ADVANCING BIM FOR INFRASTRUCTURE

NATIONAL STRATEGIC ROADMAP

JUNE 2021

U.S. Department of Transportation

Federal Highway Administration

FOREWORD

The U.S. highway industry is on the precipice of a paradigm shift in which increased access to and better integration of geospatially located data will increase the efficiency and productivity of project delivery. There is steady and growing use of innovative digital technologies to design and construct capital highway projects and to monitor their condition and performance. Building Information Modeling (BIM), as applied to highway infrastructure (referred to in this roadmap as BIM for Infrastructure), is a collaborative work method for structuring, managing, and using data and information about transportation assets throughout their lifecycle. It involves delivering capital projects collaboratively (through the planning, design, and construction phases) and efficiently managing services the built infrastructure is expected to provide using digital rather than traditional paper-based processes. By aligning data within and across an agency's information systems in a manner that allows them to be managed easily (e.g., creating a digital twin), the potential exists to break down information silos and offer major productivity gains and cost efficiencies for roadway agencies across all lifecycle phases of built infrastructure. As highway agencies increasingly apply BIM for Infrastructure concepts and approaches, the Federal Highway Administration (FHWA) convened stakeholders to develop a comprehensive and coordinated approach to implementing BIM for Infrastructure. This national strategic roadmap is the result of that effort.

The objective of the roadmap outlined in this document is to help State departments of transportation (DOTs) strategically develop a uniform, nationwide framework related to BIM for Infrastructure, open data–exchange standards and methods for adopting those standards, BIM tools, and a robust personnel training and upskilling program. These State-led and FHWA-supported actions can then become the basis for planning and implementing BIM for Infrastructure to better deliver projects and transportation services at the State DOT level. Approaching BIM for Infrastructure with a coordinated approach will allow the greater highway industry to make investments with fewer concerns about differing requirements across the States. The roadmap is an initial step and is intended to be a living document as progress is made.

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16. Abstract
Building Information Modeling (BIM) for Infrastructure is an open standards–based collaborative work method for structuring, managing, and using data about transportation assets and networks throughout their lifecycles. It liberates data from siloed systems and makes it easier for automated processes to generate asset information and distribute it to anyone who needs it when they need it. The roadmap outlined in this document is intended to help State departments of transportation (DOTs) strategically develop a uniform, nationwide policy framework related to BIM for Infrastructure, open data–exchange standards and methods for adopting those standards, BIM tools, and a robust personnel training and upskilling program. These State-led and Federal Highway Administration–supported actions can then become the basis for planning and implementing BIM for Infrastructure to better deliver projects and transportation services at the State DOT level.

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BIM deployment, building information modeling, digital data, digitalization, infrastructure lifecycle, return on investment

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Advancing BIM for Infrastructure: National Strategic Roadmap

June 2021

U.S. Department of Transportation
Federal Highway Administration

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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List of Abbreviations

AASHTO	American Association of State Highway and Transportation Officials
AMG	automated machine guidance
API	application programming interface
BEP	BIM Execution Plan
BIM	Building Information Modeling
CAD	computer-aided design
CDE	common-data environment
CIM	civil integrated management
DB	design-build
DBB	design-bid-build
DBOM	design-build-operate-maintain
DOT	department of transportation
EIR	Employer's Information Requirement
ELT	extract, load, transform
ETL	extract, transform, load
EU	European Union
FHWA	Federal Highway Administration
GIS	geographic information system
GML	geography markup language
ICT	information and communications technology
IFC	industry foundation class
IT	information technology
JSON	JavaScript object notation
LiDAR	light detection and ranging
MVD	model-view definition
O&M	operations and maintenance
OTL	object-type library
ROI	return on investment
STIP	Statewide Transportation Improvement Program
TIP	Transportation Improvement Program
UDOT	Utah Department of Transportation
VDC	virtual design and construction
XML	extensible markup language
2D	two dimensional
3D	three dimensional
4D	four dimensional

Executive Summary

Building Information Modeling (BIM) for Infrastructure is an open standards–based collaborative work method for structuring, managing, and using data about transportation assets and networks throughout their lifecycles. It liberates data from siloed systems and makes it easier for automated processes to generate asset information and distribute it to anyone who needs it when they need it.

The objective of the roadmap outlined in this document is to help State departments of transportation (DOTs) strategically develop a uniform, nationwide policy framework related to BIM for Infrastructure, open data–exchange standards and methods for adopting those standards, BIM tools, and a robust personnel training and upskilling program. These State-led and Federal Highway Administration–supported actions can then become the basis for planning and implementing BIM for Infrastructure to better deliver projects and transportation services at the State DOT level.

1.0 Background and Overview

Over the past few decades, information and communications technologies (ICTs) have revolutionized the way we live our lives. From internet banking to hailing a taxi to booking an airline ticket to shopping online, we take for granted the convenience afforded by these modern-day digital technologies.

Behind these conveniences, and largely hidden from the user, is a complex array of digital transactions and customer and supplier interactions made possible by well-orchestrated internal business and work process realignments in several industries. The new ways of working and new types of customer interactions made possible by these changes harness and are built upon the power of ever-evolving data modeling and exchange techniques, big data management solutions, data analytics, the internet (cloud), sensors, mobile devices, and other technologies.

These fundamental changes in ICTs are resetting customer expectations and transforming work tasks that were labor intensive and analog or paper-based only a few years ago. Simultaneously, these changes are also bringing revenue and profit growth to adopting industries.

While many sectors of our economy, in both the public and private spheres, are increasingly digitalizing, the highway infrastructure industry has only just started to pay attention to data-management and governance practices. The way we plan, design, construct, and manage the highway system still underutilizes the power of data and information.

This underutilization is not due to the lack of penetration of digital tools and technologies into the highway infrastructure industry. Highway agencies are adopting and implementing ICT innovations at an increasing rate. Examples include computer-aided design (CAD) and drafting tools, intelligent construction techniques, e-Construction technologies and work methods, geographic information systems (GISs), and asset-management systems. However, much of the digital data and information captured by these tools and work processes are locked into siloed data systems specific to a phase of a project (e.g., design, construction, or operations and maintenance (O&M)) and are not interoperable.

Without structured and streamlined data-modeling and exchange practices, data cannot be efficiently exchanged between the data systems, stakeholders, and processes associated with managing assets during various phases of their lifecycles, and work processes cannot be automated. And, perhaps most importantly, the efficiencies and benefits achieved through digitalization in other sectors of the economy cannot be realized within the highway infrastructure industry.

Overcoming this situation necessitates a lifecycle view of the data and information collected about highway infrastructure assets and their operation as well as a fundamental reorganization of the way all data systems, stakeholders, and processes structure, manage, and use this information. This is the promise of Building Information Modeling (BIM).

BIM is a collaborative work method for structuring, managing, and using data and information about transportation assets and networks throughout their lifecycles. It liberates data from siloed systems and makes those data available to anyone who needs them when they need them.

During the economic downturn more than a decade ago, many industrialized countries turned to BIM to improve the productivity of their flatlining construction sectors. The goal was to spend less and get more value for investments made by introducing a new way of working collaboratively across asset lifecycles by using interoperable digital data. A recent report estimates that, starting in 2020, some BIM-mature nations in Europe are expected to witness annual savings of between 5 and 20 percent in their construction budgets by using BIM processes (Meerkerk and Koehorst 2017). Another study reports that an overwhelming majority of BIM users surveyed across the United States and Europe experienced a positive return on investment (ROI) from implementing BIM (Jones and Laquidara-Carr 2017).

These benefit estimations are primarily based on efficiencies introduced during the design and construction phases alone. When the value of BIM to asset managers is accounted for (where BIM can reduce the effort and cost associated with asset inventory data collection), the ROI estimates attributable to BIM look even more promising.

BIM for Infrastructure offers an opportunity to digitalize and transform traditional analog or paper-based information-exchange processes within the highway infrastructure industry. BIM for Infrastructure relies on uniform data-modeling techniques, nationally and internationally accepted open data–exchange standards, and future-proof and sustainable data-linking approaches to other domains, such as GISs, to minimize business inefficiencies associated with information loss, eliminate information silos (figure 1), and preserve the data value chain.

Although these monetary benefits and efficiency improvements are compelling, BIM processes offer other qualitative benefits, such as increased collaboration across disciplines, improved transparency and accountability, and enhanced communications with stakeholders. Furthermore, BIM for Infrastructure directly supports U.S. regulatory requirements, including the requirements on data-driven and performance-based approaches to asset management outlined in Title 23 of the United States Code (23 CFR § 515.9, 23 CFR § 144 (a)(2), 23 CFR § 150, and 23 CFR § 106(j)) and the Federal Highway Administration's (FHWA's) national strategic goals on infrastructure and innovation.

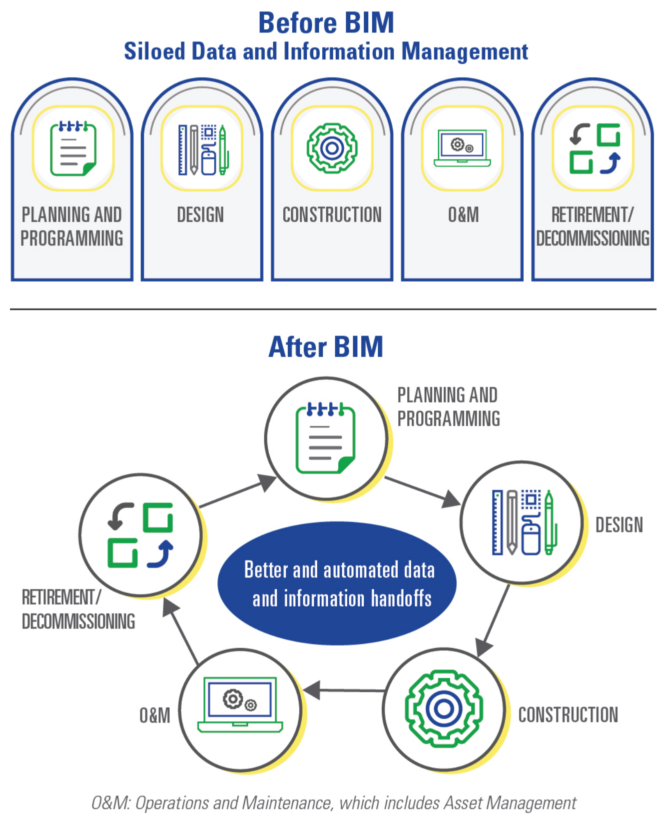


Figure 1. Illustration. Silos versus collaborative use of interoperable data.[1]

BIM deployment in the U.S. highway infrastructure industry lags behind that of other countries. In the current climate of shortages in funding and skilled workers, however, the industry can ill afford to ignore the monetary gains and advantages for information and knowledge management promised by BIM.

Therefore, FHWA has initiated the strategic roadmap for BIM implementation described in this document. The roadmap aims to assist in the concerted and effective deployment of BIM processes for all stakeholders nationwide. The purpose of this roadmap is to propose key implementation activities to carry out over the next 10 years to guide FHWA, State departments of transportation (DOTs), and their industry partners toward the goal of increasing the maturity and growth of BIM for Infrastructure nationwide while maximizing returns on investment.

This roadmap targets the information and data-exchange activities that should be carried out within and across all asset lifecycle phases. However, the work activities

[1] This image was taken from unpublished materials produced by HDR, Inc.

outlined consider the need for incremental change to ensure the pace of change is manageable and sustainable. For example, the roadmap emphasizes starting with improvements to the design and construction phases and the handoff to asset management, collectively referred to as the "little BIM" lifecycle phases. These initial improvements are followed by improvements to the planning and programming and O&M phases. Eventually, BIM processes will be implemented within and across all lifecycle phases to ultimately result in what is referred to as "big BIM" at the end of 10 years.

At the end of 10 years, this roadmap envisions the following scenario: State DOTs, in cooperation with their external partners, will have mature BIM processes in place and trained and skilled personnel who use open-data standards, information-exchange specifications, and digital workflows to collaborate with each other to create, collect, store, process, share, analyze, and autonomously exchange data and information across a large number of key systems of record, including those related to planning, programming, surveying, design, engineering analysis, construction management, asset and maintenance management, GISs, and linear referencing. The data created and updated within these systems of record will be used in enterprise-level information models designed using open standards and managed in a centralized, common-data environment (CDE).

As part of this scenario, State DOTs and their external partners will deploy people, processes, policies, tools, and technology systems to ensure the enterprise-level information models incrementally grow as additional data become available with each subsequent asset lifecycle phase, minimize data loss to the enterprise-level information models by federating all internal and external systems of record within the CDE, and maximize efficiency and productivity across all capital improvement, asset operations, and maintenance projects. This scenario is defined as BIM Maturity Level 2 in the roadmap.

To achieve this vision, an incremental set of foundational, developmental, and deployment activities will need to be undertaken by infrastructure owners and operators across the country. The roadmap articulates these activities under three distinct phases of work: the short-term or early pilot projects phase (Year 0 to Year 2), the medium-term or extended pilot projects phase (Year 2 to Year 5), and the long-term or mainstreaming phase (Year 5 to Year 10). Each phase seeks to grow the maturity of four BIM for Infrastructure elements: policies and processes, people and skills, data and standards, and tools and technologies. The activities in each phase are defined and sequenced such that all BIM framework components grow simultaneously toward a given maturity level.

BIM promises substantial rewards in terms of lower costs for design and construction, fewer cost and schedule overruns and change orders during construction, lower data-collection costs, and higher quality information to better support decisions regarding asset management. At the same time, BIM is not without its share of challenges, including the need to manage the significant organizational changes necessary for data to be considered a shared responsibility, a lack of standards for information modeling and exchange, a lack of funding to overhaul information technology (IT) processes, the need for workforce training to upskill personnel to handle the data, and risks to the performance and reputation of implementing organizations due to unmet expectations.

Therefore, implementing organizations should carefully follow a coordinated sequence of what are known as "crawl, walk, run, fly" activities for BIM to consistently deliver the desired benefits. The activities outlined in this roadmap thus describe a pathway to defray risks and maximize benefits.

As implementing organizations carry out the program of activities, there is little doubt this roadmap and its suggested activities will need to be reviewed, updated, and enhanced periodically based on lessons learned internationally and within the United States and to incorporate other BIM-enabling activities within the highway infrastructure industry, such as the development of new standards, tools, and technologies.

2.0 Purpose and Organization of this Document

Through this document, FHWA articulates a vision and proposes a roadmap of structured activities to advance BIM for Infrastructure in the United States. Using this roadmap, FHWA proposes collaborating with stakeholders on a shared vision, goal, and objective to facilitate BIM for Infrastructure implementation. This document is organized into the following chapters:

- Chapter 3 summarizes the opportunities BIM offers for improving the U.S. highway infrastructure industry as well as the challenges and risks of implementing BIM.
- Chapter 4 defines BIM for Infrastructure, presents its fundamental concepts, and introduces its four elements: policies and processes, people and skills, data and standards, and tools and technologies. Enhancing each of these elements is critical for BIM's growth in an organization.
- Chapter 5 expands on the benefits of deploying BIM summarized in chapter 3 and provides a more in-depth discussion of the BIM benefits for State DOTs. A thorough understanding of the benefits at an elementary level is necessary for articulating the value of BIM for Infrastructure and justifying future investments.
- Chapter 6 assesses the current state of the practice to understand where State DOTs are in terms of deploying and realizing the benefits of BIM for Infrastructure. This assessment forms the basis for the vision statement, goals, and objectives of the roadmap described in chapters 7 and 8.
- Chapter 7 articulates a national vision for BIM for Infrastructure. It introduces the BIM maturity model and defines maturity stages or levels. The chapter then explains how BIM-based data and information exchange fits within and across the various phases of the project and service delivery lifecycle. Finally, the chapter identifies a starter list of BIM for Infrastructure use cases for State DOTs to consider as they plan and develop their BIM-based workflows.
- Chapter 8 presents a roadmap of structured activities that, if performed, can help agencies achieve the various BIM maturity levels articulated in chapter 7. The activities are categorized based on whether they are foundational or contribute to development or deployment. Furthermore, the activities proposed in the roadmap are mapped to objectives that focus on enhancing the current state of the practice regarding BIM policies and processes, people and skills, and data and standards to demonstrate how the structured activities contribute to advancing the agency's BIM maturity.

3.0 Potential for BIM in the U.S. Infrastructure Industry

Delivering highway projects on schedule and within budget as well as planning for and maintaining built infrastructure in a state of good repair at the minimum practicable cost are among the top strategic objectives of State DOTs. State DOTs are increasingly becoming aware that well-organized and integrated data and information directly support these objectives.

Consequently, the use of digital data, tools, and information and communication technologies has seen significant growth in the highway infrastructure industry over the past decade. Commonplace examples of such digital initiatives in the U.S. highway infrastructure industry include high-accuracy mass geospatial survey techniques (e.g., light detection and ranging (LiDAR)), three-dimensional (3D) modeling, automated machine guidance (AMG), e Construction technologies (e.g., mobile devices, electronic document management systems, electronic signatures and approvals, digital inspection), federated data systems (e.g., GIS, geodatabases, data marts), and digital workflows.

Although these digitalization efforts are taking shape and gaining momentum, most DOT agencies do not have a comprehensive shared view of their data and information across the enterprise, nor do they have a governance structure for that data and information. Figure 2 illustrates the current state of the practice regarding the quality and integrity of information management at State DOTs and contrasts that scenario with an ideal lifecycle information-management model.

The figure shows that most State DOTs currently experience data and information loss (and therefore knowledge loss) across asset lifecycle phases and a broken data value chain. At best, data are transferred between subsequent phases (e.g., planning and programming to design, design to construction), but information growth does not span the entire lifecycle.

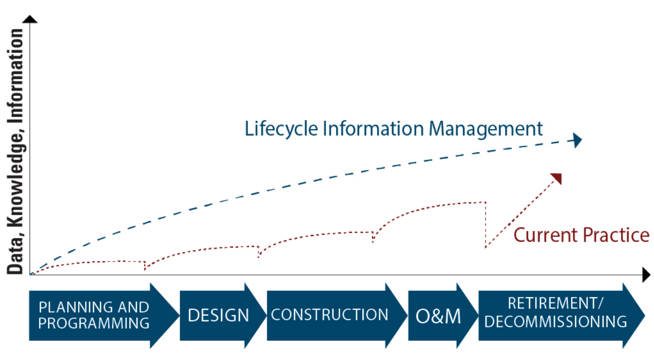


Figure 2. Graph. Current practice versus ideal lifecycle information management.

This dilemma, in which information created during one phase of a project's lifecycle is lost and subsequently recreated (presumably using additional resources), has prevailed for decades and contributes to multiple specific business inefficiencies, including the following:

- Undermining the building momentum within State DOTs to modernize and digitalize their practices.
- Duplicating data-collection efforts or contributing to suboptimal decisionmaking by using limited data sets.
- Creating information silos in which the connections between the data stored in various enterprise systems are nonexistent or highly customized. Custom data integrations are typically "vendor locked-in," are unsustainable, and are unable to absorb changes or disruptions to the data value chain without significant retooling costs.
- Inability to work collaboratively with internal stakeholders or external partners.

