transportation agencies, not contractors or consultants, should lead the CIM development effort to ensure that the resulting system meets the agency's long-term needs.

Stakeholder Support

Leadership and commitment from upper management is necessary because CIM implementation requires considerable investments and cooperation from stakeholders throughout the entire agency, and even beyond the agency. During the CIM implementation process, other partners such as contractors and utilities should be involved because they can be important allies. The agency might need to provide additional training for construction personnel to make sure they are capable of working with 3D models effectively. Construction personnel, including contractors, should work with design staff to identify what elements should be included in 3D models to be useful and ensure that the models are constructible. This collaboration will improve the accuracy of quantities and will ensure that the resulting model can be further refined for use as 4D/5D models or for AMG.

IT Support Requirements

Many of the software applications and workflows that are required for CIM implementation should be highly customized to meet an agency's particular business needs. Therefore, IT expertise is necessary to implement CIM tools successfully. However, there is a trend for state government agencies to consolidate IT specialists from various departments into a single, statewide, centralized IT entity that provides IT-related services or support to all other state government entities. While such an arrangement can be an efficient way of providing support for common IT functions that are used statewide, it may create shortfalls where specialized IT expertise is required by a particular work group or for a particular process. Successful implementation of CIM tools requires that leaders strive to provide IT support arrangements that allow personnel to become sufficiently specialized to support CIM software applications, hardware, and workflow, yet meet the requirements for efficiency and standardization needed by other state government functions.

Attention to Details

Consideration of certain details, such as legal issues, data interoperability, IT security, and personnel issues, is extremely important. Project-related intellectual property issues should be addressed in the contracts for design consultants who will develop items that will be included in a CIM system. Specifically, these issues include how to maintain the intellectual property of the electronic files, which files can be distributed, and how the contract should address related state laws or policies. In addition, which people are eligible to make corrections or changes on models or other electronic documents should be specified, and who should be responsible when design errors are found before or after contract letting. In addition, license issues and consultant drawing reviews should be carefully considered and planned. The agency can address data interoperability by specifying the accepted data formats, software, hardware, and other related submittal requirements. This data standardization can make the whole process easier and help retain the data integrity. Moreover, the agency should develop a thorough plan for data storage, maintaining IT security and future data access.

Personnel Issues

Personnel issues such as team motivation and support from upper management have been discussed elsewhere in this report. In addition to those issues, the end users and personnel involved with CIM should understand technology and the specific operations and processes used to produce and check quantity calculations. Properly approaching training is a key to success.

Iowa DOT and MDOT have used just-in-time training, a proven approach in which personnel are periodically trained immediately before they use the technology. Individuals best remember and apply what they learned in training if they can apply it soon after the training. Without practice, they will lose many of the details they learned.

Some agencies have developed their own online training courses or manuals on work-related topics so that their employees can access the training materials anytime. One example of this is MDOT's Power GEOPAK[24] training video series.

[24] Power GEOPAK Training Videos, Michigan Department of Transportation, http://www.michigan.gov/mdot/0,4616,7-151-9625_21540_36037_65127---,00.html

8 Recommended Methods for Enlisting Support

The following could be helpful for enlisting support from stakeholders or other data users:

- CIM champions should communicate benefits to other agency functional areas in addition to design and construction to justify the investment in CIM and develop support from upper management for an effort that will be agency wide in scope.
- Champions should explain to stakeholders that proper implementation of CIM will streamline the way they do business. One way to illustrate this is by using microwave ovens as an example. Most people would find it challenging to live without a microwave oven. A day might be coming when those in the transportation industry want CIM as much as people want a microwave oven to make daily living easier.
- Champions should explain to stakeholders that the benefits of CIM are not limited to the ones currently envisioned, because right now future innovations that will make the data and the system more useful are unknown
- CIM developers should consider including geospatial platforms in their development plans, because these platforms are useful and effective integrating transportation-related features and associated databases.
- CIM developers should encourage others to recognize the value of the data that transportation agencies hold. Transportation agencies are data rich, and stakeholders who wish to use this data will support CIM development. For example, businesses are interested in knowing traffic counts areas so that they can make business decisions accordingly. TV and radio station are interested in obtaining information related to traffic conditions and road delays so that they can provide the most up-to-date traffic information to the public.

9 Key Findings

CIM concepts can be categorized as shown in Figure 9.1. Agencies might consider starting with some fundamental concepts that facilitate CIM implementation. Next, enabling technologies that are highly useful in a CIM system should be considered. Different from enabling technologies, contributing technologies are those technologies that may not be necessary for initial CIM implementation, but have the potential to amplify the usefulness of a CIM system.

