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Proof of Concept and Deployment Plan

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16. Abstract
This report integrates the proof of concept (PoC) and deployment planning for the Central BIM Transportation Library (CBTL). It documents representative transportation BIM use cases, artifact types, a hybrid Directory–Gateway–Repository concept, participant groups, pilot evaluation methods, and a phased pathway for potential deployment. The framework emphasizes evidence-based decision-making, federated access to authoritative sources, governance and content stewardship, state participation, organizational readiness, security, workforce development, training, resource planning, and performance measurement. The report does not represent execution or validation of the PoC and does not presume national implementation.

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Executive Summary

This report integrates the Central BIM Transportation Library (CBTL) proof of concept (PoC) planning and deployment planning. Building on the findings of *Towards a Centralized BIM Transportation Library* (Costin, Ketterl, & Grant, 2025), this report defines a bounded approach for evaluating the concept and an evidence-based pathway for determining whether and how the CBTL could advance toward broader implementation. The report does not represent execution or validation of a proof of concept, nor does it presume that national deployment will occur.

For this report, a bounded PoC means a deliberately limited evaluation with a defined set of use cases, representative BIM artifacts, participant groups, technical capabilities, and evaluation criteria. The intent is to test whether the CBTL concept is feasible and useful under representative conditions without attempting to build or certify a production-scale national system. The boundaries also identify what is intentionally deferred, such as broad operational data hosting, replacement of state systems, and production-scale compliance implementation.

In practical terms, the bounded PoC establishes the scope of the evaluation before testing begins: what will be tested, who will participate, what data and systems will be used, and what is outside the evaluation. This allows the results to be interpreted against agreed expectations and keeps the pilot focused on the questions that matter most for future decisions.

The PoC framework focuses on representative transportation BIM use cases, artifact types, user groups, technical capabilities, and structured evaluation methods. The deployment planning framework then translates the evidence expected from future pilot activities into phased governance, content stewardship, organizational readiness, training, resource, and scaling considerations. Together, these elements provide continuity from research and technical concept development to pilot validation and potential implementation.

Key Findings

- A hybrid Directory–Gateway–Repository model provides a practical basis for a single CBTL user experience while preserving authoritative source systems and avoiding unnecessary duplication of state or external repositories.
- The PoC is most useful when it remains bounded around selected high-value use cases, representative artifacts, clearly identified participant groups, and a limited technical layer sufficient to evaluate technical feasibility, functional utility, and operational readiness.
- The pilot validation framework is organized around functional, performance, security, usability, integration, regression, and data integrity/recovery testing. These complementary areas provide a structured basis for evaluating technical performance and user experience during Phase 1.
- Governance, ownership, content stewardship, state participation, security, organizational readiness, workforce development, and long-term resourcing develop in parallel with the technology and materially influence the viability of broader deployment.
- Deployment is best treated as a phased, evidence-based progression. Advancement between phases can be informed by documented performance, readiness, user outcomes, governance maturity, resource capacity, and unresolved risks rather than by schedule alone.
- The framework remains organization- and technology-neutral so that future governance, platform, hosting, and procurement decisions can be informed by PoC evidence and subsequent program decisions.

Recommended Path Forward

1. **Targeted pilots and operational validation:** Identify candidate early adopter DOT(s), apply the bounded PoC framework to selected use cases and representative artifacts, capture structured user and technical findings, and document readiness considerations.
2. **Peer Exchange and Early Network Development:** Translate pilot findings into reusable implementation resources, refine governance and content practices, and establish a practical advisory community across participating agencies. Identify and engage potential CBTL owners/operators, and use pilot evidence to assess and demonstrate CBTL's value and viability, including the governance, funding, and operational requirements for sustained delivery.
3. **Expanded state-level adoption:** Support repeatable participation across a broader set of state departments of transportation (DOTs), while allowing agencies to adopt CBTL capabilities at different levels of depth based on maturity and local context.
4. **National harmonization and continuous improvement:** Coordinate recurring governance, standards alignment, content stewardship, performance monitoring, and continuous improvement if evidence supports sustained national operations.