3.1 The Opportunity for BIM in the U.S. Highway Infrastructure Industry

Many leading market trend forecasters predict digitalization of the engineering and construction sector is imminent (Jones and Laquidara-Carr 2017; Gerbert et al. 2016; Panetta 2018). Digitalization is the process of employing digital technologies (e.g., computers, communication systems) and digital information (as opposed to paper-based and analog information) to transform business operations to create either new revenue or value-producing opportunities (Muro et al. 2017). Digitalization is specifically tied to business processes digital technologies can transform, and these transformations can change the nature of people's jobs. Process automation is a key part of the digitalization story.

The U.S. highway infrastructure industry generally feels digitalization of its business processes is well underway. For example, many State DOTs are using GISs to integrate data generated or used by planning, design, construction, and financial- and asset-management systems. Federated mobile and web applications are also being used to seamlessly share data across certain systems and asset lifecycle phases.

However, although digitalization is certainly underway, uniform data-modeling techniques and open data–exchange standards between systems have not yet been developed. This lack of standards and techniques has led most agencies to create custom integrations among their disparate systems. Moreover, few attempts have been made in the United States to channel these data-integration efforts and strategically determine the level of investment and the type of activities involved in managing data as an asset for information extraction and knowledge creation.

At the same time, with the emergence of data offices and data-governance boards and the creation of roles such as chief data officer within State DOTs, critical questions are being asked: Which data are critical? What benefits does data management provide? Which data models and data-exchange standards offer the most value? What needs to be done? These questions need to be addressed in a strategic manner to ease the difficulties surrounding efficient data management.

With its emphasis on collaborative and organized data management across lifecycle phases, BIM provides a set of principles and practices directly applicable to digitalization efforts across the highway infrastructure industry. BIM leverages modern-day digital technologies and digital data and information to create higher levels of integration among automated systems, which in turn drives greater efficiency and productivity gains. By one estimate, the financial gains to be made from digitalizing engineering, construction, and operations or lifecycle processes for roadway and bridge projects using BIM for Infrastructure are in the range of a 16-percent savings on total capital project expenditures, clearly a significant benefit (Jones and Laquidara-Carr 2017).

A European Union (EU) report notes that from 2020 onward, the estimated yearly cost savings from using BIM processes in the design and construction phases of roadway projects, as a percentage of the total construction budgets in five EU countries (i.e., the Netherlands, Sweden, Finland, Norway, and the United Kingdom), vary between 5 and 20 percent, with an average of 8.2 percent (Meerkerk and Koehorst 2017). The report further notes these savings are expected to be even greater when the benefits of BIM processes at the O&M phase are factored in, although no specific figures are given.

The cost savings and positive returns on investment are a result of the efficiencies gained by using BIM processes in various lifecycle phases and are shared by all stakeholders (see chapter 5 for further explanation).

3.2 Challenges and Risks of BIM Implementation

Implementing BIM for Infrastructure is not free of challenges or risks. As some BIM-mature organizations have found, specific challenges include the following:

- Implementing changes to the management and organization of an agency regarding its data, information, and knowledge resources.
- Changing cultural attitudes and behaviors to accommodate a new way of doing business for the benefit of the larger enterprise.
- Investing in and deploying the appropriate systems, technologies, and communication tools to effect the change.
- Obtaining buy-in and commitment from outside stakeholders.
- Adopting open standards at the enterprise level for data management (i.e., standards for creating data models, data quality control, data security, data exchange, document and content management, and business intelligence).

The potential risks of premature implementation include the following:

- Expectations regarding the results are excessively high or nonuniform.
- Lack of agreed-upon national standards for implementation.
- Withdrawal of external stakeholder support.
- Reliance on ad hoc versus strategic implementation activities.

Because of these challenges and risks, implementing BIM for Infrastructure within an organization benefits from deliberate, strategic planning; involves all stakeholders; and tightly couples broader strategy goals with tactical efforts on the ground.

The objective of the roadmap outlined in this document is to help guide State DOTs in strategically developing a uniform, nationwide policy framework related to BIM for Infrastructure, open standards and methods for adopting those standards, BIM tools, and a robust personnel training and upskilling program. These State-led (and FHWA-supported) actions can then become the basis of planning for and implementing BIM for Infrastructure to better deliver projects and services at the State DOT level.

4.0 Defining BIM for Infrastructure

For the purposes of this document, BIM for Infrastructure is formally defined as follows: BIM for Infrastructure is a collaborative work method for structuring, managing, and using data and information about transportation assets throughout their lifecycles.

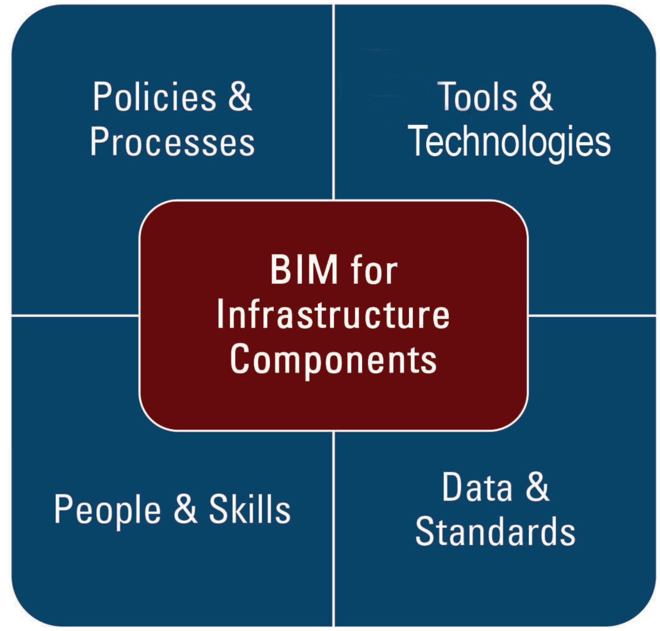
This definition of BIM for Infrastructure describes big BIM, in which BIM for Infrastructure enables a holistic digital representation of the physical and functional characteristics of an infrastructure asset. Chapter 7 further explains big BIM.

As defined here, BIM for Infrastructure involves preparing the ground rules, frameworks, and workforces at Federal agencies, State DOTs, and local highway agencies to allow information and data on infrastructure assets to move seamlessly across the enterprises of both these agencies and their stakeholders.

The term "data" encompasses geometric and nongeometric data, sometimes referred to as graphical and nongraphical data. Geometric data include spatial or geolocated data as well as drawings defining the form of a physical infrastructure asset and the volume it occupies in space using points, lines, curves, shapes, etc. These data are typically captured using GISs or CAD. Nongeometric data include information about the physical asset, such as its name, type, installation date, and so on, which can be used to manage and operate the asset and make decisions regarding it. For both types of data, the term data management describes the modeling, provisioning, exchanging, and sharing of data.

BIM for Infrastructure involves creating, storing, processing, and moving data within and across asset lifecycle phases using software and hardware tools and technology systems. Policies, processes, people, and skills are put in place to manage the data using these tools and systems (figure 3).

A true (or maximally effective) BIM framework involves adopting open standards for data modeling, processing, and sharing. Therefore, the tools and technologies that are used to manage the data need to support open standards (in addition to any proprietary standards associated with particular tools and technologies). The people who use these tools and technologies to execute the standards-based processes are certified professionals who have the skills to use BIM tools and understand the BIM policies, processes, and standards.



Source: FHWA.

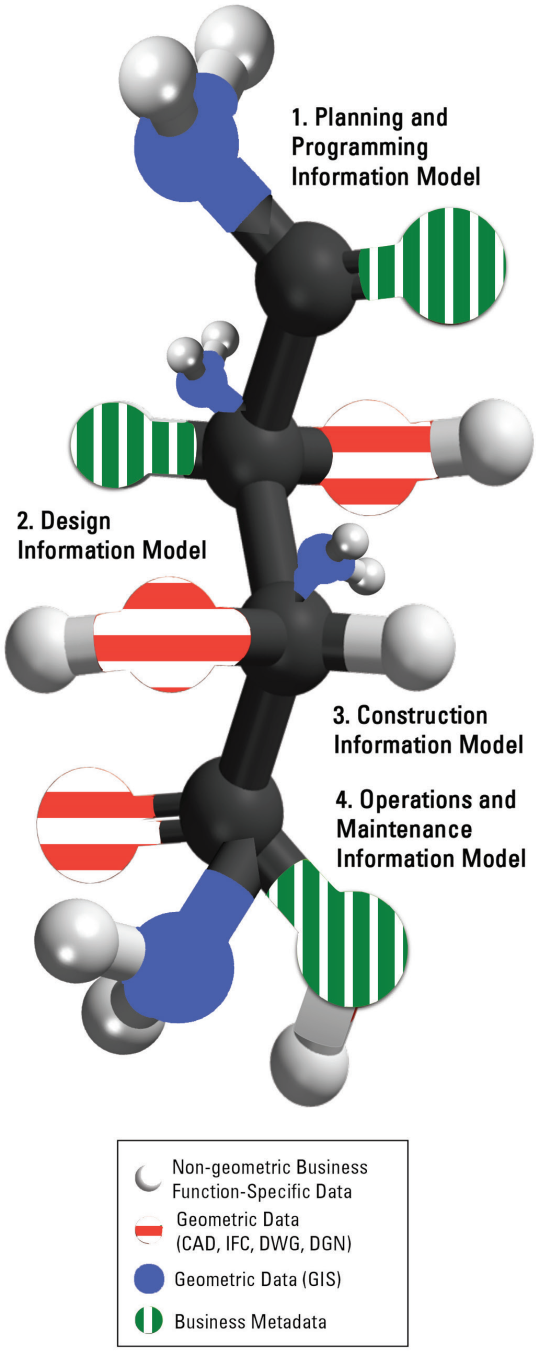
Figure 3. Illustration. Components of BIM for Infrastructure.

BIM for Infrastructure allows information models to grow in terms of content, significance, and value as data are created during the planning and programming, design, construction, and O&M phases of the asset life cycle (Figure 2). Data created within and across the asset life-cycle phases in various data models (e.g., roadway alignment model, bridge design model) are integrated to create a unified information model for each infrastructure asset (e.g., bridge, road, sign, project), thereby resulting in a single source of truth for knowledge generation and decision making (Figure 4).

This enterprise-wide information model, assembled using open standards, is managed in a common data environment (CDE).

For example, the planning and programming information model shown in figure 4 uses open GIS data-modeling standards to spatially locate the project by identifying the highway and asset locations using a geographic- or linear-referencing method. In addition to GIS data, open standards–based project attributes can be added to the model.

Then, the model can be shared with designers and surveyors using standards-based information-exchange packages. The design team can then collaborate using BIM processes, tools, and techniques to add engineering information about the asset to develop the Design Information Model. To model the engineering



Source: FHWA.
DWG=CAD file format.

Figure 4. Illustration. Unified information model developed through BIM processes.

data, open design standards such as CAD, industry foundation classes (IFC), and LandXML can be used (ISO 2018; W3C 2021).

Finally, during the construction and O&M phases, a combination of open data–modeling and exchange standards can be used, including—for example—IFC, geography markup language (GML), LandXML, TransXML, InfraGML, CityGML, JavaScript object notation (JSON), extensible markup language (XML), Resource Description Framework (RDF), and LAS (ISO 2018; OGC 2021a; LandXML 2018; Ziering et al. 2007; OGC 2021b; JSON 2021; W3C 2021a; W3C 2021b; ASPRS 2017). Using such standards ensures the data created during these phases provide interoperable and technology-neutral content for the information models (in this case, the construction information model and O&M information model).

Furthermore, BIM for Infrastructure processes—if followed correctly—can ensure the information models created during any lifecycle phase include business metadata (i.e., information such as the accuracy, precision, resolution, temporality, creator, and owner of the data). Such metadata will remain with the model when shared among stakeholders and be readily available and easily interpreted.

BIM infrastructure fully encapsulates the framework and concepts of civil integrated management (CIM), a term adopted in recent years by FHWA to represent a variety of digital project-delivery and data-management practices (FHWA et al. 2013). This encapsulation is unsurprising, because the term CIM originated from BIM and was adopted by the highway infrastructure industry to differentiate its practices from those in the building sector. Therefore, State DOTs that have embraced the CIM vision need only negotiate the challenge posed by the change in terminology.

The reason for the transition to the term BIM for Infrastructure is two-fold: to better align U.S. efforts with international efforts in this area, particularly with the ISO 19650 standard (ISO 2018), and to adopt a term more commonly known by various industry sectors.

5.0 Benefits of Adopting BIM for Infrastructure

As noted in chapter 3, BIM offers State DOTs an opportunity to digitalize and transform traditional analog or paper-based information-exchange processes and address inefficiencies related to information loss. Examples of such inefficiencies include the following:

- Redundant and costly data-collection efforts.
- Inconsistent terms and definitions for data across enterprise systems.
- Lack of enterprise-wide data management and governance, inadequate data use and sharing, and trust issues between internal and external stakeholders (e.g., design and construction contractors).
- Construction cost overruns due to communication and coordination problems related to data exchange.
- Lack of high-quality, reliable, and readily available data for decision support during the planning and programming, design, construction, and O&M phases of the asset lifecycle.

Addressing these inefficiencies allows State DOTs to save time, mitigate risks, reduce transaction costs, improve quality of outcomes, minimize loss of information, clarify workflows and schedules, improve global competitiveness and market position, and provide an economic stimulus to one or more nontransportation industries (e.g., the technology sector). These benefits can be realized within and across each of the asset lifecycle phases for all stakeholders. Several studies report the time savings and lower transaction costs derive mostly from eliminating duplicate data-collection efforts, reducing review and coordination times, increasing efficiency through streamlined processes, minimizing the number of change orders, and resolving conflicts before construction begins (Gerbert et al. 2016; Sillars et al. 2017; Mitchell et al. 2019; Parve 2013; University of Colorado Boulder et al. 2018; Molenaar and Duval 2016).

In a recent survey of BIM users that included transportation sector owners, engineers, and subcontractors in the United States, United Kingdom, Germany, and France, two-thirds of respondents reported that they experienced a positive ROI from BIM implementation, with nearly half of those reporting an ROI greater than 25 percent (figure 5) (Jones and Laquidara-Carr 2017).

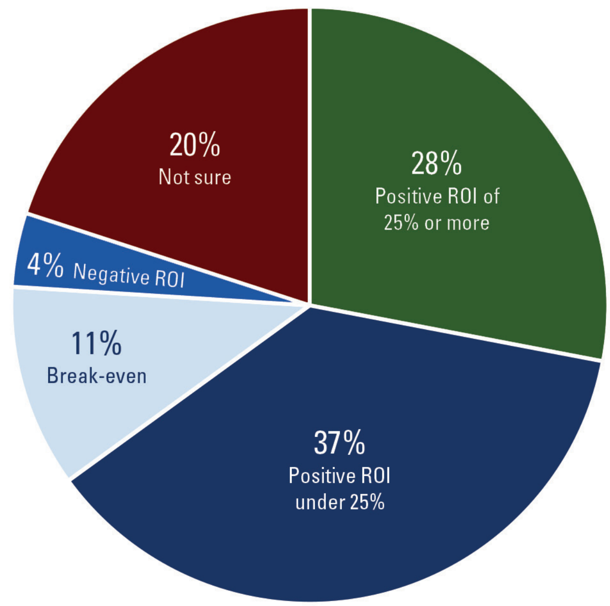


Figure 5. Chart. Perceived ROI from BIM processes among users in the transportation sector (Jones and Laquidara-Carr 2017).

One-third of respondents indicated that BIM improved project and process outcomes by generating fewer errors in data models created during construction. Respondents also reported BIM processes led to fewer conflicts and field-coordination problems during the construction phase. More than 20 percent of respondents mentioned BIM improved cost predictability and minimized rework. Respondents agreed that improved communication and 3D visualization provided a better understanding of the project among all stakeholders.

Moreover, more than 30 percent of respondents reported the high ROI from BIM could be attributed to reduced conflicts in data modeling and early detection of problems due to efficiencies in data modeling and visualization, which led to better coordination and communication. More than 20 percent of respondents reported a reduction in construction cost and time overruns due to BIM (see figure 6).

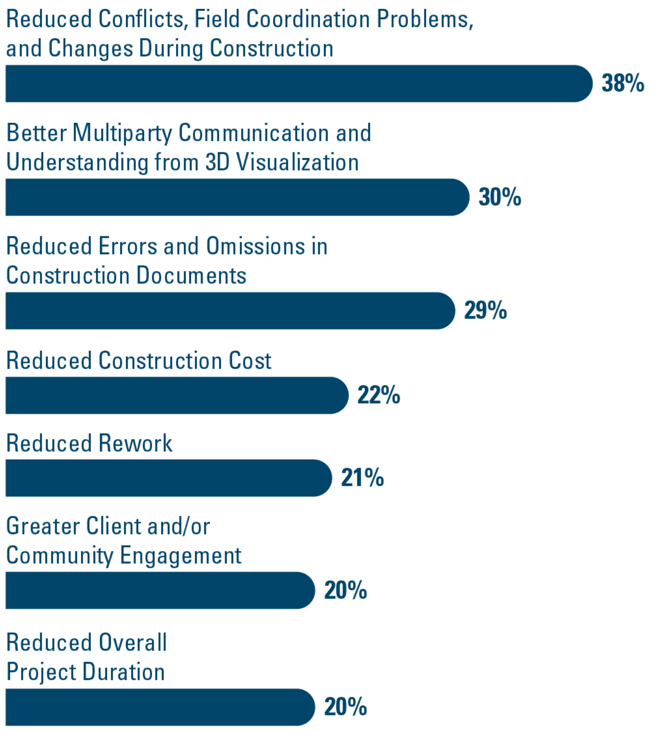


Figure 6. Chart. Reported benefits of BIM for Infrastructure among users in the transportation sector (Jones and Laquidara-Carr 2017).

Other benefits of BIM that all BIM users rated highly or very highly included the following:

- Improvement in the ability to show younger staff the relationships between different project phases.
- Establishment of a consistent and repeatable project delivery process.
- Ability to maintain business with past clients.
- Reduction in time spent documenting and increase in time spent designing.
- Reduction in claims and litigation.
- Improvement in staff recruitment and retention.
- Reduction of errors and omissions in construction documents.
- Improvement in information transfer to or within the O&M phase.

In addition to the benefits identified in the survey, the ability to know the location and the as-built and as-maintained condition of assets in the system is invaluable, as summarized in table 1.

While these efficiencies and their attendant cost savings may persuade agencies in the United States to consider adopting BIM for Infrastructure, there are two other important reasons.