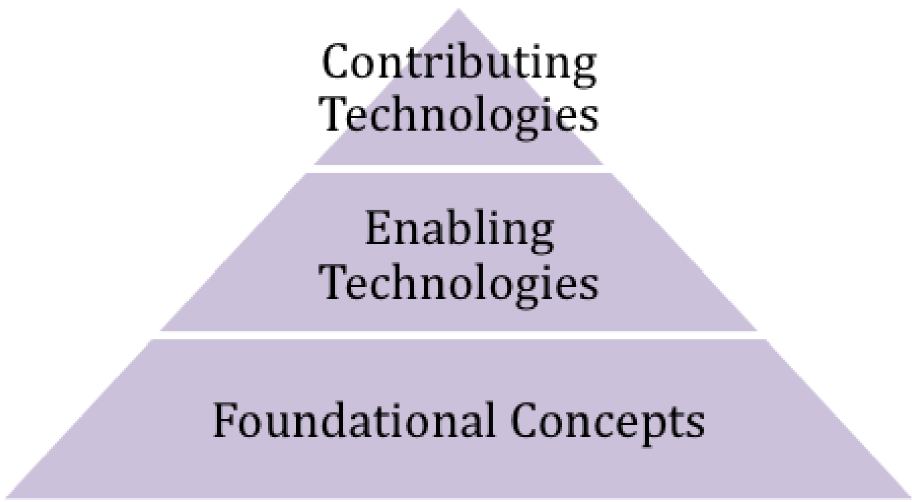

Figure 9.1 CIM concepts pyramid

Foundational Concepts

- *Establish a data warehouse or enterprise integration core that stores data, information, and knowledge on existing transportation assets and new or planned transportation projects.*
  This data warehouse or enterprise could be an important asset that the entire agency could share. Proper data integration and data management are important for the maintenance of the data warehouse. UDOT has developed the following definitions with regard to the concept of a data warehouse.
  - Data Warehouse: "A large store of data accumulated from a wide range of sources within [an enterprise that is] used to guide management decisions"
  - Data Integration: "Involves combining data residing in different sources and providing users with a unified view of these data"
  - Data Management: "The development, execution, and supervision of plans, policies, programs, and practices that control, protect, deliver, and enhance the value of data and information assets"
- *Promote innovation within the whole agency.*
  Innovation is important for facilitating the development of CIM. An adequate vision of both the CIM system's benefits and its implementation are required for it to be developed and refined into a mature system.

- *Ensure information technology arrangements that are responsive to agency business needs.*
  Agency leaders should determine the framework for CIM that best meet the agency's needs and programs. A clear framework will help information technology specialists as they collaborate with other stakeholders to contribute effectively to develop the desired CIM system.

- *Enable users to obtain needed data and improve decision making*
  Proper levels of authorization should be provided for personnel or groups that require access to the data. Project-related data needs to be shared among stakeholders for them to make the best decisions.

- *Employ model-based design as a starting point for CIM implementation.*
  Moving from 2D plans to 3D models appears to be a trend for the transportation industry. Some state DOTs have been providing 3D models to contractors for informational use. In addition, models are being used for AMG during construction. Pioneering agencies can contribute greatly to the advancement of CIM by sharing their standards and implementation processes to help guide other transportation agencies that are just starting 3D modeling.

- *Consider other possible areas to jump-start CIM—statewide mass data acquisition, such as UPlan and post-construction as-builts.*
  Acquisition of mass data is important so that the data can be retrieved from the database anytime it is needed. As-built data should be collected right after the component is constructed so that it can be used in the facility's asset management and reconstruction phases. Extracting data from a database is much easier than collecting it in the field while having to overcome obstacles. For underground utilities especially, identifying the location of utilities is a challenging task.

- *Think beyond the next data user in a facility's life cycle to ensure that data remains useful during the facility's entire life cycle and throughout the enterprise.*
  Data needs to be collected and placed into the data pool as soon as possible so that it can be used during subsequent phases of a facility's life cycle. For example, the utility as-built data should be collected when the utility is constructed and the location is plainly visible. If the utility is covered before it is located, considerably more effort will be required to locate it prior to the next reconstruction cycle.

- *Establish a strong geospatial foundation and consider investments in the National Spatial Reference System (NSRS).*
  Geospatial information (i.e., location coordinates) relative to the NSRS is recommended for managing a local or statewide transportation system to ensure efficient geospatial data collaboration and adherence to a uniform positional reference system.