1. Introduction

1.1 Purpose and Scope

This report consolidates the CBTL proof of concept plan and deployment plan into a practical framework for implementation. The PoC planning effort defined what can be evaluated, who can participate, and how findings can be collected. The deployment planning effort then identified how those findings can inform governance, content stewardship, organizational readiness, resource planning, phased adoption, and potential national scaling.

The report is intended to support informed decisions about future CBTL development. It does not document execution of a prototype or pilot, and it does not indicate that a particular governance organization, technology platform, hosting environment, procurement approach, or national implementation decision has been selected.

1.2 Relationship to Prior CBTL Research

The primary published research foundation is *Towards a Centralized BIM Transportation Library* (Costin, Ketterl, & Grant, 2025), available through the U.S. Department of Transportation Repository and Open Science Access Portal (ROSA P). The study documented the transportation BIM state of practice, stakeholder perspectives, existing technical resources and repositories, and foundational requirements for improving the discovery, interoperability, governance, and reuse of BIM artifacts across transportation agencies.

Subsequent CBTL research expanded this foundation through the development of technical requirements, testing considerations, and a structured proof of concept plan. These efforts examined representative transportation workflows, BIM artifact types, technical capabilities, user groups, and methods for evaluating a federated CBTL environment.

The proof of concept planning effort accomplished three objectives that this report carries forward. First, it validated priority BIM use cases and artifacts against nationally recognized FHWA workflows, identifying for each use case the artifacts that support execution and where gaps in accessibility, consistency, or interoperability inhibit reuse. Second, it translated those use-case needs into technical and architectural requirements by mapping each artifact type to the capabilities needed for discovery, governance, interoperability, and secure access, and by determining when the CBTL should act as a directory, a gateway, a repository, or a hybrid rather than assuming centralized storage. Third, it defined a bounded PoC framework, including objectives, functional boundaries, a structured user interaction protocol, participant groups, stakeholder structure, and evaluation criteria, so that future pilot findings link directly to deployment decisions.

This report integrates those prior findings into a bounded proof of concept framework and an evidence-based deployment planning pathway. It distinguishes the technical and organizational conditions proposed for future evaluation from capabilities that have been demonstrated through implementation. The resulting framework is intended to inform subsequent pilot decisions without presuming that a production-scale national CBTL has been validated or authorized.

1.3 Report Organization

Chapter 2 summarizes the PoC framework and principal findings. Chapter 3 presents the deployment planning framework and phased sequencing. Chapter 4 describes pilot testing, validation, decision gates, and performance measurement. Chapter 5 addresses governance, organizational readiness, sustainability, training, and resources. Chapter 6 describes the transition pathway from PoC evidence to potential broader deployment. Appendix A provides the detailed use-case and artifact analysis and Appendix B provides the technical capability analysis that underlie the PoC framework.

2. Proof of Concept Framework and Findings

Terminology in this chapter is intentional. “PoC framework” refers to the proposed structure for conducting and evaluating a future CBTL proof of concept. “PoC planning” refers to the research and planning work performed to develop that framework. The proof of concept itself has not been executed under this report.

The chapter integrates the substantive results of the proof of concept planning effort: the use-case and artifact analysis, the trends and barriers that bound the evaluation, the interaction-role assignment logic, the minimum technical layer, and the evaluation framework with its user interaction protocol, participant groups, and stakeholder structure. The detailed artifact-by-artifact matrices and the full use-case narratives are provided in Appendices A and B.

2.1 Research Methodology

The research team developed the PoC framework through a sequence that tied previously validated transportation workflows to the information and technical capabilities needed for evaluation. The overall research process began with the BIM workflows presented in FHWA's BIM Workflows and Centralized BIM Transportation Library for Bridges and Roadways (Bhargava et al., 2024; FHWA-HIF-24-004). The team identified the BIM artifacts associated with those workflows and evaluated recurring national trends and barriers. As a component of this broader research process, a technical capability analysis examined how a single CBTL user experience could support discovery, access, and use of content distributed across multiple systems.