The first is that adopting BIM for Infrastructure supports the following requirements established in Title 23 of the United States Code:

- 23 CFR § 515.9 *Asset Management Plan Requirements* and 23 CFR § 144 (a)(2) *National Bridge and Tunnel Inventory and Inspection Standards* discuss implementation of risk-based lifecycle cost optimization principles for asset management.
- 23 CFR § 150 *National Goals and Performance Management Measures* discusses making project decisions using data-driven and performance-based approaches that consider the state of the infrastructure and safety concerns.
- 23 CFR § 106(j) *Use of Advanced Modeling Technologies* discusses improving the cost, schedule, and quality outcomes of project delivery through enhancements in the detail and accuracy of designs, better construction planning and communication, mitigation of unforeseen conditions relating to utilities and geotechnical and environmental factors, fewer change orders, and more efficient network-traffic management and administration.

Table 1. Summary of key benefits realized through BIM for Infrastructure

Benefit	Sources of Benefit	Design	Construction	O&M
Time savings or efficiency gains	• Enhanced project delivery process due to improved collaboration and digital data exchange among stakeholders (e.g., those involved in design, construction, securing right-of-way, utilities, and environmental surveys) • Faster quantity determination for cost estimation • Reduced time and effort to prepare bids • Increased workforce utilization for construction inspection • Faster construction due to automation of equipment • Reduced data-collection effort (e.g., for subsurface utility data, asset data collected via LiDAR surveys, and as-built data used to create asset inventory)	✓	✓	✓
Lower transaction costs	• Optimized data collection (e.g., surveys are collected once and used many times) • Lower bids due to improved communication of design intent • Reduced number of change orders due to improved clash detection analysis and constructability assessments • Early identification of errors and omissions	✓	✓	✓
Risk mitigation	• Improved construction interfacing and planning • Better data for programming future projects • Improved as-built data for maintenance and operations • Cost optimization for capital expenditure during the design and construction phases to enable operational-expenditure outcomes	✓	✓	✓

✓ = applies to this phase.

Additionally, BIM for Infrastructure supports FHWA's strategic goals related to infrastructure and innovation. Because Federal investments are critically important to the National Highway System, the close alignment of BIM for Infrastructure with FHWA's strategic objectives can help foster and sustain this innovative method for the highway sector in the years to come.

The second reason for agencies to adopt BIM for Infrastructure is that different sectors in the U.S. public and private spheres have already made significant investments over the decades in closely related fields, including virtual design and construction (VDC), 3D-engineered models, CIM, digital twinning (i.e., city- and district-scale efforts), and construction automation (e.g., technologies such as e Construction and partnering, AMG, intelligent construction systems, and unmanned aerial systems).

In the building sector, the United States is an early leader in information modeling. In the highway infrastructure industry, considerable strides are being made to develop standards, suggested practices, and manuals to facilitate the use of buildingSMART® International's Infrastructure Room efforts related to the IFC data-exchange standard for bridge projects and the developing IFC roads standards. These investments and the resulting knowledge are the perfect starting point from which to take the next logical steps in the development of an information-management framework specific to highway infrastructure with a potential for significant returns.

6.0 Current State of the Practice

Information-modeling practices vary significantly across State DOTs. Even within a State DOT, information-modeling practices vary across the different phases of the asset lifecycle. Most agencies do not associate the term "BIM" with information modeling as it is described in the previous chapters. Rather, to most State DOTs BIM involves creating 3D-engineered models during the design phase for use in construction.

Current efforts to produce 3D-engineered models for project delivery have moved forward without a comprehensive and consistent set of requirements and BIM-compliant software. These pilot efforts have demonstrated the importance of standards, processes, and proper technology. To successfully implement BIM for Infrastructure, all four of its elements—policies and processes, people and skills, data and standards, and tools and technologies—need to be functional within the organization.

This chapter summarizes the current state of the practice of BIM for Infrastructure and highlights the work agencies are doing to deploy it. The chapter also highlights the work that still needs to be done to deploy BIM according to the concepts and principles outlined in national and international open standards, e.g., ISO 19650, so the gaps can inform the BIM for Infrastructure roadmap (ISO 2018). The discussion is organized around the four elements of BIM for Infrastructure.

6.1 Policies and Processes

Organizational and enterprise-wide policies on managing data play a key role in driving all departments and business units toward BIM for Infrastructure at the enterprise level. The objective of the policies is to integrate the data and open the silos within the organization to maximize the usage of and benefits derived from the data.

Some State DOTs have created data offices and governance councils to establish policies, standards, and suggested practices related to data processes and exchanges between systems. For example, Connecticut and Florida are establishing data-governance committees, policies, processes, and tools to guide their future BIM initiatives. These DOTs are considering establishing standards and processes to guide what data should be modeled, when the data should be modified or enhanced, and who should have possession of or access to the data at different times. In agencies developing such policies, data stewards work with subject matter experts to understand how to connect the dots between one stage of asset creation to the next. Such agencies understand data should be managed as an asset and data governance is essential.

However, most State DOTs lack a common perspective, leadership, and suggested practices on enterprise-wide information management because the connection between the agency's organizational goals and its ICT is limited or nonexistent. As a result, the multiple enterprise data systems, processes, models, and integrations that have been deployed are limited in scope. For example, most agencies have deployed enterprise-level survey and design systems, created survey-to-design and design-to-design data-collaboration processes, and trained staff to ensure survey and design data are handled effectively. The impact of these systems and data processes, however, is limited to only those stakeholders involved in the project-development process before construction. Planners and asset managers do not benefit from such limited BIM frameworks.

Even agencies that have taken the initiative to begin deploying BIM for Infrastructure are taking different approaches and carrying out a variety of implementation activities to establish enterprise-information management. Both across and often within agencies, no set of standard procedures or activities is being used to deploy BIM for Infrastructure. Rather, the deployment goals, milestones, benchmarks, implementation activities, and performance metrics related to BIM for Infrastructure vary.

6.2 People and Skills

The deployment of new and updated technology systems compatible with BIM for Infrastructure has been the driving factor for State DOTs to establish training curriculums and develop training sessions that provide relevant resources and improve the skills needed to implement BIM for Infrastructure. Employees are being trained to record data in a digital information model (as opposed to using paper-based systems), collect data in the field using mobile devices during the construction and O&M phases, create 3D data models, and use BIM tools to enable data exchange between systems.

However, these training curriculums and sessions have been primarily focused on proprietary software and systems and internal information-modeling standards. Training is needed on the concepts and principles associated with BIM for Infrastructure and the use of open standards (e.g., IFC, ISO 19650, InfraGML, CityGML) for data modeling, organization, and exchange. Such training should be tailored to specific project types and their associated use cases and business needs and processes. The skills of staff employed in the various business units involved in infrastructure development and management should be developed in a strategic and systematic manner to support the drive toward enterprise-level information management.

6.3 Data and Standards

State transportation departments in the United States create three types of data models: paper based (e.g., those using hard copy plan documents), file based (e.g., those using .pdf, .dgn, .dxf, .csv, .xls, or .doc files), and object based (e.g., those using data stored in GISs that capture both the geographic and nongeographic attributes of assets and other physical infrastructure entities).

These data models support a variety of business processes during the planning and programming, design, construction, and O&M phases. During the design and construction phases, the information modeling largely involves paper- or file-based, not object-based, data models. The object-based data models are primarily used during the planning and programming and O&M phases. At most agencies, object-based data models contain information about the locations of infrastructure assets or other entities (e.g., projects). Additionally, at most agencies the data in the data models created during the design and construction phases are not integrated into the GIS-based data models created during the O&M phase. However, the as-built plan documents are typically made available to asset managers and asset-management systems through shared document repositories or other document-management systems.

Agencies in several States (e.g., Ohio, Minnesota, and Utah) have tried to establish processes for importing asset location data from the CAD-based data models created during the design and construction phases into the agencies' GIS-based asset-management systems. Such data-exchange processes might involve, for example, importing CAD format (.dgn) files into a GIS system to create shapefiles or populate asset geodatabases. The objective of these efforts is to allow agencies to extract as-designed or as-built information about assets from existing data models and build up the agencies' asset inventories.

To extract the functional and physical characteristics of the built asset from the digital plan documents or file-based models for use during the O&M phase, State DOTs currently follow a variety of agency-specific multistep processes. While the processes vary from one agency to another, most involve extracting location or geographic data attributes differently than nongeographic data attributes. Additionally, the data file formats and data-exchange processes are not based on open standards.

There is opportunity to significantly simplify these CAD-to-GIS data-exchange processes by migrating to BIM models, processes, and tools. Because of the complexities involved in the CAD-to-GIS data exchange, many State DOTs currently resort to simply sharing digital plan documents (e.g., PDFs) to share information about the as-built asset and its attributes. However, an asset's information cannot be easily retrieved from these design and construction documents. State DOTs do continue to invest in efforts to deploy centralized data repositories for document or content management and to implement intelligent workflows within these systems to facilitate the routing, review, and approval or signing of documents. But these workflows are built on file-based models, not object-based models, and are not based on open standards.

To migrate to object-based models, agencies in some States (e.g., Utah, Minnesota, and Florida) are looking to define asset-information requirements so this information can be added to data models created during the design and construction phases. However, even these agencies currently rely on ad hoc definitions of information needs; there are no national or even statewide standards for asset information requirements. At most State DOTs, these information requirements are also not included in contract documents created during the design and construction phases. Rather, the specifications regarding information requirements are not well documented or lack clarity and consistency. As a result, there is a significant amount of redundancy in data-collection efforts across the phases of an asset's lifecycle, especially after construction and during the O&M phase, because of lost, inconsistent, incomprehensive, and unreliable data.

A more concerted national effort is needed to establish standard templates for information requirements, but some agencies have already begun to address this issue. For example, Michigan DOT is considering the establishment of processes and standards for defining levels of development (for objects) to help surveyors, designers, and construction staff understand the data that should be included in a construction model and what the data may be used for based on its level of development. Utah DOT (UDOT) is leading the way in developing partnering practices to pilot using the design model as the legal document for both roadway and bridge projects. Iowa DOT is also piloting using 3D-engineered models as the legal document for roadway projects and recently released a bridge project with the design model as the contract deliverable.

Most agencies currently use data-quality control and quality assurance procedures during information modeling and exchange. However, similarly to data-exchange procedures and information requirements, these procedures have also not been standardized within or across agencies, and there are no consistent data-quality checks within or across agencies. Instead, the availability of funding, technical skills, configurable software, and data stewards determine which data sets receive which quality checks and where agency dollars are invested.

Additionally, the maturity of data quality-control and quality-assurance processes varies, and issues often arise regarding the alignment of data-quality requirements with data-modeling approaches, technologies, and standards. For example, the State DOTs in Georgia and New York have deployed comprehensive data-quality checking processes to ensure bridge inspection data collected for the agencies' bridge-management systems are of sufficient quality. However, the two agencies have established different data-quality assessment procedures even though both follow the American Association of State Highway and Transportation Officials (AASHTO) manual for bridge inspections (AASHTO 2019).

Over the last decade, State DOTs have been working with software vendors, contractors, and consultants to explore how engineering design models may be used for construction applications. However, these efforts have been focused on 3D-engineered models rather than information modeling beyond project delivery. Similarly, some State DOTs are creating survey 3D models for design applications, design surfaces for AMG (e.g., for grading and paving), and as-built geospatial models for GIS applications to build up asset inventories. However, agencies are finding that each discipline (e.g., those involved in design, construction, and O&M) uses different data libraries that are often proprietary and that intertwine data and functionality to create data that are locked into a specific system or vendor.

Within and across agencies, there is limited to no use of open data-modeling standards, data terminology, object definitions, and object-type libraries (OTLs). So, although agencies have started using object-based data models in the design and construction phases, due to the lack of open-modeling standards the data need to be transformed after they are extracted from the source system to ensure they are compatible with the data dictionary of the target system. Agencies are heavily invested in data exchanges based on such extract, transform, load (ETL) or extract, load, transform (ELT) operations, when in fact they can establish a greater level of interoperability and consequently reduce data integration costs by using open standards.

6.4 Technology and Tools

Over the past two decades, State DOTs have come a long way in deploying web-based enterprise data–management systems, mobile applications, data warehouses, business-intelligence systems, and reporting portals. For example, UDOT has worked with multiple stakeholders to define a process for sharing digital data with contractors that replaces traditional plan sheets (i.e., those captured on paper or in two-dimensional (2D) PDFs) for highway-project contracts. To this end, UDOT has equipped construction inspectors with tablets that can be used to verify, in real-time, the as-designed model to the as-built model. The inspector uses a proprietary application on the tablet to view each object to be installed. From that viewer, the inspector can see specific attributes such as pay items, stations and offsets, and Global Positioning System coordinates.

However, many agencies still use paper-based data-collection processes. Even agencies that have deployed digital systems, such as mobile applications, for data collection have not necessarily selected their technologies strategically or in an organized way. Some agencies use numerous data-management applications that are not integrated and have limited information-modeling features. The use of multiple data systems also introduces data redundancy, which complicates managing master and reference data across each system.

State DOTs are in the process of replacing such systems with enterprise-level systems to better manage information models and exchanges. The deployment of federated information models has gained momentum, but in many cases the information models have not been federated in a way that links all enterprise systems. While some agencies have deployed data warehouses to store data from multiple systems, these warehouses cannot be considered a CDE because the underlying information model is not federated and is not compliant with open standards (e.g., ISO 19650) (ISO 2018). Furthermore, most data-management systems do not store business metadata (e.g., accuracy, precision, resolution, and temporality) with business data.

In short, in many agencies the use of ICT is scattered, and technologies and tools are poorly utilized. Features and functions that handle spatial and temporal data are limited to few enterprise systems, and business data are spread across hundreds of applications. Moreover, the data-exchange practices between business units and software systems are still largely manual; additional work needs to be done to automate data flows. Even when systems have been integrated or linked, the technical interfaces between them are suboptimal. For example, in an ideal scenario data exchanges consist of open standards–based application programming interfaces (APIs). Instead, databases are being integrated directly with each other, and data from multiple databases or software systems are being dumped into data warehouses to facilitate data exchanges.

7.0 Vision, Goal, and Objective

Using the roadmap outlined in this document, FHWA proposes to collaborate on a shared vision, goal, and objective for BIM, as follows:

The VISION is to digitalize project delivery, operations, and maintenance for the Nation's highway infrastructure and make information available to anyone who needs it when they need it.

The GOAL is for State DOTs to adopt BIM for Infrastructure as a standard practice.

The OBJECTIVE is for FHWA and State DOTs to develop and implement a set of activities to incentivize achieving progressively higher degrees of BIM maturity over time.

The activities in the roadmap were identified after engagement workshops with stakeholders, and are based on the current state of the practice and the conditions that need to be in place to implement BIM for Infrastructure, as described in the previous chapters. Furthermore, the roadmap activities are defined in such a manner that incremental progress can be achieved in deploying BIM for Infrastructure.

To provide context for the roadmap, the remainder of this chapter introduces the BIM for Infrastructure maturity model, maturity levels, asset lifecycle processes, and use cases.

7.1 BIM for Infrastructure Maturity Model and Maturity Levels

The concept of BIM for Infrastructure maturity levels is largely patterned after the BIM levels concept articulated by the Dutch Bouw Informatie Raad (Building Information Council) (BIR 2014). The maturity models, standards, and practices used by organizations in other countries, including the United Kingdom, Germany, France, and the Nordic countries, were also analyzed by the authors when planning the maturity model for agencies in the United States. The Netherlands' BIM maturity model is the most comprehensive and has demonstrated a great level of success: it has been used to implement effective BIM for Infrastructure practices and offers a change-management journey that allows incremental progress in a systematic and strategic manner. However, the maturity models developed across these countries overlap somewhat in their different definitions of the BIM for Infrastructure maturity levels. The Netherlands BIM maturity model provided a good starting structure, and adjustments were made by the authors to incorporate lessons learned from models used in other countries.

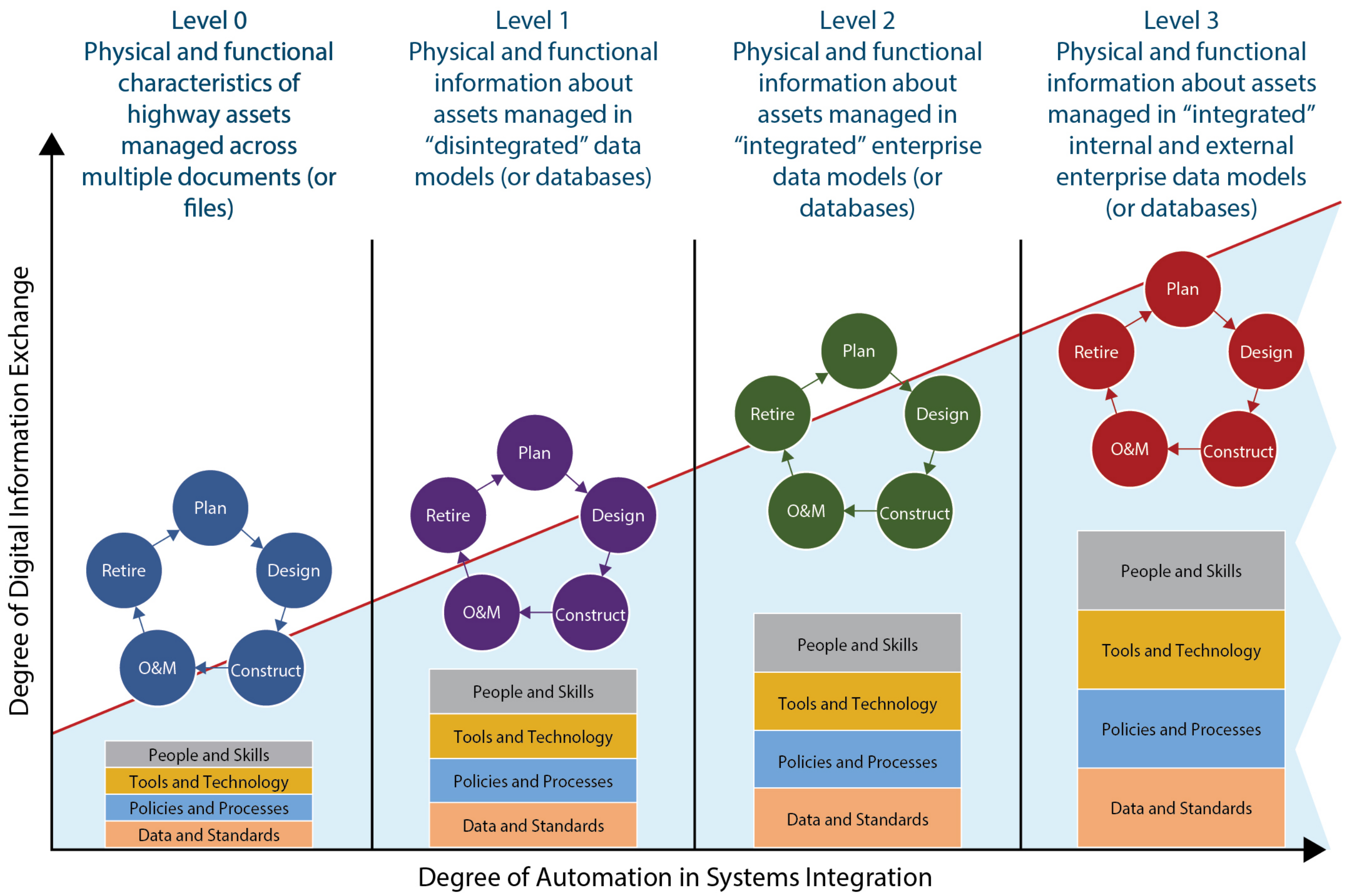
The maturity model developed for the roadmap for U.S. agencies defines four different BIM for Infrastructure maturity levels—0 through 3—based on two characteristics of an organization's BIM processes. According to the Dutch Building Information Council, these are the "degree of significant digital information exchange (i.e., the amount, type, and value of data modeled)" and the "degree of information technology (IT) integration (i.e., the extent of automation in processes and the use of technology systems for data management)" (BIR 2014).