- *Use common exchange formats to facilitate wide sharing of data*
  Using uniform file exchange formats enables stakeholders on a project to work together efficiently while using equipment and/or software based on their own preference. Efforts have been made to define uniform exchange formats (e.g., LandXML, TransXML, IFC, and others). However, some of these uniform exchange formats have several drawbacks, such as data loss during file conversion and excessive file size, which need to be improved. More attention should be drawn to national or international efforts to define and enhance uniform common exchange formats.

- *Employ information modeling within the agency*
  The benefits of 3D engineered models and AMG are well established. Information modeling generally improves design and construction quality and increases productivity. The use of building information modeling in the building industry has had substantial benefits. Information modeling

technology could have similar substantial benefits for transportation agencies in the near future.

- *Make the required IT investments to support a large concept*
  CIM is a broad concept so substantial investments in IT would be required to develop data warehouses, electronic file collaboration systems, and systems to support other technologies or tools.
- *Collaborate with contractors and utility trade groups to enhance the usefulness of CIM and enlist support*
  Transportation agencies should work with contractors and utility groups to make sure that electronic files built during the earlier planning and design phases meet needs for later project phases. Their input will also be required during the development of IT systems (i.e., an electronic file collaboration systems and support for other technologies or tools) so that the resulting systems are useful for contractors during the construction phase.

Enabling Technologies

Based on visited agencies' experiences with various advanced technologies, the scan team determined that the following enabling technologies are particularly beneficial for transportation projects and should be implemented in a wider scale: GIS, 3D engineered models, LiDAR, GPS, AMG/AMC, mobile devices and electronic document management systems.

Contributing Technologies

The following contributing technologies are not widely implemented in the visited agencies, but they can be beneficial and should be implemented based on an agency's needs: IC, electronic signatures and 4D/5D models.

10 Recommended Next Steps

Implementation plans or frameworks should be developed to support transportation agencies that are leading in CIM development. These implementation plans and frameworks could serve as case study and examples that would help agencies in their CIM development efforts. Another recommended next step would be to hold peer exchange workshops to document data pool development efforts, data governance approaches, data exchange formats, and workflow development.

11 Planned Dissemination Actions

The following actions are planned for promoting and disseminating the results of this domestic scan to the transportation industry.

Presentations

Scan team members will present the CIM concept and key findings from the scan at meetings and conferences. Scan team members are planning to give presentations at meetings held by the following entities:

- American Association of State Highway and Transportation Officials (AASHTO) and its subcommittees
- Federal Highway Administration (FHWA)
- American Society of Civil Engineers (ASCE)
- National Association of County Engineers
- Environmental Systems Research Institute
- Mid America Association of State Transportation Officials
- Western Association of State Highway and Transportation Officials
- Southeastern Association of State Highway and Transportation Officials
- State chapters of American Council of Engineering Companies
- State chapters of the AGC
- Local chapters of ARTBA
- TRB and its subcommittees
- Florida Association of County Engineers and Road Superintendents
- Michigan Infrastructure & Transportation Association
- PennDOT CADD Steering Committee

Information will also be disseminated to other industry practitioners and academic professionals during the following conferences:

- International Highway Engineering Exchange Program Conference
- Midcontinent Transportation Research Symposium
- UDOT Transportation Conference
- Florida Transportation Builders Association / FDOT Construction Conference

In addition, scan team members will present the scan findings during their agencies' internal meetings.

Webinar and Video

A webinar will be made to promote the CIM-related knowledge through TRB or National Highway Institute activities. Video materials will be delivered through AASHTO News. A webinar or video would allow the CIM concept and the scan's findings to be conveyed to a broader range of audiences that cannot attend the meetings or conferences included in this dissemination plan.

Training and Continuing Education

Internal training is important for transportation agency's employees to understand CIM so that they can perform CIM-related duties better. FDOT plans to include the scan's findings in the agency's internal training materials for their consultants. Information about CIM will be provided to the Michigan Section of the ASCE as continuing education materials.

Articles and Papers

Articles and papers will be produced for sharing CIM-related knowledge with other professionals or researchers. Examples of such publications are Transportation Research Record[25] and/or conference, Journal of Construction Engineering Management[26], and Civil Engineering[27].

Further Research Opportunities

The findings from this scan project will be a starting point for future research opportunities. More investigations could be conducted to explore CIM-related practices or technologies and to develop a comprehensive CIM system that is beneficial for the transportation industry.