This technical capability analysis was performed in three steps. First, each artifact type was evaluated against technical capabilities needed for discovery, access, governance, interoperability, and use. Second, the research team assigned an appropriate CBTL interaction role—Directory, Gateway, Repository, or a hybrid—based on authoritative ownership, lifecycle-management responsibility, access patterns, data scale and sensitivity, national harmonization needs, and dependency on external systems or standards. Third, the technical capability baseline was refined to match the assigned role so the PoC would include only the services necessary to test the selected scenarios.

This approach was deliberately conservative. Existing authoritative repositories and agency systems remain the source of truth unless there is a clear reason for national stewardship. The CBTL therefore is evaluated as an integration and knowledge layer rather than as a replacement for state or federal operational systems.

Table 1. Research Method Used to Define the CBTL PoC Framework

Analysis Step	Question Addressed	Primary Output
1. Use cases and artifacts	What information and artifacts support real transportation workflows?	Priority use cases and artifact mapping
2. Interaction role	Where should content reside and how should CBTL interact with it?	Directory, Gateway, Repository, or hybrid role
3. Technical alignment	What capabilities are actually needed for the assigned role?	Role-aligned technical baseline for PoC scoping

The research team developed the PoC framework through the proof of concept planning effort, translating earlier CBTL research into a focused structure for evaluating whether a federated CBTL approach can provide practical value across state DOT and FHWA workflows. The PoC framework defines representative use cases, artifact types, interface concepts, technical capabilities, participant groups, evaluation methods, and decision criteria for a future proof of concept; the proof of concept itself has not been executed under this report.

2.2 Priority Use Cases and BIM Artifact Findings

The research team evaluated ten transportation BIM use cases (Step 1 in Table 1) spanning planning, design, construction, and asset management. The use cases were selected from FHWA’s BIM Workflows and Centralized BIM Transportation Library for Bridges and Roadways (FHWA-HIF-24-004) and were used to identify representative BIM artifacts, information exchanges, and cross-discipline discovery needs for PoC evaluation.

Table 2. Priority Use Cases Evaluated for the PoC

Use Case	Priority Workflow
PSD.1	Create project scoping documents for design engineers from planning data.
PSD.3	Create visualizations for alternatives evaluation and public outreach.
DA.9	Provide data for interdisciplinary coordination and clash detection.

Use Case	Priority Workflow
DA.11	Develop final structural analysis model.
DA.12	Produce final plans and model.
DC.2	Create detailed quantity take-off and estimate.
DC.3	Provide design information for automated machine guidance (AMG).
DC.6	Develop and review shop drawings and models.
DC.7	Verify construction results and record as-built data.
DCA.3	Provide routine bridge inspection data for asset management.

Use case identifiers and names follow Table 2-2 of Bhargava et al. (2024): PSD = planning, survey, and design; DA = design and analysis; DC = design and construction; DCA = design, construction, and asset management. These workflows have already been vetted through FHWA technical leadership, DOT interviews, Transportation Research Board (TRB) committees, and peer exchanges, and adopting them ensures alignment with DOT needs, avoids duplicative process development, maintains compatibility with digital delivery initiatives in leading states, and provides a cross-disciplinary, lifecycle-based view of artifact creation and use.

Across these workflows, the research team identified recurring artifact groups that include BIM processes and workflows, information needs, BIM models, object-type libraries, parametric resources, 3D cells, data dictionaries, information delivery manuals, information exchange specifications, Model View Definitions, Information Delivery Specifications, and geospatial data. The mapping also reinforced cross-cutting barriers documented in earlier CBTL research, including inconsistent metadata and object definitions, uneven workforce capacity, proprietary formats, multi-platform environments, security and access constraints, and limited visibility into existing model content.