Figure 7 illustrates the BIM for Infrastructure maturity levels, with the vertical axis representing the degree of significant information exchange and the horizontal axis reflecting the degree of IT integration. Each BIM for Infrastructure maturity level has its own operating procedures and organizational culture and involves different data types, software and tools, and methods of collaboration.

An organization achieves BIM maturity when all of the following BIM for Infrastructure elements reach maturity within each maturity level. For strategic and sustainable change management, progress should be made in each area:

- People and skills used to operate BIM-related tools and technologies, administer BIM policies and processes, and carry out BIM tasks.
- Data and standards used to populate and guide the development of information models. Modeling and information-exchange standards make data and their movement between systems and stakeholders consistent and predictable.
- Tools and technologies used to build information models and collect, store, share, provision, and analyze the data held in those models. Tools and technologies enable the deployment of BIM policies and processes.
- Policies and processes used to minimize data loss, ensure information oversight, and encourage attention to and elevation of details captured in digital data through an automated and seamless information flow across all stakeholders.

To ascend from one maturity level to the next, an organization should mature in each of the four BIM



Source: FHWA.
Note: This phase includes asset management of facilities as well as facility maintenance management.

Figure 7. Illustration. BIM for Infrastructure maturity model and maturity levels.

for Infrastructure elements. In other words, an organization cannot rely on just improving BIM tools and technologies to achieve higher BIM maturity. Enhancements in tools and technologies necessitate staff training, and implementing the data-modeling and exchange processes afforded by improved tools and technologies necessitates data standards. Progress in all four BIM for Infrastructure elements is necessary to realize the ROI from enhancing tools and technologies.

By developing each of the four BIM for Infrastructure elements simultaneously, State DOTs can strategically control how data are collected, synthesized, stored, delivered, exchanged, and used within and across asset lifecycle phases. This concept is illustrated in figure 7 by the heights of the boxes that represent each of the four BIM for Infrastructure elements at each maturity level. The boxes increase in height as the maturity levels progress from 0 to 3, indicating an increase in both the degree of information exchange and the degree of automation in systems integration.

At each BIM for Infrastructure maturity level, progress is measured by how agencies collect, create, receive, process, store, exchange, deliver, and analyze data. Ultimately, at Level 3, the ease, efficiency, value, comprehensiveness, and automation of BIM is maximized, and information is easily exchanged among stakeholders with minimal data loss and costs. The appendix presents the details of how the four BIM for Infrastructure elements should evolve from one maturity level to another.

In summary, the minimum state of the practice at each BIM maturity level can be described as follows (see the appendix for more detail regarding each of the four BIM elements at each level):

- Level 0: Information is modeled using electronic or paper documents, and the definitions of data, terms, objects, and attributes is inconsistent across the enterprise. Knowledge about BIM within the organization is limited or nonexistent. Open standards are not used for data management (i.e., modeling, exchange, security, storage). Disparate information and technology systems are used throughout the organization, making data exchanges between these systems difficult. Most of the data integrations that have been carried out are within an asset lifecycle phase (e.g., within the design or O&M phases). Information is often exchanged through informal means such as emails, phone calls, and paper documents.

- Level 1: A foundation has been built to deploy BIM through adopting open standards for defining data, terms, objects, and attributes. High-value data exchanges across disciplines are being piloted. The industry in general and the agency's internal and external stakeholders are aware of BIM processes, policies, standards, tools, and systems. The agency is bringing together all stakeholders to create implementation action plans, plan data governance policies, and execute early pilot projects. Specific types of projects are being targeted as BIM early pilot projects (e.g., bridge projects using design-bid-build (DBB) contracting).
- Level 2: The data libraries, terms, and definitions based on open information–exchange standards and adopted in Level 1 have been used to develop standard templates for data exchanges that need to happen within the organization between asset lifecycle phases. These standards have been used to automate information exchanges. Information requirements and delivery specifications are clearly defined.
- Level 3: Relationships have been built with external stakeholders, such as contractors, who are involved in design-build (DB) projects or public–private partnerships. There is an understanding between internal and external stakeholders about the standards, processes, and protocols used to exchange information. Data are available to both internal and external stakeholders through automated systems.

7.2 BIM for Infrastructure Asset Lifecycle Processes

Figure 8 presents the asset lifecycle phases (i.e., planning and programming, design, construction, O&M, and retirement and decommissioning) and key activities that happen in each phase. The figure illustrates the lifecycle of a project that uses DBB contracting and as such might look different for projects using alternative contracting methods.

BIM for Infrastructure offers the opportunity to automate the exchange of digital data during and across each of the lifecycle phases rather than rely on analog exchanges and custom data linking and integration (i.e., linking and integrating interrelated pieces of information across multiple databases). The big BIM scenario articulated in the strategic roadmap in chapter 8 encompasses all lifecycle phases and all potential information and data exchanges that can be automated for an infrastructure asset.

However, to ensure an agency's institutional capacity and maturity grow in a way that allows the agency to embrace BIM processes incrementally, the roadmap regulates the scope of the work activities in a phased manner. Particular emphasis is placed on the design and construction phases and the handoff to asset management—collectively referred to as the little BIM lifecycle phases—as an initial area for improvement. This is followed by improvements to the planning and programming and O&M phases. Eventually, BIM processes will be implemented within and across all lifecycle phases to ultimately result in what is referred to as big BIM over 10 years. The proposed work activities are agnostic to lifecycle phases, however, and can be used to incrementally accomplish both the little BIM and big BIM vision over 10 years.

The information handoffs involved in the asset lifecycle processes can become significantly more streamlined and automated if the information is modeled using BIM standards, OTLs, information-delivery specifications, and model-view definitions (MVDs). For example, BIM-based information modeling can be used to improve information handoffs in the following ways:

- The benefit–cost analysis conducted during the planning and programming phase to justify a new project can be informed by data for related assets that originated in the design phase, were documented and accepted during the construction phase, and appended during the O&M phase to capture all changes to the asset over its lifecycle.
- The detection of opportunities for coordination and the potential for conflicts or clashes (e.g., involving utilities, structural components, or construction phasing) can start early in the design phase, and information about issues identified and flagged for investigation can be made part of the information model distributed to various parties (e.g., in the form of 3D renderings or visualizations for the public).

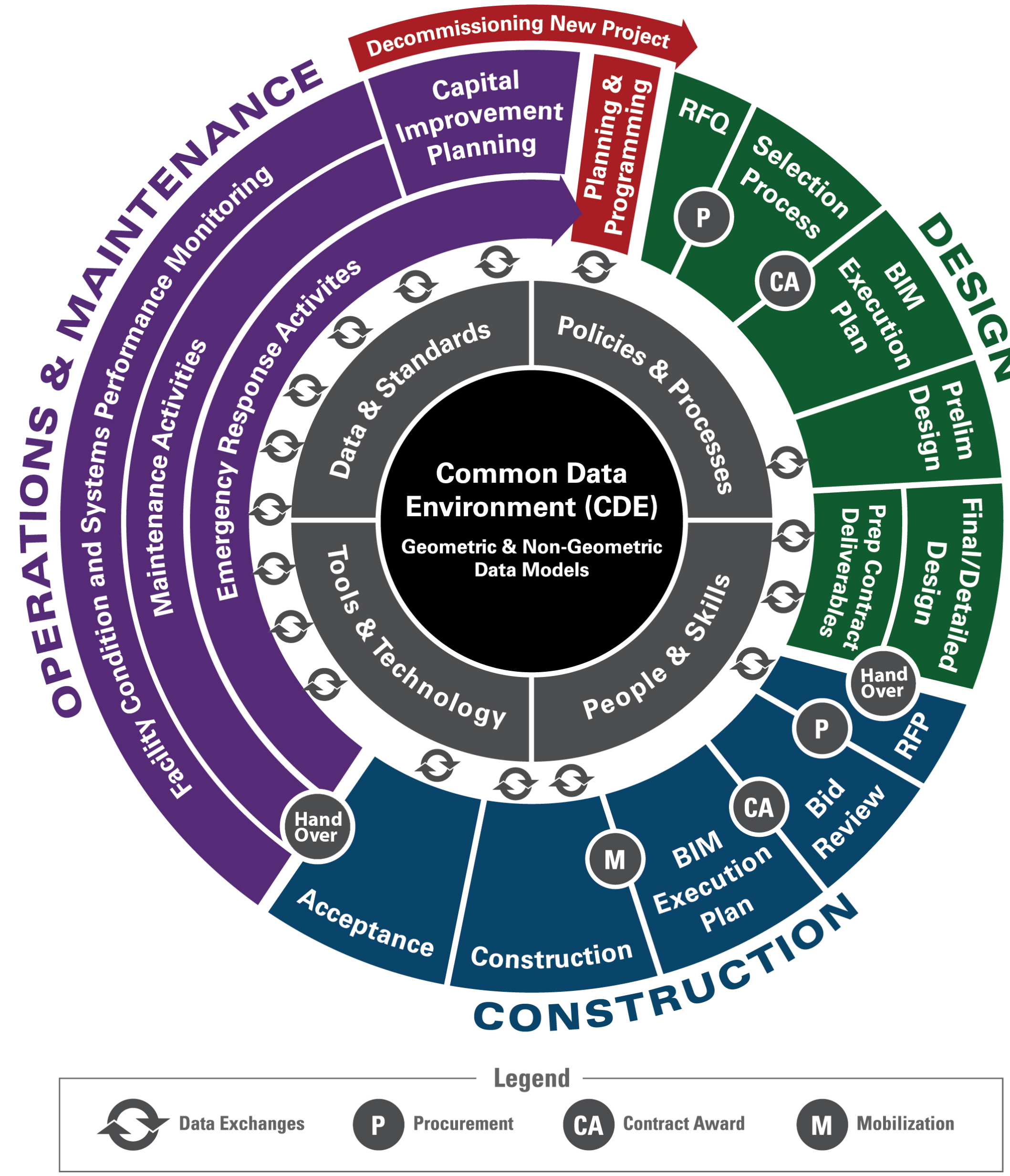


Figure 8. Illustration. BIM for Infrastructure lifecycle for projects that use DBB contracting.

- The preconstruction survey, geotechnical and utility investigations, and site-history information can be modeled using BIM objects and handed over to the designer to provide detailed insights into the construction site environment.
- The as-designed and as-built information created during the design and construction phases and the postconstruction survey of built facilities can be used to build an asset inventory containing detailed information about the specifications, materials, and components used to build the assets, their projected lives, and warranty and cost information.

The number and type of information handoffs involved can vary depending on the type of project and the project delivery approach taken. Once funds have been programmed, the project delivery stage begins, and depending on the contracting method chosen (e.g., DBB, DB), the design and construction phases may need to be separated, as illustrated in figure 8. The data exchanges within the design phase and between the design, construction, and O&M phases are often iterative and nonlinear. However, BIM for Infrastructure workflows allow for the easy and seamless exchange of data between various stakeholders to facilitate collaboration, streamline processes, and accelerate project delivery.

In a BIM environment, the owner requirements for a design team or a DB venture include what is known as a BIM execution plan (BEP). The BEP is a quality management plan that guides the use of digital information, including the roles and responsibilities of each party, the information to be included in each deliverable, how and when the deliverables should be exchanged between stakeholders, and how and in which part of the agency the project information should be managed. A robust BEP, developed in collaboration with major project stakeholders from the very beginning, is critical to the success of BIM for Infrastructure implementation.

In the case of a DBB contract, two separate BEPs will be developed, one during the design phase and the second during the construction phase. Nevertheless, once the design data are delivered to the contractor, both the design and construction BEPs should be integrated to enable streamlined data flow throughout the entire project lifecycle. For DB projects, one BEP encompasses both the design and construction teams' collaborative processes.

Regardless of the chosen contracting method, BIM for Infrastructure enables the collection of as-built condition data and documentation of acceptance throughout the construction phase, rather than after the end of the phase when all assets have been built. At the end of the construction phase, the asset—both the physical asset and its digital twin—is handed over to asset managers for O&M. Assets are then managed during their lifecycles in response to condition deterioration due to wear and tear or age and to repair damage imposed by emergency events. BIM for Infrastructure offers the opportunity to integrate data about the asset across all lifecycle activities using an information model and exchange protocol between systems, the foundation for which is laid at the outset to ensure minimal data loss through the various phases.

7.3 BIM for Infrastructure Use Cases (Data Exchange Opportunities)

Table 2 presents a sample starter list of specific use cases that can be taken up in the near term to create a foundation for BIM for Infrastructure workflows throughout the asset lifecycle.

Since this is a starter list, the use cases deal with the primary focus areas of BIM implementation for many State DOTs (i.e., activities within the design and construction phases and the subsequent handoff to asset management, collectively known as the little BIM lifecycle phases). Eventually, it is expected this list will expand to include the BIM use cases associated with the planning and programming and the O&M phases.

Within this little BIM framework, the use cases generally considered to be of high priority are flagged in table 2. Each of these use cases relies on the four BIM for Infrastructure elements to ensure data are consistently and systematically managed in an information model and exchanged between business users carrying out various work activities in a lifecycle phase or across phases.

buildingSMART International selected several of the use cases presented in table 2 to develop future model standards for BIM using IFC, a common open-data format schema used to exchange model information (Moon et al. 2018). In addition, the authors included a few other use cases that buildingSMART did not consider to broaden this sample starter list. Additional infrastructure use cases can be identified as part of future activities. These use cases can be prioritized and eventually included in implementation plans so all high-priority work activities involved in the asset lifecycle can leverage and benefit from the BIM for Infrastructure workflows.

Table 2. Sample starter list of BIM for Infrastructure use cases.

Data-Exchange Opportunities	Use Cases From Within the Asset Lifecycle Phases That Would Benefit From BIM for Infrastructure Implementation
Planning to design	• Use planning and project data for design (e.g., location, design speed, traffic count)
Survey to design	• Collect preconstruction survey data
Survey to construction	• Track progress of construction through periodic surveys
Geotechnical to design	• Use geotechnical investigations for road design (e.g., road dimensioning, limiting deformation, ensuring road stability) • Conduct earthwork design using geotechnical data
Design to geotechnical	• Facilitate geotechnical construction by analyzing ground reinforcement and preloading sheet piling using design data
Design to design*	• Create 3D design as a technical visualization for public information • Estimate quantities or quantity takeoffs • Conduct a structural analysis, including the code compliance of parametric design • Conduct design reviews (interdisciplinary coordination/clash detection)* • Develop a detailed design using the early-design model
Design to construction*	• Create 3D design as a technical visualization for conflict and clash detection* • Create 3D design as a technical visualization for work-zone review and management • Use design data for bid-package preparation and construction (quantity take offs and AMG-related data)* • Draft prefinal and final plans with model as a contract document* • Develop four-dimensional (4D) scheduling (i.e., construction simulation and activity sequence modeling) • Develop earthwork cut and fill design for incorporating designed structure into the existing ground • Determine construction inspection and payment conditions, including inspection verification (compare as-built to as-planned assets) and acceptance*
Construction to construction	• Track construction progress • Measure quantities for payment • Conduct construction planning using geotechnical data, including safety reviews
Construction to asset management*	• Collect as-built data for assets (e.g., structures, pavements, safety appurtenances, road geometry, signs and striping, drainage and hydraulics and culverts), particularly for underground utility assets*
Design to asset management	• Determine asset inspection, condition forecast, and roadmap-related attributes • Transfer data associated with asset design to GIS and asset management systems
Asset management to design	• Model initial state using existing asset data
Asset management to planning	• Propose projects for authorization and programming

*High-priority use cases for BIM deployment.

8.0 BIM for Infrastructure Roadmap

This chapter presents the roadmap to guide BIM for Infrastructure implementation in the United States. It covers the scope and target audience of the roadmap as well as the process used to create the roadmap. The chapter closes with a description of specific roadmap activities.

8.1 Scope

The concept of BIM for Infrastructure as envisioned by this document is broad and covers the entire highway asset lifecycle (see figure 7 and figure 8). To realize the full set of benefits that come from completely integrated processes and a high degree of automation, State DOTs should strive to achieve BIM Maturity Level 3.

However, given the current state of the practice, which is somewhere between Levels 0 and 1, BIM Maturity Level 2 appears to be a reasonable goal to achieve within the next 10 years. The implementation activities in this roadmap have been strategically formulated so this 10-year growth target can be achieved, and lessons learned from the experience of implementing this roadmap can be used to identify activities for achieving BIM Maturity Level 3. During the 10 year period in which the implementation activities described in this roadmap are being executed, a periodic review of progress and updates to this roadmap are suggested.

8.2 Target Audience

This roadmap is primarily aimed at personnel within State DOTs who develop highway infrastructure policies; procure projects; and manage the design, construction, ownership, or operation of highway infrastructure facilities, although collaboration with IT personnel at State DOTs will also be essential. For all of these roadmap users, the roadmap provides a common basis for understanding what BIM for Infrastructure maturity and growth means, why BIM for Infrastructure is important, what actions need to be taken to implement this innovative method within their agencies, and how they can collaborate with other State DOTs and stakeholders to advance national implementation efforts and leverage them for use within their own agencies.

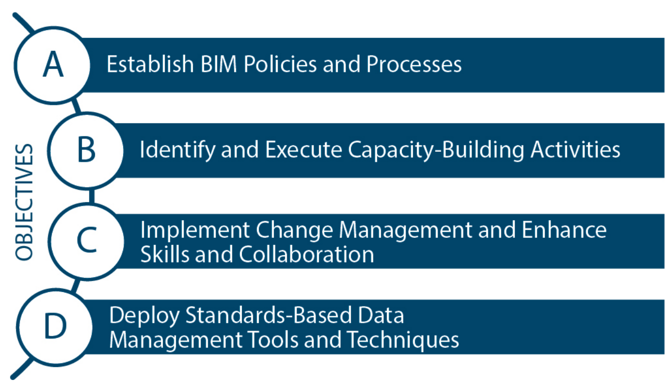
8.3 Development Process

The BIM for Infrastructure roadmap was developed using input from stakeholders provided through several venues, including the BIM for Infrastructure Panel at the 2018 International Highway Engineering Exchange Program Conference, the BIM for Infrastructure workshop held at the FHWA Turner-Fairbank Highway Research Center in 2019, as well as ongoing dialogue with the national and international communities, including representatives from Denmark, Finland, Germany, the Netherlands, and the United Kingdom.