25 Transportation Research Record, Transportation Research Board, http://www.trb.org/Main/Blurbs/154702.aspx

26 Journal of Construction Engineering and Management, American Society of Civil Engineers, http://ascelibrary.org/journal/jcemd4

27 Civil Engineering, American Society of Civil Engineers, http://www.asce.org/cemagazine/

Appendix A: Scan Team Biographical Sketches

JOHN F. ADAM (AASHTO CHAIR) is the Highway Division Director and Chief Engineer for the Iowa Department of Transportation. In this position, he is responsible for all aspects of highway infrastructure, including right-of-way management, project development from design through construction and contract administration, and operation and maintenance of the system, including winter maintenance operations. He has been with the Iowa DOT for 31 years. Adam is an active member of the AASHTO Standing Committee on Highways, and the AASHTO Standing Committee on Highway Traffic Safety. He holds a bachelor's degree in construction engineering from Iowa State University and is a licensed civil engineer in Iowa.

BRYAN CAWLEY (FHWA CO-CHAIR) is the Team Leader for the Construction and System Preservation with the Federal Highway Administration. Since joining FHWA in the fall of 1997, Bryan has held a variety of positions in the agency, including working in Utah as the Assistant Division Administrator and the Nebraska, Resource Center, and North Dakota FHWA Offices. Prior to working with FHWA, Bryan worked with Staker Paving and Construction and the Utah Department of Transportation. Bryan holds a MBA from the University of Nebraska, Master's Degree in Construction Management from Iowa State University and a Bachelor Degree in Civil Engineering from the University of Utah. Bryan is also a licensed Professional Engineer in the state of North Dakota.

KATHERINE PETROS is the Team Leader for the Infrastructure Analysis and Construction Team within the Federal Highway Administration's (FHWA's) Office of Infrastructure Research & Development at the Turner-Fairbank Highway Research Center. The team is responsible for research and development activities focused on advancing knowledge and technology associated with infrastructure construction, project delivery, and preservation optimization within the broader context of asset management and pavement performance assessment and prediction technology. The team's activities focus on the development of procedures and processes to increase efficiency while improving the physical condition of the nation's highway infrastructure and include evaluating the effects of construction processes, procedures, and specifications, and infrastructure repair and preservation on the performance, safety, and sustainability aspects of highway infrastructure. Petros is the secretary of the American Association of State Highway and Transportation Officials Subcommittee on Construction's Research Steering Group and a member of its Computers and Technology Technical Section. She has held positions in various parts of FHWA's organization, including its headquarters office, its New Jersey Division office, and its Western Resource Center in San Francisco. Prior to joining FHWA, Petros earned her bachelor's and master's degrees in civil engineering from the University of Illinois at Urbana-Champaign.

DUANE F. BRAUTIGAM serves as Director, Office of Design, with the Florida Department of Transportation. He has more than 41 years of experience in transportation, including more than 17 with FDOT, where he has also served as State Specifications Engineer and Manager in the Specifications and Estimates Office. Prior to joining FDOT, Brautigam's career involved major bridges in the private sector, with assignments in design, construction, project management, construction engineering, contract administration, and engineering management, including 16 years with bridge contractors and eight years as Associate Vice President of a bridge engineering consultant firm. Brautigam holds a bachelor's degree in civil engineering from the University of Pittsburgh and is a licensed Professional Engineer in Pennsylvania and Florida.

REBECCA S. BURNS is the State Construction Engineer and Chief of the Innovation and Support Services Division of the Bureau of Project Delivery at the Pennsylvania Department of Transportation, where she has served for over 30 years. Her organizational responsibilities include construction quality assurance, materials testing, new product evaluations, geotechnical engineering, photogrammetry, and

IT systems support services for the agency. She is a graduate of Bucknell University, where she earned bachelor's and master's degrees in civil engineering, and is a registered professional engineer. Burns also received her Juris Doctorate from Widener University and is a member of the Pennsylvania Bar.

STAN BURNS is the Director of Asset Management for the Utah Department of Transportation. He holds a BSCE degree from the University of Utah. He is a registered professional engineer with 25 years of experience. During his career, he has held positions in design, operations, planning and program management.

JULIE KLIEWER is the Assistant State Engineer for Construction for the Arizona Department of Transportation. Kliewer has been with the Arizona DOT for almost 20 years. She has held numerous positions with the Arizona DOT, including Pavements Materials Testing Engineer and District Engineer for the Phoenix Construction District. She holds a BS and MS in Forest Engineering and a BS and PhD in Civil Engineering, all from Oregon State University. She is a licensed professional engineer in Arizona.