The artifact categories follow the definitions established in the prior NIBS research (Costin, Ketterl, & Grant, 2025). The BIM model category is subdivided (3a through 3d) because models, object-type libraries, parametric objects, and 3D cells have distinct creation workflows, governance needs, and storage characteristics that warrant differentiated treatment in the CBTL architecture. Table 3 defines each category as applied in the PoC analysis.

Table 3. BIM Artifact Categories Used in the PoC Analysis

Artifact category	Definition
1. BIM processes, workflows, terms, and definitions	Standardized procedures, language, terminology, and semantics for BIM implementation and coordination.
2. BIM information needs	Requirements for the information to be captured at different stages of the asset life cycle.
3a. BIM models	Structured digital representations of components and systems used in BIM software, including existing conditions, discipline, coordination, analysis, as-built, and asset information models.
3b. Object-type libraries (OTL)	Standardized definitions of object classes and their attributes used to produce consistent, reusable model content.
3c. Parametric objects	Reusable, rule-driven components whose geometry and attributes adjust to design parameters.
3d. 3D cells	Predefined three-dimensional components (for example, signs, barriers, inlets) reused across models for consistency and efficiency.
4. Data dictionary	A centralized repository of information about data (metadata) that describes the content, format, and structure of a dataset and the relationships between its elements.
5. Information Delivery Manuals (IDM)	Standardized methodology and guidelines that specify who needs to send what information, when, and in what format to enable reliable, software-interpretable BIM data exchange throughout the facility life cycle.
6. Information exchange specifications	Standards for how data is structured, shared, and validated across platforms, including detail levels, tolerances, and reference datasets.
7. Model View Definitions (MVD)	Specifications defining which data from Industry Foundation Classes (IFC) must be included in a model for a specific use case.
8. Information Delivery Specification (IDS)	A buildingSMART standard for defining information requirements in a computer-interpretable form, which supports automated compliance checking of IFC models.

Artifact category	Definition
9. Geospatial data	Standardized geospatial formats representing infrastructure assets, terrain models, and spatial relationships, enabling GIS and BIM integration for spatial analysis, asset management, and validation of existing structures.

These ten priority workflows form the basis for artifact selection and PoC evaluation. To connect the selected transportation workflows to the proposed PoC evaluation, the research team mapped the information required for each use case to representative BIM artifact categories. This mapping supports the selection of pilot datasets and identifies the types of information that would need to be discoverable, interpretable, or accessible through the CBTL. Table 4 summarizes representative relationships between selected workflows, supporting artifacts, and evaluation considerations.

Table 4. Representative Use Cases, BIM Artifacts, and PoC Evaluation Considerations

FHWA use case	Representative artifacts	Proposed evaluation consideration
PSD.1 — Project scoping	Planning model, structured property sets, geospatial data	Discovery of planning information
PSD.3 — Alternatives visualization	Visualization models, terrain, imagery	Retrieval and contextual interpretation
DA.9 — Coordination and clash detection	Discipline models, coordination model, MVDs	Cross-disciplinary interoperability
DA.11 — Structural analysis	Structural design and analytical models	Artifact identification and metadata
DA.12 — Final plans and model	Final design model, PS&E information	Version and lifecycle identification
DC.2 — Quantity takeoff	Design models, quantity-related attributes	Discoverability of information needed for estimating
DC.3 — Automated machine guidance	Roadway, survey, grading, and alignment models	Access to AMG-related design information
DC.6 — Shop drawings	Fabrication models and detailing information	Discovery and version identification
DC.7 — As-built verification	Existing conditions and as-built models	Lifecycle relationships and traceability
DCA.3 — Bridge inspection	Asset information model, inspection attributes, GIS data	Asset information discovery and contextual interpretation

The mapping demonstrates that the selected workflows depend on different combinations of BIM models, structured attributes, standards-related resources, and geospatial information. Consequently, the PoC should not assume that every use case requires the same technical capabilities or level of integration. Representative pilot datasets and evaluation activities should be selected according to the information needs of each workflow while preserving access to authoritative source systems.