8.4 Implementation Activities

Roadmap-related change-management activities are defined and sequenced so that all four BIM for Infrastructure elements systematically and simultaneously grow. The simultaneous growth of each element is important because BIM for Infrastructure relies on people collaborating via standard processes and using BIM workflow-oriented data-management tools and technologies to create, collect, store, and analyze asset data in an information model.

To assist in establishing processes, managing data, implementing change management and enhancing skills and collaboration, and utilizing technology and information-modeling standards, four objectives have been established for the roadmap, as presented in figure 9.



Source: FHWA.

Figure 9. Illustration. BIM strategic roadmap objectives.

Agencies should establish transparent policies (e.g., regarding intellectual property rights and data liability, security, and quality) and processes to consistently create and manage an asset's information during its lifecycle. They should also identify and execute capacity-building activities to ensure the identified policies and processes result in the creation of digital data models that are managed (e.g., stored, shared, provisioned, secured, and accessed) using standards in a collaborative manner by all stakeholders involved in the BIM workflow.

The roadmap activities are described in table 3 along with suggestions on whether the activity should be led by State DOTs or FHWA. The activities presented in the table have included in the roadmap based on the current state of the industry. The activities are categorized by the roadmap objective they will help meet. These objectives map to the BIM for Infrastructure elements that must mature to ensure BIM for Infrastructure Maturity Levels 1 and 2 can be attained at the end of 5 and 10 years, respectively. The activities considered most important, and which should be prioritized, are flagged. FHWA has suggested that a State-led pooled fund might be the most appropriate stakeholder group to drive the BIM roadmap forward.

Table 4 shows the schedule of roadmap activities over the 10-year implementation period. The activities are scheduled such that BIM for Infrastructure Maturity Levels 1 and 2 can be attained at the end of 5 and 10 years, respectively. The identified activities are interdependent.

Table 3. Roadmap activities: description and leadership.

Objective	Activity Type	Work Plan Activities	National Leadership	State DOT Leadership
Objective A: Establish BIM policies and processes	Foundational	A1*—Establish national, State-led BIM pooled fund	✓	—
		A2*—Assemble a stakeholder group as part of the pooled fund group activities for communications and outreach	—	✓
	Development	A3*—Develop contract model language to guide BIM procurements	✓	—
		A4*—Develop model BIM execution plans (BEPs)	✓	—
		A5—Develop templates and tools for employer's information requirements	✓	—
	Deployment	A6—Set up the criteria for contractor selection during procurement of BIM projects	—	✓
Objective B: Identify and execute capacity-building activities	Foundational	B1—Establish project-selection criteria for BIM implementation	—	✓
		B2*—Establish pilot project program. Identify project types and use cases for early pilot projects phase (i.e., Phase 1) and medium-term (Phase 2) and long-term (Phase 3) pilot projects	—	✓
	Development	B3*—Develop requirements for implementing BIM for Infrastructure projects (by project type)	✓	—
	Deployment	B4*—Create BIM performance-measurement and return on investment (ROI) calculation tool	✓	—
Objective C: Implement change management and enhance skills and collaboration	Foundational	C1—Establish workforce-training curriculum to set expectations about required BIM qualifications	✓	—
		C2—Establish specific training modules to prepare BIM-certified professionals	✓	—
	Deployment	C3*—Set up a "matrixed" BIM organization and address its fit within the traditional infrastructure–owner–operator organizational structure so BIM roles and responsibilities are understood and data silos are connected	—	✓
		C4—Set up strategies to manage the risk of mainstreaming the BIM Maturity Level 2 framework	—	✓
Objective D: Deploy standards-based data management tools and techniques	Development	D1—Develop a catalog of information-model requirements to define what data should be created and why	✓	—
		D2*—Develop a national object type library (OTL) (i.e., an inventory of object terms and definition standards and classification categories (reference data) for creating data models)	✓	—
		D3*—Develop standard information-delivery specifications for data exchange between systems	✓	—
	Deployment	D4*—Set up BIM tools and technologies (e.g., common data environment, (CDE) system interfaces)	—	✓

*Key foundational, development, and deployment activities in the strategic roadmap.

✓ = the group is primarily responsible for the work plan activities listed; — = the group is not primarily responsible for the work plan activities listed.

Table 4. Schedule of BIM for Infrastructure roadmap activities over 10 years.

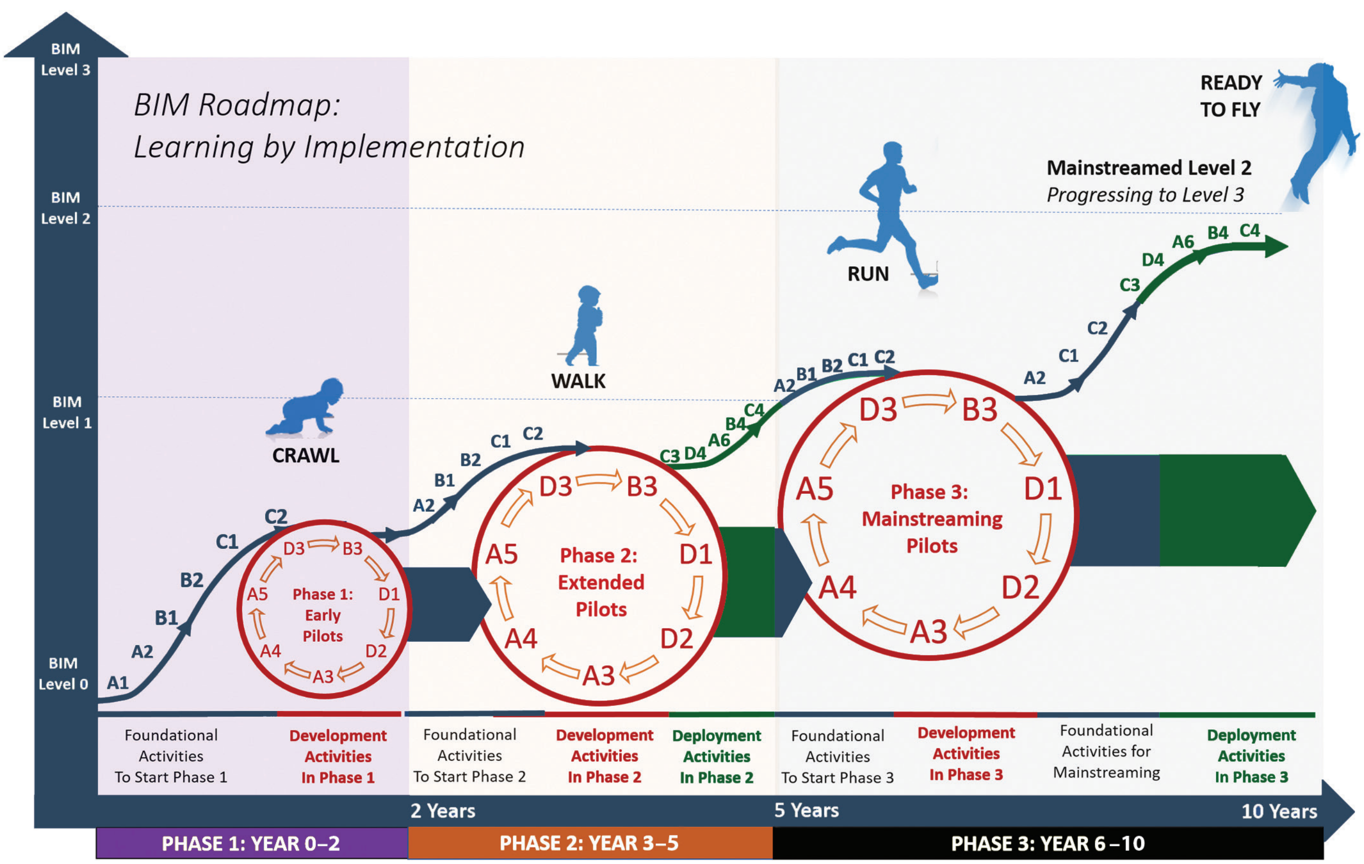
Activity Code	Activity Description	Activity Type	Phase 1 (0–2 Years)	Phase 2 (3–5 Years)	Phase 3 (6–10 Years)
A1	Establish national, State-led BIM pooled fund	01—Foundational	Establish: 100% complete in Year 1	NA	NA
A2	Assemble a stakeholder group as part of the pooled fund group activities for communications and outreach	01—Foundational	Establish: 100% complete in Year 1	NA	NA
B1	Establish project-selection criteria for BIM implementation	01—Foundational	Initiate: 10% complete in Year 1	Extend and refine: 50% complete in Year 3, 75% in Year 5	Extend and refine: 100% complete in Year 6
B2	Establish pilot project program. Identify project types and use cases for early pilot projects phase (i.e., Phase 1) as well as medium- (Phase 2) and long-term (Phase 3) pilot projects	01—Foundational	Initiate: 10% complete in Year 1	Extend and refine: 50% complete in Year 3, 75% in Year 5	Extend and refine: 100% complete in Year 6
C1	Establish workforce-training curriculum to set expectations about required BIM qualifications	01—Foundational	Initiate: 10% complete in Year 2	Extend and refine: 50% complete in Year 4	Extend and refine: 75% complete in Year 6, 100% in Year 8
C2	Establish specific training modules to prepare BIM-certified professionals	01—Foundational	Initiate: 10% complete in Year 2	Extend and refine: 50% complete in Year 4	Extend and refine: 75% complete in Year 6, 100% in Year 8
B3	Develop requirements for implementing BIM for Infrastructure projects (by project type)	02—Development	Initiate: 10% complete in Year 2	Extend and refine: 50% complete in Year 4	Extend and refine: 75% complete in Year 6, 100% in Year 8
D1	Develop catalog of information-model requirements to define what data should be created and why	02—Development	Initiate: 10% complete in Year 2	Extend and refine: 50% complete in Year 4	Extend and refine: 75% complete in Year 6, 100% in Year 8
D2	Develop national object type library (OTL) (i.e., an inventory of object terms and definition standards and classification categories (reference data) for creating data models)	02—Development	Initiate: 10% complete in Year 2	Extend and refine: 50% complete in Year 4	Extend and refine: 75% complete in Year 6, 100% in Year 8
A3	Develop contract-model language to guide BIM procurements	02—Development	Initiate: 10% complete in Year 2	Extend and refine: 50% complete in Year 4	Extend and refine: 75% complete in Year 6, 100% in Year 8
A4	Develop model BIM execution plans (BEPs)	02—Development	Initiate: 10% complete in Year 2	Extend and refine: 50% complete in Year 4	Extend and refine: 75% complete in Year 6, 100% in Year 8
A5	Develop templates and tools for employer information requirements	02—Development	Initiate: 10% complete in Year 2	Extend and refine: 50% complete in Year 4	Extend and refine: 75% complete in Year 6, 100% in Year 8
D3	Develop standard information-delivery specifications for data exchange between systems	02—Development	Initiate: 10% complete in Year 2	Extend and refine: 50% complete in Year 4	Extend and refine: 75% complete in Year 6, 100% in Year 8
C3	Set up a "matrixed" BIM organization and address its fit within the traditional infrastructure–owner–operator organizational structure so BIM roles and responsibilities are understood and data silos are connected	03—Deployment	NA	Initiate: 10% complete in Year 3, 50% in Year 5	Extend and refine: 75% complete in Year 7, 100% in Year 9
D4	Set up BIM tools and technologies (e.g., common data environment (CDE), system interfaces)	03—Deployment	NA	Initiate: 10% complete in Year 3, 50% in Year 5	Extend and refine: 75% complete in Year 7, 100% in Year 9
A6	Set up the criteria for contractor selection during procurement of BIM projects	03—Deployment	NA	Initiate: 10% complete in Year 3, 50% in Year 5	Extend and refine: 75% complete in Year 7, 100% in Year 9
B4	Create BIM performance-measurement and return on investment (ROI) calculation tool	03—Deployment	NA	Initiate: 10% complete in Year 5	Extend and refine: 50% complete in Year 7, 75% in Year 8, 100% in Year 10
C4	Set up strategies to manage the risk of mainstreaming the BIM Maturity Level 2 framework	03—Deployment	NA	Initiate: 10% complete in Year 5	Extend and refine: 50% complete in Year 7, 75% in Year 8, 100% in Year 10

Figure 10 illustrates the sequence in which the roadmap activities (e.g., A1, A2) should be performed over the 10-year implementation period. The sequencing has been designed to ensure incremental progress can be made toward meeting the objectives presented in figure 9.

A set of six foundational activities (i.e., A1, A2, B1, B2, C1, and C2) can be performed at the beginning of each phase to lay the groundwork for developing and deploying the elements of the BIM framework during that particular phase. The foundational activities relate to the subsequent activities in the roadmap as follows:

- To develop the policies and processes associated with the BIM framework and consequently achieve Objective A, foundational activities A1 and A2 should be performed before the development activities associated with achieving Objective A are carried out (i.e., A3, A4, and A5).
- To identify and execute the capacity-building activities and thereby achieve Objective B, foundational activities B1 and B2 should be performed before the development and deployment activities associated with achieving Objective B are carried out (i.e., B3 and B4, respectively).
- The foundational activities related to BIM workforce training (i.e., C1 and C2) should be carried out at the beginning of each phase so the people involved in that phase are trained in the appropriate skills to successfully execute the activities in the BIM roadmap before the development and deployment activities can begin. Additionally, these foundational training activities need to be carried out toward the end of Phase 3, before the developed BIM Maturity Level 2 framework is mainstreamed, so that qualified and trained professionals are in charge of the mainstreamed BIM Maturity Level 2 framework.

A set of seven development activities (i.e., B3, D1, D2, A3, A4, A5, and D3) have been identified for each phase to incrementally build the BIM framework needed to achieve Objectives A, B, and D and ultimately achieve BIM Maturity Level 2 over the 10-year period. These development activities should be carried out through pilot projects so the developed framework is realistic and can be mainstreamed at the end of Phase 3. The pilot projects in Phases 1 and 2 should consider all asset lifecycle phases and BIM for Infrastructure use cases so during Phase 3 the mainstreaming pilot projects can use the lessons learned from the Phase 1 and 2 pilot projects.



Source: FHWA.

Figure 10. Illustration. Achieving BIM Maturity Level 2 by executing the foundational, development, and deployment activities in the roadmap.

A set of five deployment activities (i.e., C3, D4, A6, B4, and C4) have been identified for Phase 2 so by the end of 5 years the developed BIM framework can be deployed and assessed for different types of infrastructure projects and BIM for Infrastructure use cases. At the end of 5 years, after the deployment activities in Phase 2 are complete, BIM Maturity Level 1 will be achieved. The foundation will then be set to achieve BIM Maturity Level 2 over the next 5 years (i.e., during Phase 3) through the mainstreaming pilot projects.

Through a national BIM pooled fund effort, State DOTs will lead all deployment activities, such as pilot planning, demonstrations, and procedures development, leading up to the full-scale adoption of BIM in their respective agencies. This State-led effort will also provide leadership in setting the research and development agenda, engaging industry, and performing other technology transfer activities to accomplish all foundational and developmental objectives. FHWA is expected to participate in this effort in an advisory capacity alongside other stakeholders, including AASHTO, the Associated General Contractors of America, the American Road and Transportation Builders Association, and the Transportation Research Board.

8.4.1 Short-Term: Phase 1

During the first 2 years (Phase 1), efforts should be focused on foundational and developmental activities in the BIM roadmap that establish a clear understanding among stakeholders of what BIM for Infrastructure is, validate the value in terms of ROI that it offers to agencies, help develop the BIM framework, and build experience in deploying the framework using early pilot projects. This section outlines the work that should be performed as part of each foundational and development activity in Phase 1 and provides details on sequencing, scheduling, and milestones.

Phase 1: Foundational Activities Before Initiating BIM Framework Development

Table 4 presents the schedule and milestones associated with the foundational activities in Phase 1. Each activity, identified by its activity code in table 4, is described in more detail in the following paragraphs.

Activity A1: Establish a national, State-led BIM pooled fund. A national, State-led BIM pooled fund program should be established to clearly outline the BIM for Infrastructure objectives, along with its scope, goals, and performance targets, and to articulate stakeholder expectations. Once established, the pooled fund group will establish a set of BIM-advancement activities, policies, and processes and prioritize, fund, authorize, direct, and review BIM-related initiatives and implementation activities.

Activity A2: Assemble a stakeholder group as part of the pooled fund activities to enhance communication of pooled fund activities and engage in education and outreach. A stakeholder group should be established by the pooled fund group to provide feedback on the BIM activities, policies, and processes. This group can include members from FHWA, AASHTO, the consulting and contracting communities, academia, and the BIM software and hardware industries.

The pooled fund and stakeholder groups will periodically meet to exchange information. The pooled fund group will provide information to stakeholders about the progress achieved, issues encountered, risks anticipated, and challenges experienced. The group will also educate stakeholders on national BIM policies, processes, and standards. Education and outreach will occur through formal communication mechanisms such as the BIM pooled fund website and periodic web conferences, workshops, and webinars. The stakeholder group will be responsible for reviewing the information provided to them and providing feedback on the practicality and feasibility of implementation. The stakeholder group will also be responsible for implementing the policies and processes on any BIM-related projects in which they are involved.

Periodic and productive two-way communication between the stakeholder group and pooled fund group is critical to ensuring the BIM for Infrastructure roadmap objectives are met.

Activity B1: Establish project selection criteria for BIM implementation. This activity will establish the types of projects (e.g., capital projects such as mobility improvement, infrastructure expansion, or new construction), BIM for Infrastructure use cases, and asset lifecycle phases (i.e., planning and programming, design, construction, and O&M) for which the BIM framework should be developed during Phase 1. For example, criteria such as the following can be considered to prioritize and select projects for early piloting during Phase 1:

- Focus on a core set of high-value and high-urgency use cases to document early successful implementations of BIM practices.

- Focus on the BIM use cases that have the most mature BIM processes at this stage, such as the project delivery phase of capital improvement projects (e.g., reconstruction, rehabilitation, widening, new alignment, or improvements to safety and operations). Such use cases are likely to span the design and construction phases as well as the handoff to asset management within the highway infrastructure lifecycle.

Activity B2: Establish pilot project program and identify project types and use cases for Phase 1–3 pilot projects. This activity will involve conducting new or researching existing pilot projects to document and communicate early successes, identify implementation risks, improve processes and skills, educate stakeholders, and prepare exchange information requirements (EIRs). The pilot projects (i.e., use cases) should be identified and prioritized using the selection criteria developed in Activity B1.