JOHN LOBBESTAEL is the Supervising Land Surveyor for the Michigan Department of Transportation in the Bureau of Highway Development, Design Division. He has been involved in 3D engineered models and Civil Integrated Management-related activities at MDOT since 2010. As a member of MDOT's EDC2 3D Engineered Models for Construction Team, he has assisted in developing 3D engineered model requirements, developing data streamlining workflows, and integrating modern survey technology and practices into MDOT's QA toolbox. In addition to his DOT duties, Lobbestael is a member of the technical working group developing web-based training modules in support of 3D engineered models in construction as part of the Federal Highway Administration's EDC2 Initiative. Prior to joining MDOT in 2009, Lobbestael was employed in the private sector as a surveyor, filling various roles, from field technician to project management, on several commercial land development, residential housing, municipal transportation, and utility projects in southeast Michigan. He is a 2004 graduate of Michigan Technological University and is a licensed professional surveyor in Michigan and Ohio.

RANDALL R. PARK, is the Project Development Director for the Utah Department of Transportation, where he oversees the department's engineering, construction, and materials efforts. With the technologies of today, UDOT is interested in all of the many opportunities that are being developed within Civil Integrated Management. Improving communication, transparency, efficiency, partnering, and quality can all be achieved with the tools provided by CIM. UDOT is currently developing expertise in 3D design, e-construction, variable-speed work zones, geographic information systems, and light detection and ranging mapping and asset collection. He currently serves as the Standard Committee Chairman for UDOT, is a member of the AASHTO Standard Committee on Highways, and is a member of the Free Market Protection and Privatization Board of the State of Utah. Park is a graduate of Utah State University and a licensed professional and structural engineer.

CHARLES T. JAHREN (Subject Matter Expert) is the W. A. Klinger Teaching Professor and the Assistant Chair for Construction Engineering in the Department of Civil, Construction, and Environmental Engineering at Iowa State University. He also serves as the Chair of the Editorial Board of the American Society of Civil Engineers (ASCE) Journal of Construction Engineering and Management (formerly Editor-in-Chief), Chair of the ASCE Construction Engineering Education Committee, and a member of the Transportation Research Board Pavement Maintenance Committee. Jahren has experience as an Assistant Professor at the University of Washington, over six years of industrial experience as a Bridge Construction Project Engineer for a construction contractor and as a Research Engineer for the Naval Civil Engineering Laboratory in Port Hueneme, California. His teaching interests include construction equipment, cost estimating, and construction process design. His research interests include highway and heavy construction methods, road maintenance methods, and innovations in construction process administration. Jahren earned a bachelor's degree in civil engineering and a master's degree in business administration from the University of Minnesota and his doctorate in civil engineering (specializing in Construction Engineering and Management) from Purdue University.

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Appendix C: Amplifying Questions

Amplifying Questions

The rapid development of information technologies and the growing need for accelerated project delivery with improved quality are driving transportation project participants to develop and use more effective ways of planning, designing, constructing, maintaining, operating, and managing transportation facilities through their life cycle. A recently developed paradigm of Civil Integrated Management (CIM) is generally being accepted as the preferred framework to achieve this goal in the highway industry.

FHWA, AASHTO, ARTBA, and AGC define CIM as “the collection, organization, and managed accessibility to accurate data and information related to a highway facility. The concept may be used by all affected parties for a wide range of purposes, including planning, environmental assessment, surveying, construction, maintenance, asset management, and risk assessment.” Some specific technology examples may include:

- Civil information modeling
- Geospatial collaboration, advanced surveying with modern surveying technology such as robotic total stations, RTK GPS, and LiDAR
- Real-time verification such as intelligent compaction, automated machine guidance, pavement thermal imaging, video surveillance for remote construction inspection and recording, digital project and document management systems and alternative contracting methods

Beyond the technologies, CIM also brings together a collaborative work environment where all parties understand and respect each other’s goals and work together to reduce duplication, reduce risk, balance or eliminate conflict, diffuse power, establish unified business goals, harmonize and optimize systems, create consistency, improve communication, and enhance safety.

The NCHRP Domestic Scan 13-02 team was established to harvest early experience, knowledge and opinions of engineers, managers and staff members who have been involved with the implementation of CIM for their projects and organizations. This questionnaire is uniquely structured to facilitate discussions of various considerations in implementing CIM practices and tools and to facilitate the drawing of meaningful opinions of and experience with CIM by DOTs.