For each workflow, the research team reviewed the information being created, exchanged, or consumed and mapped it to recurring artifact categories, including BIM processes and workflows, information needs, BIM models, object-type and parametric libraries, 3D cells, data dictionaries, information delivery manuals, information exchange specifications, Model View Definitions, Information Delivery Specifications, and geospatial data. The mapping was then used to determine which artifacts should be represented in pilot datasets and which technical capabilities would be necessary to discover, interpret, or connect them.

Appendix A presents the full use case to artifact mapping, including which artifact types each workflow explicitly uses and which it could use, together with a narrative for each use case describing the information created, exchanged, and consumed.

2.2.1 National BIM for Transportation Workflows and Model Types

The BIM for transportation workflows identified in the prior research as being used nationally span the entire project life cycle: planning and scoping (generating early design intent and alternatives); survey and existing conditions (establishing terrain, point clouds, and baseline models); design and analysis (developing roadway, bridge, drainage, and structural models); construction and AMG (producing fabrication-level models and AMG-ready data); and as-builts and asset information models (transitioning models into operations and maintenance).

These workflows demonstrate that DOTs are generating, or planning to generate, high-value BIM artifacts but lack

consistent metadata structures, standardized object libraries, reliable cross-disciplinary discoverability, integration across computer-aided design and drafting (CADD), geographic information system (GIS), asset management, and document control systems, and mechanisms for sharing knowledge, data, and standards between DOTs. A federated CBTL addresses these gaps by providing a harmonized environment for indexing, linking, and discovering model-based artifacts.

Transportation digital delivery produces a recurring set of model types across the life cycle. The categories below summarize the most common types used across DOT programs, with typical contents and the consistency issues that affect reuse, integration, and long-term operations:

- Existing conditions models: digital terrain models, point clouds, and survey deliverables.
- Design discipline models: roadway, structural, drainage, geotechnical, materials, pavement, traffic, and utilities; often inconsistent in naming, metadata, and object definitions.
- Visualization models: level of development (LOD) 200 to 300 conceptual and alternatives models used for public outreach.
- Structural analysis models: LOD 300 engineering models used to validate structural performance.
- Construction and AMG models: AMG-ready subgrade, earthwork, alignment, and reinforcing steel models; critical in FHWA e-Construction and AMG programs.
- As-built and asset information models: GIS-linked, maintenance-ready deliverables used for digital twins, robotics, and automated tools, including e-Ticketing and materials data and certification tracking (materials, Buy America) for contract closeout. This is the most inconsistent artifact category across DOTs.

2.2.2 National Trends and Barriers Informing PoC Scope

The trends and barriers that bound the PoC are not newly derived. They synthesize the conclusions of the prior CBTL research, which drew on technology scans, repository assessments, state DOT feasibility studies, state-of-practice reviews, and findings from multiple Transportation Pooled Fund (TPF) initiatives, and they were subsequently validated through structured interviews with DOTs and industry partners, surveys, peer exchanges, workshops, and participation in national and state digital delivery forums. Those activities did not alter the core conclusions but expanded contextual understanding and provided practical insight into implementation considerations.

The evaluation followed a five-step sequence:

1. review and synthesis of prior findings to identify recurring issues, unresolved gaps, and areas of convergence;
2. cross-referencing with related research and ongoing CBTL activities, including stakeholder engagements and workshops;
3. trend identification and validation by comparing historical findings with current observations to distinguish persistent structural barriers from emerging risks and areas of increased readiness;
4. barrier categorization and impact assessment by thematic grouping (technical, organizational, policy, data governance, and workforce); and
5. aggregation into a PoC-specific framework that informs scope definition, sequencing, and risk mitigation.

Where DOT library structures could not be accessed directly because of security or access limitations, validated patterns from the prior research were used to inform reasoned assumptions, and structured stakeholder interviews are recommended during pilot preparation where critical gaps remain. Table 5 summarizes each trend and barrier and the implication it carries for PoC scope.