Figure 11 shows examples of design and construction use cases. Such use cases should be identified and prioritized by the national BIM pooled fund group established as part of Activity A1. Figure 11 also serves as a template that can be used to identify and assess the current maturity of BIM use cases and prioritize these use cases for early pilot projects. The levels in this table correspond to the four BIM for Infrastructure maturity levels presented in figure 7. For the identified pilot projects, rules should be developed for testing the digital data against the requirements specified in the EIRs supplied by the service providers.

In addition to identifying the early pilot projects for Phase 1, the pooled fund group should also strategically develop the pilot project program for future phases and clearly communicate its vision and future direction. This task will involve considering the goals of Phases 2 and 3 and envisioning and developing a draft list of Phase 2 and 3 pilot projects. During Phase 2, the goal of the pilot projects should be to build on the Phase 1 (early) pilot projects and include additional project types and BIM for Infrastructure use cases so BIM Maturity Level 1 can be achieved across all project types and use cases by Year 5. During Phase 3, the goal of the pilot

ID	Data-Exchange Type	Use Case Description	Level 0	Level 1	Level 2	Level 3	Growth Obstacles and Challenges
01	Project system to estimation, design	Provision of project data (e.g., location and assets) for design, cost estimation, and project development					
02	Design to visualization	Technical visualization through 3D design					
03	Design to design	Conflict and clash detection: transfer and combine models to detect interferences (i.e., clashes)					
04	Design to 4D scheduling	Construction simulation (i.e., sequence modeling): organization of construction site and activities					
05	Design to design	Quantity takeoff: determine quantities from model for cost estimation					
06	Design to structure analysis	Structural analysis of design to ensure stability					
07	Design to design	Checking code compliance of asset design					
08	Design to design	Detailed design using early design model					
09	Design to construction	AMG using design					
10	Survey to visualization	Construction progress tracking through periodic surveys					
11	Asset management (GIS) to design	Initial-state modeling using existing asset data					
12	Design to letting and construction	Bid package preparation and construction using design data					
13	Design to construction	Comparison between as-built and as-planned structure; construction quality check					
14	Geotechnical to design, letting, and construction	Earthwork cut-and-fill design for incorporating designed structure into existing ground, letting, and construction planning using geotechnical data					
15	Geotechnical to design	Geotechnical investigations for road dimensioning, limiting deformation, and ensuring road stability					
16	Design to geotechnical	Facilitation of geotechnical construction by analyzing ground reinforcement and preloading sheet piling using design					
17	Design to asset management	Asset inspection, condition forecast, work planning					
18	Design to asset management	Spatial analysis of major asset design attributes					

Source: FHWA.

Figure 11. Table. Sample table for identifying and assessing current maturity level and prioritizing BIM use cases for early pilot projects in Phase 1.

projects should be to develop, deploy, and mainstream the BIM Maturity Level 2 framework by building on the accomplishments from Phases 1 and 2.

As shown in figure 10, the pilot projects to be conducted in Phases 1, 2, and 3 should be identified and prioritized during Phase 1 so the BIM Maturity Level 2 Framework can be developed incrementally over the 10-year period for all project types and BIM use cases. At the beginning of Phases 2 and 3, the draft list and scope of the Phase 2 and 3 pilot projects developed during Phase 1 can be updated and further refined as needed, as long as the goal to achieve BIM Maturity Levels 1 and 2 by Years 5 and 10, respectively, are not compromised.

Activity C1: Establish workforce training curriculum to set expectations about required BIM qualifications. This activity will ensure personnel equipped with the necessary skills are available to develop the BIM framework. A training curriculum will be developed that ties into the early pilot projects identified for Phase 1 and their corresponding BIM for Infrastructure use cases. The curriculum should focus on the need to understand BIM for Infrastructure tools, technologies, policies, and processes.

During Phase 1, the curriculum should address the following objectives:

- Providing education on BIM-based processes.
- Developing training curriculums for educational institutions, including both engineering and vocational programs.
- Imparting knowledge and improving skills and abilities.
- Providing training on developing the BIM Maturity Level 1 framework.

Activity C2: Establish specific training modules to prepare BIM-certified professionals. Training modules will be developed for each of the courses identified in the training curriculum prepared under Activity C1. These structured synchronous or asynchronous learning modules will be designed to ensure they follow a "leap, not creep" approach to BIM and address introductory BIM topics, including working with BIM tools; executing BIM projects; incorporating BIM into the design, construction, and O&M lifecycle phases; and systems engineering. The target audiences will include owner executives, project managers, IT staff, and future BIM managers, designers, contractors, and other participants in the asset lifecycle.

As the curriculum is updated, the training modules should also be updated. Lessons learned from implementing early pilot projects can also be used to develop the training modules.

Phase 1: BIM Framework Development Activities

After completing the Phase 1 foundational activities, as shown in figure 10, execution of the early pilot projects identified in Activity B2 should begin so various elements of the BIM Maturity Level 1 framework can be developed. During Phase 1, the BIM framework development efforts will be focused on the project types and BIM for Infrastructure use cases selected and scoped as candidates for early pilot projects.

The key outcome targeted in Phase 1 is to achieve BIM Maturity Level 1 by the end of Year 2 for the project types and BIM use cases selected for early pilot projects. Figure 10 shows the BIM framework development activities that should be performed as part of the early pilot projects. Table 4 shows the schedule and milestones associated with executing the development activities in Phase 1. By following this schedule and achieving the percentage completion for each of the milestones shown in table 4, progress can be made toward achieving BIM Maturity Level 1 consistently across all asset lifecycle phases, project types, and BIM use cases. Figure 10 illustrates this goal by aligning the schedule of the Phase 1 development activities with the BIM for Infrastructure maturity levels. More details about the development activities in Phase 1, listed by activity code in table 4, are presented in the following paragraphs.

Activity B3: Develop requirements for implementing BIM for Infrastructure projects (by project type). This activity will involve defining the requirements associated with implementing the BIM framework for each of the project types and BIM for Infrastructure use cases selected for early pilot projects. The resulting list of requirements will outline the outcomes that need to be achieved across all asset lifecycle phases when the BIM framework is deployed.

Activity D1: Develop a Catalog of Model Information Requirements to Define What Data Should Be Created. Develop a catalog of model information requirements to define what data should be created. This activity will involve defining a standard and model set of information requirements for each type of infrastructure project (e.g., roads or bridges) and each use case selected for early pilot projects. The information requirements should specify the data that need to be collected, processed, stored, analyzed, exchanged, shared, and provisioned at each of the BIM for Infrastructure lifecycle phases as part of each lifecycle use case. The requirements should also specify the level of development corresponding to each of the data lifecycle stages (i.e., collection, creation, processing, storage, analysis, exchange, sharing, and provisioning).

Activity D2: Develop a national Object Type Library (OTL) for creating data models. Using the catalogs of model information requirements developed under Activity D1, a national OTL will be developed for the project types and use cases selected for early pilot projects. The OTL should include an inventory of the object type names, definitions, and attributes and the data classification categories—typically referred to as reference data—for those object attributes that should only allow a standard and limited set of options during information modeling.

The OTL needs to be built so it can be used consistently across all BIM for Infrastructure use cases and lifecycle phases. Therefore, while Activity D1 will result in a catalog of information requirements for each use case, the OTL should be developed in Activity D2 to ensure common information requirements across use cases and lifecycle phases are identified and used to define the object type names, definitions, and attributes and data-classification categories.

Activity A3: Develop model contract language to guide BIM procurements. This activity will involve developing model contract documents to guide BIM procurements for various project types (e.g., capital projects, maintenance projects) under various project delivery settings (e.g., DBB, DB). The model contract documents will include language about the arrangements that should be in place to ensure BIM practices are used to foster effective and collaborative working practices, proper allocation of resources, and appropriate sequencing of activities. For example, language in the contract should ensure all parties producing and delivering information use common standards and other practices to facilitate a collaborative working environment and all parties support the appropriate data-related obligations and liabilities, permit data to be distributed to and used by other stakeholders, share an understanding of model ownership and intellectual property rights, and ensure the accessibility of data.

Activity A4: Develop model BIM Execution Plans (BEPs). This activity will involve developing model BEPs for various procurement scenarios. Each BEP should define the interfaces between the various parties across the various project delivery phases as well as the parties' roles and interactions. Principles and rules for the creation, use, administration, and sharing of information should also be defined across all project phases. BIM deliverables (e.g., EIRs), the timing of deliverables, data exchanges, and specifications should also be identified.

Activity A5: Develop templates and tools for Employer Information Requirements (EIRs). This activity will involve creating templates and tools for EIRs for different types of projects. The templates and tools will include methods for specifying technical details such as the software platform and the level of development captured in the EIRs.

Activity D3: Develop standard information delivery specifications for data exchanges between systems. This activity will involve determining the data to be exchanged and the format in which they will be exchanged for each BIM for Infrastructure use case. The objective of this activity is to define the MVDs and develop specifications for the data to be exchanged using nonproprietary, neutral exchange standards (e.g., IFC, ISO 19650, InfraGML).

8.4.2 Medium-Term: Phase 2

Building on the Phase 1 BIM for Infrastructure roadmap activities, the development and deployment activities in Phase 2 occurring during Years 3 through 5 of the roadmap, or in the medium term, should be carried out so that at the end of Phase 2, BIM Maturity Level 1 can be achieved across all project types and BIM for Infrastructure use cases.

Phase 2: Foundational Activities Before Continuing BIM Framework Development

The foundational activities that should be carried out in Phase 2 are a subset of the foundational activities carried out in Phase 1. As shown in figure 10, these activities need to be performed before development can continue on the various elements of the BIM Maturity Level 1 framework initiated based on the project types and use cases selected for the Phase 1 early pilot projects.

As in Phase 1, the objective of the Phase 2 foundational activities is to define and scope the pilot projects and train the BIM workforce to extend the BIM Maturity Level 1 framework initiated in Phase 1. Table 4 shows the schedule and milestones associated with executing these activities. Figure 10 illustrates the progress that can be made toward achieving BIM Maturity Level 1 by executing the Phase 2 foundational activities; the figure plots the schedule of Phase 2 foundational activities on the timeline against the BIM for Infrastructure maturity levels on the vertical axis.

Activity A2: Assemble a stakeholder group as part of the pooled fund activities to enhance communication of pooled fund activities and engage in education and outreach. This activity is a recurring foundational activity in Phase 1. The two-way communication with the stakeholder group and the associated education and outreach activities will continue in Phase 2. The goals of this activity in Phase 2 are the same as those described for Phase 1.

Activity B1: Establish project selection criteria for BIM implementation. The BIM for Infrastructure project selection criteria developed in Phase 1 may need to be updated and refined based on the lessons learned in Phase 1. The emphasis of this activity in Phase 2 will be on ensuring the established selection criteria can be used to identify all relevant project types and use cases that should be considered for BIM implementation.

Activity B2: Establish pilot project program and identify project types and use cases for Phase 1–3 pilot projects. The early pilot projects program was established in Phase 1. At that time, a draft list of pilot projects was developed for Phases 2 and 3 to lay out the vision of the pilot projects program and strategically plan the schedule and sequence of BIM framework development using the pilot projects.

In Phase 2, the focus of Activity B2 will be on refining and updating the draft list of pilot projects identified for Phase 2. The goal is to identify and include additional project types and BIM for Infrastructure use cases in the pilot projects program. This Phase 2 activity should extend the early pilot projects identified as part of Activity B2 in Phase 1, with the ultimate objective of achieving BIM Maturity Level 1 across all project types and use cases by the end of Year 5.

This task will involve reviewing the draft list, objectives, and scope of the Phase 3 pilot projects. As mentioned, the overarching goal of Phase 3 is to develop the BIM Maturity Level 2 framework using pilot projects representing all project types and BIM use cases. Therefore, it is essential the scope and definition of the Phase 2 pilot projects are such that the BIM Maturity Level 1 framework is developed for all the project types and use cases identified for BIM implementation using the selection criteria established as part of Activity B1.

Activity C1: Establish workforce training curriculum to set expectations about required BIM qualifications. During Phase 2, the training curriculum established under Activity C1 in Phase 1 will need to be extended and refined to cover additional project types and BIM for Infrastructure use cases.

This task may involve gathering and disseminating information about new and additional BIM tools and technologies relevant for managing data and developing the BIM Maturity Level 1 framework for the project types and BIM use cases identified in Phase 2. The training courses developed in Phase 1 on BIM policies and processes may also need to be updated. Similarly, the training courses related to data and standards may also need extension and refinement, especially if new or different data-management standards or new versions of existing standards need to be included. For example, as new versions of IFC or new data warehousing, data integration, and cloud-based storage solutions become available, the BIM for Infrastructure workforce will need to update its skills.

Therefore, to ensure the BIM for Infrastructure workforce stays current with how data management standards, policies, processes, tools, and technologies can be used to implement BIM, it is important to continue to refine and extend the workforce training curriculum.

Activity C2: Establish specific training modules to prepare BIM-certified professionals. The training modules developed during Activity C2 in Phase 1 will need to be updated and extended to complement the training curriculum modified under Activity C1 in Phase 2. The BIM professionals responsible for developing and implementing the BIM Maturity Level 1 framework for various project types and use cases will need to go through the updated training program to ensure they are qualified and certified to continue developing the BIM Maturity Level 1 framework in Phase 2 and well-positioned to help achieve BIM Maturity Level 1 across all project types and use cases.

Phase 2: Development Activities for Completing BIM Maturity Level 1 Framework Development

After completing the Phase 2 foundational activities for the additional project types and BIM for Infrastructure use cases identified during Activity B2 in Phase 2, the extended pilot projects should be executed to develop the BIM Maturity Level 1 framework. Execution will involve repeating the development activities performed during the Phase 1 pilot projects and accomplishing the work outlined for each activity described in chapter 8 in the Phase 1: BIM framework Development Activities section. Figure 10 illustrates this concept of reexecuting the BIM framework development activities for the Phase 2 pilot projects after the Phase 2 foundational activities are complete.

Table 4 shows the schedule and milestones associated with executing the BIM framework development activities in Phase 2. By following this schedule and achieving the percentage completion for each of the milestones shown in table 4, significant progress can be made toward achieving BIM Maturity Level 1. Figure 10 illustrates this progress by plotting the schedule of the Phase 2 development activities with the BIM for Infrastructure maturity levels.

Phase 2: BIM Framework Deployment Activities to Achieve BIM Maturity Level 1

After the development of the BIM Maturity Level 1 framework is complete, it is important to carry out a set of deployment activities so the BIM Maturity Level 1 framework can be fully utilized and BIM Maturity Level 1 can be achieved. During the deployment of the framework, it is essential to implement the lessons learned from the pilot projects executed during Phases 1 and 2. As shown in figure 10, the deployment activities described in the following paragraphs can be initiated in Phase 2, per the schedule outlined in table 4, so progress can be made toward achieving BIM Maturity Level 1.

Activity C3: Set up a matrixed BIM organization and determine its fit within the traditional infrastructure–owner–operator organizational structure. This activity will involve establishing a BIM office at each State DOT, determining the roles and responsibilities for staff, and creating the BIM organizational hierarchy. The goal is to define the educational and technical certification requirements and the necessary talent profiles, experience levels, and qualifications for the various roles involved in BIM execution.

This activity is likely to take significant effort and time given the number of State DOTs and the variety of existing organizational structures and practices at each State DOT. Therefore, initiating this activity early in Phase 2 will allow for significant progress by the end of the phase. Work on this activity should continue in Phase 3 because lessons from the pilot projects conducted during Phase 2 will need to be incorporated into later updates and refinements to the BIM office roles and responsibilities.

Activity D4: Set up BIM tools and technologies (e.g., CDE, system interfaces). This activity will involve first creating a list of needs for the tools and technologies that should be utilized to create and store the information models using open standards, establish a CDE, store the information generated from implementing the BEP, and deliver the information to meet the EIR. The activity will be initiated by the BIM pooled fund and carried out in coordination with the State DOTs.

The State DOTs will then be responsible for setting up BIM tools and technologies that meet the stated needs. For this task, it is important to determine the data storage infrastructure (e.g., in-cloud or on-premises storage), determine the database schema structure for the data stored in the database, and identify standards that should be used to package and store the data—for example, standards based on a container-based approach, such as the ISO 21597 standard (ISO 2020), or the use of structured data stored in a relational database or data warehouse, semistructured data stored in files using web-based standards such as XML, JSON, and GeoJSON, or unstructured data stored in documents or content-management systems (W3C 2021; JSON 2021; IETF 2016). During deployment, the elements of the BIM framework developed as part of the Phase 2 pilot projects will need to be integrated with the tools and technology systems.

Activity A6: Set up criteria for contractor selection during procurement of BIM projects. This activity will involve developing criteria for contractor selection during the procurement of BIM projects. The criteria will consider factors such as the contractor's BIM for Infrastructure experience, certifications, and training; any successfully completed BIM for Infrastructure projects; and the contractor's ability to deliver the information per the information-delivery specifications developed under Activity A4. This activity may result in updates to the model contract language developed under Activity A3 in Phase 1 to guide BIM procurements.

Activity B4: Create BIM performance-measurement and ROI-calculation tool. This activity will involve creating tools for measuring BIM performance and calculating

ROI. As part of this activity, a performance scorecard will need to be developed that will assign point values for planning, adoption, technology, and performance. The scorecard can be developed using an approach similar to that adopted by Stanford University to develop its VDC scorecard, which has 56 performance measures (Kam 2019).

Activity C4: Set up strategies to manage the risk of mainstreaming the BIM Maturity Level 2 framework. To ensure the BIM Maturity Level 2 framework can be successfully mainstreamed at the end of 10 years, it is important to ensure strategies mitigating the risk of implementation are developed and put in place during the deployment of the BIM Maturity Level 1 framework.

The strategies should take into consideration factors likely to affect any of the four BIM elements. For example, factors such as the need for upgrades to tools and technology systems will need to be tracked as a risk in a risk register. The potential causes of the risks and factors influencing the risks should also be identified and documented. For example, a technology system may need to be upgraded due to either new features and capabilities in the software or the release of new open-data standards. Depending on the cause, the potential effects of the risk will need to be anticipated and the mitigation strategies to reduce those effects will need to be planned.

8.4.3 Long-Term: Phase 3

As shown in figure 10, the foundational, development, and deployment activities carried out in Phase 2 will be reexecuted during Phase 3. However, the objective during Phase 3 will be to build on the BIM Maturity Level 1 framework developed in Phases 1 and 2. The Phase 3 schedule and milestones outlined in table 4 illustrate how the Phase 3 activities will build on the milestones and accomplishments achieved in Phase 2 by continuing the work done in Phase 2. The schedule for the Phase 3 activities is aligned with the BIM for Infrastructure maturity levels in figure 10 to illustrate how these activities will help achieve BIM for Infrastructure Maturity Level 2 by enhancing all BIM for Infrastructure elements.