The questionnaire consists of three sections. The first briefly describes CIM components and applications to help the survey participants better understand various aspects of CIM. The second asks the survey participants to think carefully about whether their transportation agency has started any initiatives related to CIM or any projects that have used some of the components of CIM and to discuss their experiences in a narrative. The final section includes specific questions that the scan panel has developed to document CIM practices and DOTs’ efforts in transitioning into digital data based project delivery and asset management in five categories: technical considerations, organizational considerations, performance considerations, legal considerations, and future vision.

As you review and answer the amplifying questions, please focus your discussion and effort on promising and implementable solutions and strategies to the problems that you have encountered. We are particularly interested in how you have identified and overcome implementation barriers and any special implementation needs that you perceive. Please provide specific examples, supporting information, and documentation to the extent possible. We believe that this questionnaire can be best filled out using a team effort, so please encourage wide participation that includes staff members from a relevant cross-section of your organization who might be able to provide any insight on CIM-related considerations and practices.

Overview of Civil Integrated Management

CIM and electronic data transfer will allow stakeholders to collaborate across distances and help track actions and events necessary to complete tasks on time, both at the program and project level. Efficiency will be increased because the electronic data files can be shared with all stakeholders as programs and projects pass from planning, design, construction, operation and maintenance and return to planning. Thus, CIM allows a continuous cycle of information, from the creation of true as-designed and as-built models that can be integrated in to an asset management program that can facilitate operation, maintenance, and renewal for a portfolio or for transportation facilities. As a result, CIM will enable the owner agencies, consulting firms, and contractors to better manage business risks, reduce duplication, enhance safety, and manage their assets.

The core building blocks of CIM are 3D engineered models, which are compatible with ICST technologies such as LiDAR (light detecting and ranging for surveying and establishing data points for physical features), subsurface geophysics (location of water table or buried objects), automated machine guidance (AMG), and Intelligent compaction (IC)28. The departure from traditional document-based project delivery and management to a system based on models requires redefined workflow processes, raises digital data storage and data interoperability issues, and awakens legal issues such as the ownership of digital data and models. Major representative practices and tools of CIM that must be comprehensively addressed in this project are illustrated in the following figure.

Overall Experience of CIM

After reading the introductory text, would you say that your agency has any experience in any of those major CIM components, or CIM practices and tools illustrated in the figure? If you believe that other colleagues or departments in your agency can better answer the following questions that pertain to the components in Figure 1, please contact them to document their experiences and opinions.

- Do you have any success stories regarding implementation of any CIM practices in your organization? If so, please describe them.

- What challenges were involved with your organization's implementation efforts?

- What motivates your organization/program/project to use the technology-driven tools in those CIM practices?

Specific Questions for CIM

This section has 55 questions in five categories that the scan team developed to document various dimensions of CIM practices used by state transportation agencies. Please develop answers for as many of the questions as possible. Please seek support from other colleagues and departments as well.

A. Technical Considerations

a. Overall Concept and Objectives

1. How did you (or will you) get staff members to think past 2D representations with the current workforce and switch to 3D?
2. Are there any written guidelines (roadmaps) available to implement 3D modeling or other elements of CIM?
3. What are the different organizations/entities you share geospatially oriented data with and for what purpose?

b. Hardware and Software for Virtual Design and Construction

4. What data collection tools have you adopted for projects where CIM has been implemented?
5. Do you use mobile computing with online forms, publications, or web-based construction management tools?
6. What software packages did you use during CIM implementation?
7. What other construction tools do you now use or wish to use to support CIM implementation?
8. Are there other technologies or processes that were not used, but would have been beneficial?
9. Have you adopted intelligent compaction technology? If so, please describe your experience. What hardware and software did you use?
10. How do you plan and manage work zone traffic control?
11. Have you adopted any elements of intelligent transportation systems? If so, please describe what particular technology you implemented and what tools you used to support that technology.

c. Technical Implementation Considerations

12. How do you design, review, approve, and fabricate items associated with shop drawings?
13. How do you design, review, and sign the final contract plans to be used on construction projects?
14. Are digitally encrypted electronic signatures used/accepted by your agency?
15. How was 3D/4D/5D modeling technology implemented or developed? Or how do you intend to implement and develop 3D/4D/5D modeling technology?
16. What data do you need to collect and integrate into your model throughout the project? How do you collect and integrate that data?
17. What data could be reused in other phases during a facility's life cycle? How do you store and reuse the data?
18. Have you made any plans for standardization of data? If so, please describe your plans and the strategies that you used to achieve those plans.
19. What types of data and information are you using to determine the level of construction quality? How do you acquire, evaluate, and store (archive) the data?