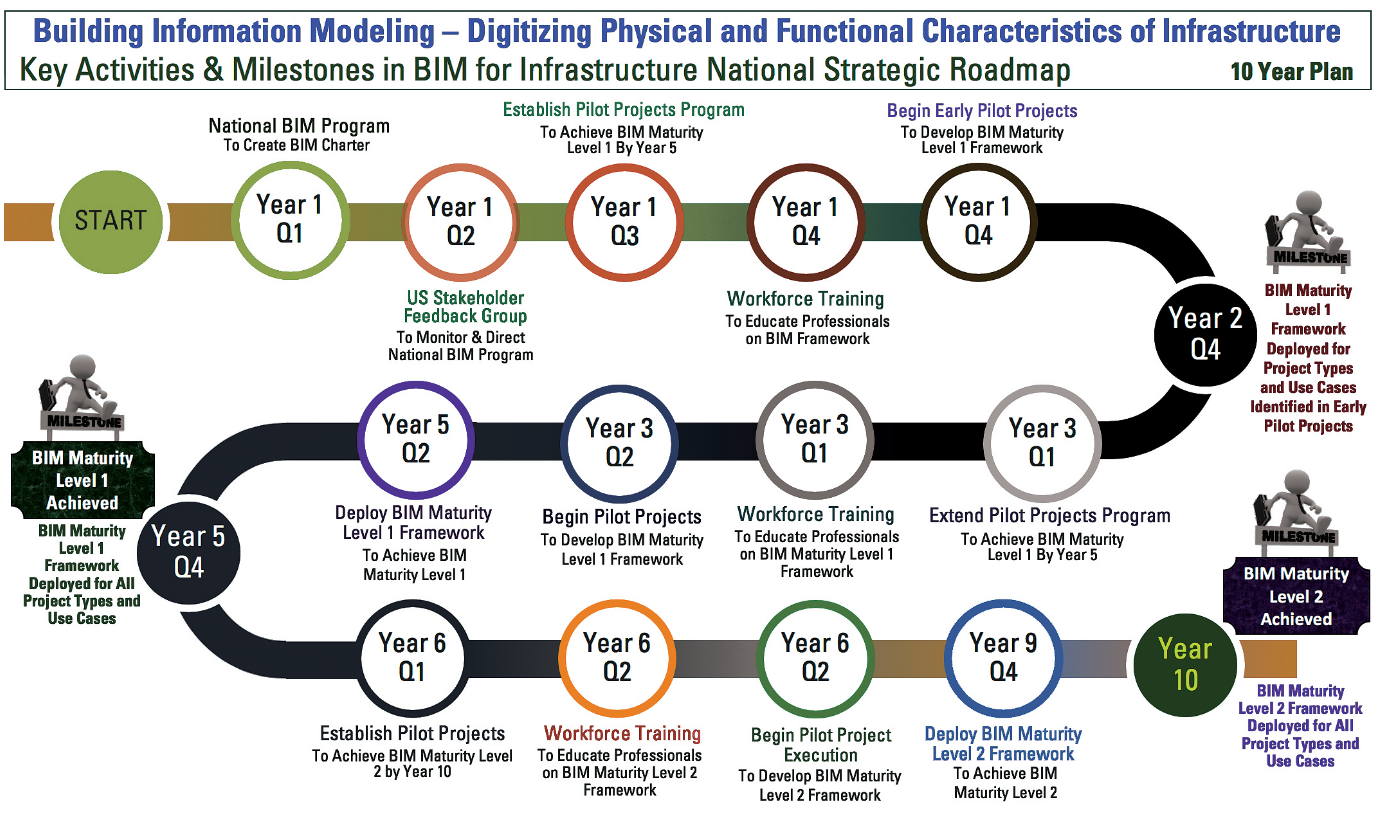
9.0 Summary

The roadmap presented in this document articulates, at a high level, seminal implementation activities that should be carried out over the next 10 years to guide State DOTs and their stakeholders toward the goal of BIM for Infrastructure Maturity Level 2. This maturity level represents a condition state in which stakeholders collaborate using integrated information models created using BIM-enabled tools and technologies and leverage BIM standards, an enterprise-wide data dictionary, OTLs, and BIM data-exchange and delivery processes.

BIM Maturity Level 1 should be attained at the end of 5 years. At BIM Maturity Level 1, data models are object based as opposed to document based, but there is little to no integration of these data models across the planning and programming, design, construction, and O&M disciplines. Each discipline has its own data libraries, and the agency lacks an organization-wide data dictionary, standard terms, object definitions, and OTL. However, within each of the disciplines, agencies have at least established an object-based data-modeling approach—several of which are based on open standards—to set the foundation for the integration of open standards–based data models.

Figure 7 presents a summary of the BIM for Infrastructure maturity levels, and the appendix provides a detailed explanation of each level. As shown in figure 12 , the implementation activities suggested in this roadmap to achieve these maturity levels are divided into three terms (i.e., phases): short (i.e., 0 to 2 years, Phase 1), medium (i.e., 3 to 5 years, Phase 2), and long (i.e., 6 to 10 years, Phase 3). The activities are defined and sequenced such that all components of the BIM framework grow simultaneously toward the following milestones:

- By Year 2, BIM Maturity Level 1 has been achieved across all phases of the asset lifecycle for some project types and BIM use cases.
- By Year 5, BIM Maturity Level 1 has been extended to most project types and BIM use cases.
- By Year 10, BIM Maturity Level 2 has been achieved for all asset lifecycle phases, project types, and BIM use cases.



Source: FHWA.

Figure 12. Illustration. Suggested implementation activities in the roadmap to achieve BIM Maturity Level 2 in the United States.

To accomplish these goals, a set of foundational, development, and deployment activities is suggested for each of the three phases. As part of the Phase 1 foundational activities, it is suggested that FHWA establish a national, State-led BIM pooled fund to advance BIM for Infrastructure at the national level. A broad cross-section of stakeholders, including State DOTs, FHWA, the contracting and consulting community, and other organizations involved in BIM for Infrastructure, would interact as pooled fund members. This pooled fund group will generate BIM development activities, establish performance targets, direct communications and outreach activities, coordinate with other BIM related efforts, direct the development of a workforce training curriculum, and establish a pilot project program to help bring a national BIM framework to maturity.

The pilot project program will identify the project types and BIM use cases on which early projects should focus so a BIM Maturity Level 1 framework can be developed that encompasses these projects. The national BIM pooled fund group will direct the development of criteria for defining and selecting the early pilot projects. These projects will focus on a core set of high-value and high-urgency project types and use cases to document early successful implementations of BIM practices.

At the same time, the project types and BIM use cases should be selected to set the foundation for achieving BIM Maturity Level 1 for all project types and use cases by the end of Year 5. In the subsequent phases, to be conducted over the medium and long terms, the foundational activities associated with workforce training and the pilot project program will expand to include additional project types and use cases so BIM Maturity Level 1 and Level 2 frameworks can be developed for all project types and use cases by end of Years 5 and 10, respectively.

During each of the phases, the pilot projects will be used to develop and advance an overarching BIM framework to maturity. Candidate project types and BIM use cases for each phase should be selected when the pilot project program is established during Phase 1. The scope of the pilot project program can then be updated and further refined at the beginning of each subsequent phase.

Developing the BIM framework will involve developing requirements for implementing BIM projects, a catalogue of model-information requirements, a national data dictionary, a national OTL, model contract language to guide BIM procurements, BEPs, tools and templates for employer information requirements, and standard information-delivery specifications for data exchanges. During the pilot projects in Phases 1 and 2, BIM framework-development activities should be executed with the goal of creating the BIM Maturity Level 1 framework. Development activities during the Phase 3 pilot projects should be executed with the goal of creating and mainstreaming the BIM Maturity Level 2 framework.

Once development of the BIM framework has been initiated in Phase 1, Phases 2 and 3 will involve carrying out a set of deployment activities. These deployment activities will involve setting up a BIM organizational matrix, BIM tools and technology systems—such as a CDE or data warehouse and system interfaces—at the State DOTs, and contractor-selection criteria during BIM project procurements, as well as creating a BIM performance-measurement tool and developing strategies for risk management during BIM deployment.

The experiences and lessons learned from deploying the BIM Maturity Level 1 framework in Phase 2 should be used to document the initial successes, identify implementation risks, improve processes and workforce skill sets, educate stakeholders, and validate the benefits of BIM for Infrastructure. In Phase 3, the deployment activities carried out in Phase 2 will be reexecuted with the objective of deploying the BIM Maturity Level 2 framework and achieving BIM Maturity Level 2.

BIM for Infrastructure should be implemented carefully. It promises big rewards but is not without its share of financial and performance risks (e.g., the risks inherent in overhauling IT processes, workforce training, and new software tooling) for organizations implementing BIM. There is a need to follow a carefully coordinated sequence of "Crawl, Walk, Run, Fly" activities to attain the desired benefits in a consistent manner. The activities described and sequenced in the roadmap outlined in this document point the way toward defraying risks and maximizing benefits.

As the program of activities is carried out, there is no doubt this roadmap and the suggested activities will need to be reviewed, updated, and enhanced periodically based on the lessons learned regarding BIM implementation in the United States and around the world and based on other BIM-enabling activities in the industry, such as the development of standards (e.g., IFC), tools, and technologies.

10.0 Future Outlook

Realizing the maximum benefits from developing and implementing BIM for Infrastructure is demanding of organizations. However, the strategic investments made by these organizations offer significant returns, both for the organizations themselves and for the U.S. highway infrastructure industry as a whole.

More effort than expected may be needed to increase the number of data and process integrations across the asset lifecycle and automate these integrations through changes to institutional, technological, and collaborative structures. To implement BIM for Infrastructure, upfront investments of capital will be needed to upgrade technologies and equip the workforce with the relevant skills. An integrated management structure and robust BEPs will also be needed to allow for a significant amount of collaboration on information delivery and to alter the existing work processes of various organizational units. In other words, implementing BIM for Infrastructure will involve replacing work silos with much more collaborative processes and making large cultural changes within the organization.

Confronting these challenges will involve careful planning, phasing, and selection of an implementation path, resulting in a gradual increase in complexity but delivering results for users at each stage. This approach will allow the organization to demonstrate early successes and refine work processes through a culture of learning throughout implementation. To take this approach, State DOTs and their stakeholders will need to carefully lay a foundation to ensure the successful execution of subsequent development and implementation activities. Given the long lead time expected between embarking on the path to implementing BIM for Infrastructure and ultimate implementation, State DOTs should seek the buy-in of leadership to ensure sustained investment of monetary and human resources during the entire implementation period but also to show accountability for the investments made.

The roadmap described in this document can help organizations prepare for the level of change needed for BIM for Infrastructure. Each State DOT should assemble a dedicated team with the right mix of individuals who are adequately trained and empowered to lead the specific initiatives identified in the roadmap. Beyond the listed roadmap activities, State DOTs should enhance coordination between various organizational units, including engineering, construction, asset management, maintenance, and IT, and improve collaboration with external partners, including Federal and peer highway agencies, contractors, and consultants at both the local and national levels.

The roadmap presented in this document describes activities that should be performed over the short (i.e., 0 to 2 years), medium (i.e., 3 to 5 years), and long (i.e., 6 to 10 years) terms to achieve BIM Maturity Level 2 at the end of 10 years. During this 10-year period, the roadmap will need to be reviewed and upgraded periodically, preferably once a year, to ensure the state of the industry (e.g., in terms of improvements to tools and technologies and updates to data standards) can be taken into consideration. Additionally, the experience gained and lessons learned from the pilot projects carried out during Phases 1 through 3 will need to be taken into consideration. Additional activities may need to be added to the roadmap or the existing set of activities may need to be revised.

At some point during Phase 3, development can begin on a roadmap to achieve BIM Maturity Level 3 based on lessons learned from implementing the pilot projects, the progress of the roadmap activities identified in this document, and the state of the industry. However, the roadmap to achieve BIM Maturity Level 3 should be finalized only after the state of the industry and the progress made toward BIM Maturity Level 2 have been assessed from the perspective of various BIM for Infrastructure components and use cases.

References

AASHTO. 2019. *Manual for Bridge Element Inspection, 2nd Edition*. Washington, DC: American Association of State Highway Transportation Officials.

AGC of America, Inc. 2019. *2019 Level of Development (LOD) Specification Part I & Commentary for Building Information Models and Data*. BIMFORUM. https://bimforum.agc.org/lod/, last accessed February 9, 2021.

ASPRS. 2013. *LAS Specification version 1.4*. Bethesda, Maryland: American Society for Photogrammetry and Remote Sensing. https://www.asprs.org/wp-content/uploads/2010/12/LAS_1_4_r13.pdf, last accessed March 15, 2021.

Borrmann, A., M. König, C. Koch, and J. Beetz, editors. 2018. *Building Information Modeling: Why? What? How? – Technology Foundations and Industry Practice*. Cham, Switzerland: Springer International Publishing. https://link.springer.com/book/10.1007%2F978-3-319-92862-3, last accessed February 9, 2021.

BIR. 2014. *BIR Leaflet Number 1 – Dutch BIM Levels*. Netherlands: Bouw Informatie Raad. https://www.bouwinformatieraad.nl/main.php?mode=download_file&id=22, last accessed February 9, 2021.

Crossrail Ltd. 2013. *Crossrail BIM Principles*. London, UK: Crossrail Limited. https://learninglegacy.crossrail.co.uk/wp-content/uploads/2017/02/12F-002-03_Crossrail-BIM-Principles_CR-XRL-Z3-RGN-CR001-50005-Revision-5.0.pdf, last accessed February 9, 2021.

Federal Ministry of Transport and Digital Infrastructure. 2016. *Road Map for Digital Design and Construction*, Berlin, Germany: Federal Ministry of Transport and Digital Infrastructure. https://www.bmvi.de/SharedDocs/EN/publications/road-map-for-digital-design-and-construction.pdf?__blob=publicationFile, last accessed February 9, 2021.

FHWA, AASHTO, ARTBA, and AGC. 2013. "Civil Integrated Management (CIM)" (web page). https://highways.dot.gov/sites/fhwa.dot.gov/files/docs/federal-lands/design/design-visualization/27946/cim-poster-0412.pdf.

Gerbert, P., S. Castagnino, C. Rothballer, A. Renz, and R. Filitz. 2016. *Digital in Engineering and Construction: The Transformative Power of Building Information Modeling*. Boston, MA: The Boston Consulting Group. http://futureofconstruction.org/content/uploads/2016/09/BCG-Digital-in-Engineering-and-Construction-Mar-2016.pdf, last accessed February 9, 2021.

IETF. 2016. "The GeoJSON Format" (website). https://tools.ietf.org/html/rfc7946, last accessed March 15, 2021.

ISO. 2020. *Information Container for Linked Document Delivery — Exchange Specification — Part 1: Container*. ISO 21597. Geneva, Switzerland: International Organization for Standardization.

ISO. 2018. *Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information Management Using Building Information Modelling – Part 1: Concepts and principles*. ISO 19650. Geneva, Switzerland: International Organization for Standardization.

ISO. 2014. *Geographic information — Metadata — Part 1: Fundamentals*. ISO 19115. Geneva, Switzerland: International Organization for Standardization.

Jones, S.A. and D. Laquidara-Carr, editors. 2017. *The Business Value of BIM for Infrastructure 2017*. Bedford, MA: SmartMarket Report Dodge Data & Analytics. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/finance/us-fas-bim-infrastructure.pdf, last accessed February 9, 2021.

JSON. 2021. "Introducing JSON" (website). https://www.json.org/json-en.html, last accessed March 15, 2021.

Kam, C. 2019. "VDC and BIM Scorecard." (website). https://vdcscorecard.stanford.edu/, last accessed February 9, 2021.

LandXML. 2018. "landXML.org" (website). http://www.landxml.org, last accessed March 15, 2021.

Meerkerk, J. and B. Koehorst. 2017. *Utilising BIM in NRAs*, Technical Report No. 2017-05. Brussels, UK: Conference of European Directors of Roads. https://www.cedr.eu/download/Publications/2017/Utilising-BIM-for-NRAs-TR2017-05.pdf, last accessed February 9, 2021.

Mitchell, A., E. Gensib, S. Sadasivam, T. Day, J. Gustafson, J. Bartlett, and T. Bonzelet. 2019. *3D Highway Design Model Cost-Benefit Analysis*. Lansing, MI: Michigan Department of Transportation. https://www.michigan.gov/documents/mdot/2019-SPR-1680_652496_7.pdf, last accessed February 9, 2021.

Molenaar, K. R. and R. B. Duval. 2016. *TechBrief: Alternative Contracting Method Performance in U.S. Highway Construction*, Report No. FHWA-HRT-17-100. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/infrastructure/17100/17100.pdf, last accessed February 9, 2021.

Moon, H., K. Anderson, A. Borrmann, J. Hyvärinen, S. Markič, S. Muhič, L. Vaessen-Mol, J. Moya, A. Marquez, and F. Zhao. 2018. *IFC Road Project: Requirements Analysis Report*. Hertfordshire, UK: buildingSMART® International.

Muro, M., S. Liu, J. Whiton, and S. Kulkarni. 2017. *Digitalization and the American Workforce*. Washington, DC: The Brookings Institution. https://www.brookings.edu/wp-content/uploads/2017/11/mpp_2017nov15_digitalization_full_report.pdf, last accessed February 9, 2021.

OGC. 2021a. "Geography Markup Language" (website). https://www.ogc.org/standards/gml, last accessed March 15, 2021.

OGC. 2021b. "LandInfra / InfraGML" (web page). https://www.ogc.org/standards/infragml, last accessed March 15, 2021.

Panetta, K. 2018. "Smarter With Gartner. Gartner Top 10 Strategic Technology Trends for 2019" (web page). https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2019/, last accessed February 9, 2021.

Parve, L. 2013. *3D Engineered Models for Construction – Understanding the Benefits of 3D Modeling in Construction: The Wisconsin Case Study*, Report No. FHWA-HIF-13-050. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/construction/pubs/hif13050.pdf, last accessed February 9, 2021.

Sillars, D.N., E. H. Ng, J. Calvo-Amodio, S. Capalbo, M. Martin, Q. Jahanger, and G. Zimmerman. 2017. *Advanced Technology: Return on Investment at the Oregon Department of Transportation*, Project No. 30530-16-14. Salem, OR: Oregon Department of Transportation.

University of Colorado Boulder, University of Kansas, and Hill International, Inc. 2018. *TechBrief: Alternative Contracting Method Performance in U.S. Highway Construction*. Report No. FHWA-HRT-17-100. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/infrastructure/17100/17100.pdf, last accessed February 9, 2021.

W3C. 2021a. "Introduction to XML" (web page). https://www.w3schools.com/xml/xml_whatis.asp, last accessed March 15, 2021.

W3C. 2021b. "Resource Description Framework (RDF)" (web page). https://www.w3.org/RDF/, last accessed March 15, 2021.