20. What type of data and information are you using to make decisions regarding material quality? How do you acquire and store these?
21. What type of data and information are you using to determine pay quantities? How much time does it take to process a pay estimate (i.e., from point in time of measurement to time in contractors' bank account, federal highway reimbursements, subcontractors, and materials suppliers)?

d. Data Sharing and Long-Term Digital Storage Considerations

22. CIM-implemented projects involve IT infrastructure that should to be tailored to the needs of the project. Are you aware of any lessons learned by agencies in terms of how to effectively store and transmit data while maintaining IT and data security? How are agencies using cloud-based storage solutions?

23. Surveying, construction, and overall project management of highway construction projects are heavily dependent on multiple forms and formats of electronic files and documents. Have you established any types of regional-level or project-level requirements for CIM architecture regarding file transmission, file sharing, and file storage?

24. How do you capture utility information or data and then how do you share the same?

25. How do you share data with other resource agencies, the public, and/or law enforcement?

B. Organizational Considerations

a. Role of Partners in CIM Project

26. How deep into construction contractual relationships has partnering language and integrated management systems been extended? Just to prime contractors and certain (first-tier) subcontractors? Has anything been done to accommodate suppliers that have limited computer experience?
27. Do you have an informal or formal way of partnering on projects? Please describe.

b. Impact of Project Delivery Methods

28. Does the process change when the project is consultant-designed? If yes, how?

c. Impact on Organizational Structure

29. Are there personnel issues at the DOTs that hindered the implementation of 3D modeling?
30. Do you always need a champion for model development and implementation? If yes, why?
31. CIM projects yield deliverables or offshoot deliverables that are nontraditional. How are these preserved and used downstream?

d. Impact of Project Type/Size on CIM Implementation

32. Is CIM considered mainstream in your organization (i.e., used in most projects) or is it applied only to major or complicated projects? (To owner/agency)
33. If it is not considered a mainstream philosophy, are there plans to make it so? If so, how? How will it be resourced and sustained as an institutionalized way of doing business?
34. How do you address the continuity of CIM in your agency? How do you address identifying, incorporating, and implementing CIM advances, new technology and processes? Equipment/software upgrades?
35. Please describe the overall project management of a project where CIM has been implemented. Is this typical for your organization or does this only occur for this type of project? Why?

e. Training

36. What are the critical areas for internal training for that are necessary to support quality assurance (QA) functions?
37. What skill set do you think is necessary for end users? Why? In what way do you train them so they can achieve that skill set?
38. What skill sets do you think are necessary for personnel who will be involved with CIM? Why? In what way do you train them to achieve that skill set?

f. Resources

39. How did you get resources allocated to do this? What are the common sources?
40. How often do you update software? What is the cost?

g. Communication

41. Do you have and use any type of specifications or rules related to formal or informal communications on a project site?
42. How do you communicate about construction inconveniences to the public? Is a public communication plan typically included? Are social media resources leveraged as part of a project's webpage? Are Facebook, Twitter, and others also used? If so, who operates, maintains, and updates the information (i.e., the agency, the contractor, or an outside vendor)?

C. Performance Measures

43. How is success measured on a project? Specifically, how is it measured with respect to CIM? Is it delivering what you wanted or expected? How?
44. What are your performance objectives for a project?
45. How is the accuracy of performance measured and the ability to detect conflicts?
46. How do you improve or maintain the quality of your final product through the project delivery process?
47. What efficiency gains are perceived and/or measured?
48. How do you minimize the impact of a project on the public?

D. Legal Considerations

49. How is transparency achieved in collaborative work environments while protecting individual privacy?
50. Were there or are there any internal or external institutional barriers/restraints to CIM (e.g., electronic signatures requirements, federal or state regulatory considerations, and others)? If so, please provide examples and explain how they were addressed.
51. Did you have any or would you expect to have legal issues during CIM implementation (e.g., intellectual property issues)? If so, please describe.
52. Can you share any information about legal issues, disagreements, concerns, or disputes with regard to sharing electronic engineered data or information? Have any been settled out of court? Are you able to share any details of the settlement? Are there any current or past court cases? What details or citations can you share regarding court cases?
53. Has your state licensing board addressed issues specific to sharing or collaboration on design documents produced by licensed individuals?

E. Future Vision

54. What plans do you have for better implementing the current CIM elements you have adopted?

55. Do you have any plans for incorporating other CIM elements you have not adopted so far? Why?

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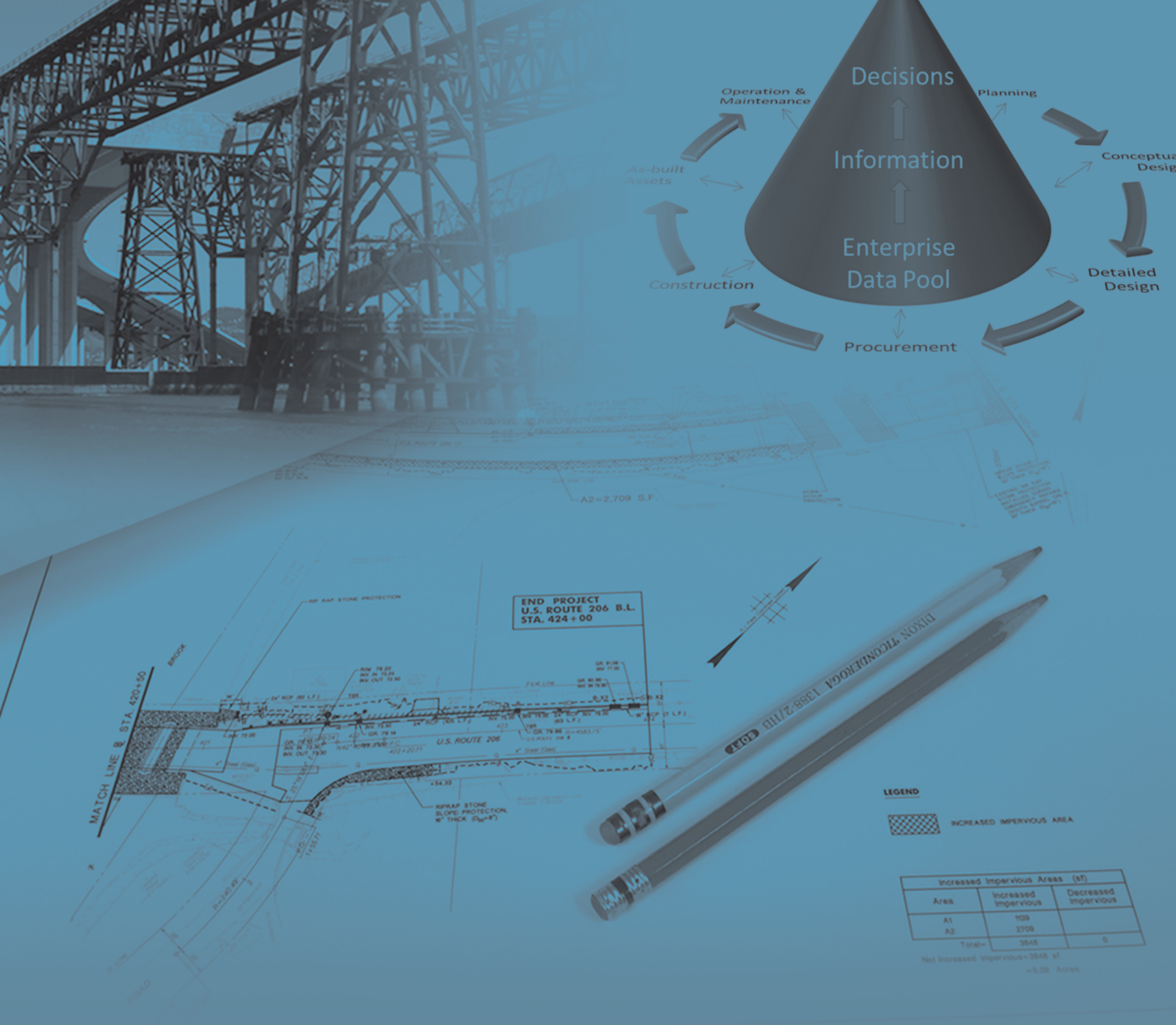
Decisions
Information
Enterprise Data Pool
Planning
Detailed Design
Procurement
Construction
As-built Assets
Operation & Maintenance
END PROJECT U.S. ROUTE 206 B.L. STA. 424+00
MATCH LINE & STA. 420+50
U.S. ROUTE 206
LEGEND
INCREASED IMPERVIOUS AREA
A2=2,709 S.F.