Appendix A: Glossary

Alternative contracting methods—Alternative contracting methods refer to various innovative contracting approaches, such as DB and design-build-operate-maintain (DBOM), used in lieu of traditional DBB contracting to design, construct, and manage assets over their lifecycles. In traditional DBB contracting, which is used by most agencies in the United States, the agency creates separate contracts for design and construction services. As an alternative to DBB, some agencies have begun using DB contracting, in which the agency creates a single contract and conducts a single bid letting event to procure both design and construction services from an industry vendor. DBOM contracting similarly involves creating a single contract, in this case one that includes design, construction, and asset-management services.

BIM-compliant software—BIM-compliant software includes software systems that support open BIM standards (e.g., IFC, GML, InfraGML, and CityGML) and BIM-compliant processes (e.g., the ability to connect to a CDE, provide a collaborative working environment, and utilize open standards–based terms and definitions).

BIM for Infrastructure—BIM is a collaborative work method for structuring, managing, and using data and information about transportation assets and networks throughout their lifecycles. It liberates data from siloed systems and makes those data available via automated processes to anyone who needs them when they need them.

BIM maturity level—BIM maturity level describes the state of development of the four BIM for Infrastructure components within an organization: policies and processes, tools and technologies, people and skills, and data and standards. An organization is assigned a BIM maturity level of 0 through 3 based on the degree of significant digital information exchange and degree of IT integration. The appendix describes the state of each of the BIM for Infrastructure components for each of the BIM maturity levels.

BIM Maturity Level 1 framework—The BIM Maturity Level 1 framework describes the states of the four BIM for Infrastructure components (i.e., policies and processes, people and skills, tools and technologies, and data and standards) needed to achieve BIM Maturity Level 1.

BIM Maturity Level 2 framework—The BIM Maturity Level 2 framework describes the states of the four BIM for Infrastructure components (i.e., policies and processes, people and skills, tools and technologies, and data and standards) needed to achieve BIM Maturity Level 2.

Common data environment (CDE)—A CDE is a centralized environment that allows for the collection, storage, collaborative editing, review, approval, sharing, and dissemination of digital data models. In typical practice, a CDE is designed and built to share information during the design and construction phases of a project, but ideally the contents of the CDE should not be limited to assets or objects created in a BIM or computer-aided design (CAD) environment. The models and documentation stored in the CDE can include both geometric and nongeometric information about assets from all of the asset lifecycle phases.

Civil Integrated Management (CIM) — 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, surveying, construction, maintenance, asset management, and risk assessment.

Construction—One of the phases in the asset lifecycle, construction involves building, rehabilitating, renovating, or decommissioning a highway infrastructure asset or facility according to the specifications laid out during the project's design phase. Most highway agencies in the United States contract out the construction work to consultants and contractors in the private sector.

Data management—Data management encompasses defining data, creating data architecture, modeling data, collecting or gathering data, processing data, storing and securing data, ensuring the quality of data, defining reference data, documenting metadata, ensuring data integration and interoperability, performing document and content management, designing and implementing data-warehousing solutions, and maintaining business intelligence.

Data modeling—Data modeling encompasses creating, storing, checking, updating, sharing, integrating, and exchanging data models during the planning and programming, design, construction, and operations and maintenance phases of asset lifecycle.

Data/information models—Data/information models are used to represent the structure of and relationships among data elements in a way that describes the real world. Data elements refer to the geometric or nongeometric attributes or properties of highway infrastructure assets. The dimensionality of a data/information model determines the type of asset data captured in the model. Two- or three-dimensional models contain data elements representing an asset's design and geometry in two or three dimensions, four-dimensional models contain data elements describing construction and maintenance scheduling for an asset, five-dimensional models contain data elements providing detailed quantity and cost information about an asset and its components, six-dimensional models contain data elements associated with the lifecycle of an asset and its components, and so on.

Data transformation—Data transformation is a data-management activity involving changing a data model using a certain OTL and a certain set of terms and definitions into a different data model using a different OTL and a different set of terms and definitions.

Design—One of the phases in the asset lifecycle, design involves creating specifications for contractors to perform construction, rehabilitation, or replacement work for one or more highway infrastructure assets. The specifications are prepared using open standards, such as IFC, or using proprietary standards such as .DGN, .ALG, or .DXF. Design begins after a project has been programmed into the Statewide Transportation Improvement Program (STIP), Transportation Improvement Program (TIP), or capital plan and funding has been allocated to the project. Transportation agencies often contract out a portion of the design work to consultants or may create designs in-house.

Digital Twin—a digital representation of a physical object, process or service.

Digitalization—Digitalization involves creating a digital version of an analog or physical thing, such as a paper document, microfilm image, photograph, or sound. Digitalization's purpose is to create systems of record or engagement. Digitalized business operations, business functions, business models and processes, and business activities have been enabled, improved, transformed by leveraging digital technologies and broadly used and contextualized digitized data, and turned into actionable knowledge, with a specific benefit in mind. Automation is a large part of creating digitalized processes.

Digitization—Digitization involves managing data and information, such as text, pictures, graphics, and tables, in a digital format for easy processing by a computer.

Extract, transform, load/extract, load, transform (ETL/ELT)—ETL is a data-management activity involving extracting data from a system, transforming the data from the format used by the source-system object model to the format used by the target-system object model, and loading the data into the target system. Sometimes the data are transformed after they have been loaded into the target system. In such cases, the term ELT is used to describe the data-processing operation.

Federated-information models—A federated-information model describes an information model consisting of connected but distinct individual information models. Federation refers to a scenario in which a group of systems and networks operates in a standard, collective, and connected environment. Federation involves establishing a central unit for integrating various disconnected entities (i.e., software systems, databases, or applications) within an enterprise. The central unit ensures the internal autonomy of the constituent systems is maintained and that these systems do not have to be integrated directly with each other to exchange information. For example, a federated-database system is a type of metadatabase-management system that transparently maps multiple autonomous-database systems into a single federated database. The constituent databases are interconnected via a computer network, may be geographically decentralized, and utilize the central authority to exchange data rather than interface with each other.

Letting—Typically discussed as part of the construction phase in the asset lifecycle, letting involves preparing and advertising a proposal. An agency creates a proposal by aggregating the scope of one or more highway infrastructure projects, as envisioned and defined during the planning and programming and design phases. To advertise the proposal, the agency prepares a bid package that provides contractors with detailed information about the scope of the project and the services expected (listed as pay items). Letting involves accepting bids from contractors and consultants, evaluating those bids, selecting the winning bid, and awarding the work to the selected contractors. At the end of letting, the agency creates a contract that serves as a legal document describing the terms and conditions of the services to be provided by the consultant or contractor to the State DOT.

Level of development—The BIMForum describes the Level of Development Specification as a reference enabling practitioners in the architecture, engineering, and construction industry to specify and articulate, with a high level of clarity, the content and reliability of their BIM design models at various stages during the design and construction processes (AGC of America, Inc. 2019).

Maturity model—A maturity model is a tool that agencies use to evaluate the effectiveness of a system, person, group, process, tool, or technology so the resulting information can be used to determine steps that should be taken to enhance the capabilities and improve the performance of the system, person, group, process, tool, or technology.

Model-view definition (MVD)—An MVD refers to a subset of objects and the attributes associated with those objects. The subset is created when two systems need to exchange certain information captured by an object's data model without necessarily exchanging the full object model. A new MVD is created for each system-to-system exchange or information export or exchange request. An MVD is created by the users of the information working in close coordination with software vendors. For example, when as-built data need to be sent from a construction system to an asset-management system for a particular type of asset or object, an MVD is created for this data exchange based on the asset's or object's data model.

Object—An object is a data entity used to represent the physical and functional elements of a real-world highway infrastructure element in the digital world. An object is described by its attributes or properties, which can include both geometric data, such as the object's dimensions in space, and nongeometric data describing the object's characteristics, such as the object's name, type, owners, and condition.

Object-type library (OTL)—An OTL lists standard object-type names (e.g., bridge, road, tunnel) and their attributes or properties.

Open data-modeling standards—Standards-development organizations such as buildingSmart International and Open Geospatial Consortium have created data-modeling standards, such as IFC, GML, InfraGML, and CityGML, to describe objects that represent the physical and functional characteristics of infrastructure assets. These standards are referred to as open data-modeling standards.

Planning—One of the phases in the asset lifecycle, typically listed alongside programming, planning involves identifying an agency's strategic direction and prioritizing investments to improve the health, safety, and mobility of the highway infrastructure system. Candidate projects for inclusion in the STIP, TIP, and the agency's capital plan are identified during this phase. For each project considered, information such as scope, cost, and benefits is determined.

Programming—One of the phases in the asset lifecycle, typically listed alongside planning, programming follows the planning phase and involves selecting specific projects for inclusion in an agency's capital plan and the STIP or TIP. Projects are selected from the list of candidate projects compiled during the planning phase based on factors such as budget categories, funding availability, project timing, resource needs, and agency-performance targets. The end product for this phase is a prioritized list of projects.

Project delivery—Project delivery refers collectively to the design and construction phases of the asset lifecycle. At the end of project delivery, the built, reconstructed, or rehabilitated asset or highway facility is handed over to the O&M units of the overseeing highway agency so the asset can be managed throughout its lifecycle.

Retirement/decommissioning—Retirement or decommissioning refers to the act of removing an asset from service by closing it to the traveling public.

Service delivery—Service delivery involves the activities performed under the O&M phase of the asset lifecycle, including asset management and performance management. The O&M phase involves managing information about the asset for the inventory, conducting periodic inspections of the asset to assess its condition, documenting the work needed to maintain the asset in a state of good repair (i.e., a state in which repairs can be performed on the asset to correct any deficiencies due to routine wear and tear), and performing the identified maintenance work on the asset.

Appendix B: BIM for Infrastructure Components at Each BIM for Infrastructure Maturity Level

Component	Level 0 Document-Oriented	Level 1 Object-Oriented	Level 2 Federated Object Models and Databases	Level 3 Integrated Lifecycle
Data and standards	Lines, curves, and text—not digital objects—are used to represent infrastructure objects and create information models. Information models are nonintelligent because the lines and curves used to represent physical assets do not store data about asset properties. Data on asset properties are stored in separate, unlinked files or tables or as free-flow text on drawings. National or agency-defined CAD standards are used to create information models.	Objects are used to represent physical assets and their properties. Objects can be geometric (1D, 2D, or 3D) or nongeometric. Intelligence is added to information models by extending the properties of 1D to 3D geometric objects (e.g., lines, arcs, curves, or solids) to store the properties of physical assets represented by these shapes. However, the data models created are still specific to a discipline and are not linked with each other. For example, design models do not contain data regarding planning, financials, construction, or asset management. The agency lacks an organization-wide data dictionary, standard terms, object definitions, and OTL. As a result, uncoordinated data models are created across planning, financial, design, construction, and asset management systems. National or agency-defined feature-based CAD standards are used to create the design and as-built construction information models. The non-geometric data models created in planning and financial systems follow agency-specific non-geometric standards. The geometric data models in planning and asset management systems utilize geographic information system (GIS) and linear referencing system (LRS) data standards. Data management is "unstructured" across agency units and projects. The use of metadata and master and reference data management is limited.	Lines, curves, and text—not digital objects—are used to represent infrastructure objects and create information models. Information models are nonintelligent because the lines and curves used to represent physical assets do not store data about asset properties. Data on asset properties are stored in separate, unlinked files or tables or as free-flow text on drawings. National or agency-defined CAD standards are used to create information models.	Lines, curves, and text—not digital objects—are used to represent infrastructure objects and create information models. Information models are nonintelligent because the lines and curves used to represent physical assets do not store data about asset properties. Data on asset properties are stored in separate, unlinked files or tables or as free-flow text on drawings. National or agency-defined CAD standards are used to create information models.
Tools and technologies	The tools utilized include CAD, GIS, and the Microsoft Office Suite (e.g., Excel, Access, Word). Paper documents and forms are heavily utilized to create, collect, model, and exchange data. During design and construction, design drawings and Excel spreadsheets are created to model data. During planning, construction, financial analysis, asset	The tools utilized include design, financial, project-management, and construction software systems as well as GIS and LRS. Several data management systems are either Excel or Access based. Relational data management systems (client-server or web-based) are deployed, but database administration is limited. There are data redundancies and schema conflicts between	The tools utilized include design, financial, project-management, and construction software systems as well as GIS and LRS. Enterprise relational data-management systems (client-server or web-based) ensure collaboration by creating a structured, controlled, monitored, quality-controlled, multiuser data-editing environment. The systems may be hosted on the premises or in the cloud.	The tools utilized include design, financial, project management, and construction software systems as well as GIS and LRS. Systems may be based in Excel, Word, or relational data-management systems (client-server or web-based). They may be hosted on the premises or in the cloud. Additionally, systems administered by external entities (e.g., contractors, data vendors, open data sources on

Component	Level 0 Document-Oriented	Level 1 Object-Oriented	Level 2 Federated Object Models and Databases	Level 3 Integrated Lifecycle
Tools and technologies	operations, and maintenance, data for the asset data are created, collected, and managed using software such as Excel or Word or using paper forms designed for individual systems (e.g., forms for populating asset inspection databases). Asset information is exchanged using paper drawings and paper documents.	the systems used to create information models. Systems may be hosted on the premises or in the cloud. The databases and applications across disciplines (e.g., planning, financial, design, construction, and asset-management systems) are autonomous and disconnected. Different object definitions are used across disciplines. Data exchanges within any discipline are file based and involve data processing and transformation. Data are not exchanged across disciplines. The level of IT integration and automation within and across systems is limited. To facilitate data exchange across the multiple systems used within each discipline—data warehouses, data lakes, and document and content repositories—web services or APIs are used. However, these data repositories do not follow any national or international standards (e.g., ISO 21597). These data repositories are administered using manual processes and through direct access (instead of using a user-friendly front-end software application that does not involve programming).	Autonomous internal (agency-owned) databases are federated and utilize a standard data dictionary and OTL. The federation of autonomous databases and the use of a national or agency-defined standard OTL allows data implementation with a higher degree of automation across internal systems. Data transformations during ETL or ELT operations become trivial and are needed less frequently. The degree of IT involvement in automating data exchanges is higher compared to BIM Maturity Level 1. File-based data exchanges between internal agency systems are automated. Web services or APIs are utilized to exchange data between agency systems using XML and JSON data files. To facilitate data exchange across the internal systems used by various disciplines—data warehouses, data lakes, document and content management repositories—web services or APIs are used. These data repositories are administered using software applications that allow for the management of multiple data sources (including sensors installed in the field or web applications that provide real-time streaming data). The software applications allow administrators to manage the CDE and the data connections, data-exchange templates, and data processing between systems.	the web, and other transportation agencies) are utilized and integrated with the agency's data systems. Autonomous internal and external system databases are federated and utilize a standard data dictionary and OTL. Autonomous databases are federated and a national or agency-defined standard OTL is used across all agency-owned and external entity–owned data systems. Use of a standard OTL allows for the highest degree of automation in data modeling and integration across internal and external systems. The degree of IT involvement in automating data creation and exchange is higher compared to BIM Maturity Level 2. National OTL-based open standards (e.g., GeoJSON, InfraGML) are utilized to exchange data between systems. To facilitate data exchange across the multiple internal and external systems used within and across disciplines, software applications are used to manage on premises and cloud-based data warehouses, data lakes, and document and content repositories. These applications are also used to track compliance with standards, perform a variety of quality assurance (QA) and quality control (QC) checks, and assess security. The tools allow the agency to track the custom configurations of data systems to ensure the data structures remain in sync across the different internal and external autonomous systems. There is a high degree of automation systems administration.
Policies and processes	There is limited to no communication about information requirements with the stakeholders involved in data collection and creation in any of the asset lifecycle phases. There is limited to no data management (data documentation, data-quality checking, data-exchange protocols).	Information requirements regarding the data that designers or construction contractors provide about the as-designed or as-built facility are not based on open standards and are not consistently defined across projects. Multiple document repositories are in place. The organizations lack standard processes for managing content (i.e., documents, images, videos, and semistructured or unstructured data files).	EIRs have been defined and consistently made part of design and construction contracts for all types of projects. Information delivery specifications have been defined nationally and are being utilized by agencies. Open standards based MVDs have been defined and are being utilized to exchange data for key processes. Model contract language has been developed for different contract types to set information modeling requirements. Data QA and QC processes are in place to ensure compliance with data-modeling and exchange standards and to ensure data quality and security across all internal systems.	EIRs have been defined and made part of design, construction, asset-inventory data collection, asset inspection, and maintenance contracts. Information delivery specifications have been defined nationally and are being utilized by agencies for all types of data acquisition (irrespective of whether it is for internal or external systems). These specifications include data acquired by the agency from external data vendors (e.g., Global Navigation Satellite System or GNSS-based real time traffic or incident data) as well as data collected and created by survey, design, and construction

Component	Level 0 Document-Oriented	Level 1 Object-Oriented	Level 2 Federated Object Models and Databases	Level 3 Integrated Lifecycle
Policies and processes				contractors. MVDs are used to exchange data for all processes in each of the asset lifecycle phases. Data QA and QC processes are in place to ensure compliance with data-modeling and exchange standards and to ensure data quality and security across both internal and external systems.
People and skills	The software skills needed to carry out activities during any of the asset lifecycle phases are limited among agency personnel. People coordinate using in person communication and email to create and manage information models.	The data and standards, policies and processes, and tools and technologies necessary for BIM Maturity Level 1 are understood by people in the agency. For example, people have the skills needed to do the following: • Understand the systems and processes relevant to their work (i.e., within their discipline). • Master the features and functions of technology (i.e., software and hardware) systems. • Master agency- and discipline-specific data management standards and processes. To coordinate, people exchange files using emails, shared document repositories, and document- and content management systems.	The data and standards, policies and processes, and tools and technologies necessary for BIM Maturity Level 2 are understood by people in the agency. For example, people have the skills needed to do the following: • Create model contracts, BEPs, employer information requirements, etc. • Develop and maintain an enterprise data dictionary, OTL, and metadata. • Manage reference data across systems and ensure compliance with standards. • Administer a CDE encompassing the agency's structured, semi-structured, and unstructured databases; data warehouses; data lakes; and document and content repositories per the applicable standards using available software tools. • Monitor compliance with data-modeling and exchange standards (e.g., CAD, IFC, GML, InfraGML, XML, JSON, and GeoJSON). To coordinate, people utilize shared working environments and version control systems.	The data and standards, policies and processes, and tools and technologies necessary for BIM Maturity Level 3 are understood by people in the agency. For example, in addition to the skills needed at BIM Maturity Level 2, staff understand the following: • How data are exchanged with systems outside the agency (i.e., those administered by contractors or data vendors who use cloud- and web services–based solutions). • How automation can be introduced in the management and administration of data systems and information models, especially in terms of automated checks to ensure compliance with standards and information modeling and exchange processes. • How various BIM groups at the national, State, and regional levels coordinate. To collaborate, people rely on automated and artificial intelligence systems that suggest the next steps in the process.

U.S. Department of Transportation

Federal Highway Administration

Advancing BIM for Infrastructure

National Strategic Roadmap

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