Table 5. National Trends and Barriers and Their Implications for the PoC

Trend or barrier	Observation	Implication for PoC scope
Trend: shift from 2D to model-based deliverables	DOTs are moving toward 3D and AMG-ready design deliverables. Several agencies are formalizing guidelines for model-based contracting while others are conducting pilot deployments. The transition is uneven across states but clearly directional.	Selected use cases should span the design-to-construction handoffs where model-based deliverables are already produced.
Trend: integration of BIM with GIS and asset systems	Digital as-built workflows now emphasize linkage between design and construction models and downstream asset management systems, introducing new metadata specifications and reinforcing the need for schema alignment across the asset life cycle.	The PoC should test lifecycle traceability (design to as-built to asset information model) and metadata consistency across systems.

Trend or barrier	Observation	Implication for PoC scope
Trend: adoption of open standards	Agencies are aligning with IFC 4.3, IDM, IDS, and ISO 19650-aligned information management, driven in part by TPF-5(372) and TPF-5(523). Convergence indicates a maturing ecosystem but also disparities between early adopters and agencies in exploratory phases.	Standards connectors and limited IFC interpretation belong in the baseline PoC; participants should span digital delivery maturity levels.
Trend: persistent multi-platform, multi-vendor ecosystems	DOTs commonly operate heterogeneous environments comprising Bentley, Autodesk, Esri, Trimble, and custom or legacy systems. No single platform is universally adopted, so interoperability challenges persist.	Reinforces federated discovery and metadata harmonization rather than consolidation into a single proprietary environment.
Barrier: fragmented metadata and inconsistent object definitions	Inconsistent metadata, naming conventions, and object-type definitions affect artifact discoverability, model reusability, and reliable cross-disciplinary queries. This barrier is repeatedly identified in FHWA documentation, TPF studies, and DOT interviews.	Metadata harmonization and data-dictionary services are core PoC capabilities, and metadata completeness is a primary evaluation measure.
Barrier: workforce capacity constraints	A substantial portion of DOT technical staff is nearing retirement, creating gaps in institutional memory, digital literacy, and technical stewardship. FHWA's Digital As-Builts initiative and TPF-5(480) confirm staffing limits as a structural constraint, especially where metadata expertise is needed.	Usability, training burden, and onboarding should be evaluated with participants of varying BIM experience.
Barrier: vendor lock-in and proprietary formats	Many agencies remain dependent on proprietary design formats, limiting their ability to export models to open schemas or integrate with external repositories.	Supports a federated, API-based architecture over centralized storage of operational models.
Barrier: security restrictions and access limitations	Stringent cybersecurity and data governance processes limit what information can be shared externally or across divisions, which constrains the metadata, model content, and library structures available for evaluation.	Dataset packages should allow metadata-only records and session-based gateway access; access-control signaling is a defined test area.
Barrier: limited visibility into existing model content	Many agencies lack a consolidated inventory of BIM content. Files are distributed across CADD servers, SharePoint sites, GIS databases, and project environments, so mapping existing artifacts involves inference, triangulation, or targeted interviews.	Locating an artifact without prior knowledge of its source is the first user task, and an artifact inventory is a dataset package requirement.

Understanding these established trends and barriers is essential for evaluating the feasibility, sequencing, and prioritization of PoC use cases and for identifying which artifacts and workflows are most appropriate for early testing. The same conditions reappear as adoption challenges in Section 5.3 and as entries in the dependency and risk registers in Section 5.6.

2.3 Hybrid CBTL Implementation Model

The research team's analysis found that a single CBTL user experience does not require all content to be stored in one national repository. Using consistent criteria for authoritative ownership, lifecycle responsibility, access patterns, data scale and sensitivity, national harmonization needs, and integration requirements, the team identified a hybrid Directory–Gateway–Repository model that preserves authoritative source systems while providing a common entry point for discovery, controlled integration, and nationally governed content where appropriate.

The research team reached this conclusion by evaluating each artifact against consistent role-assignment criteria. Directory treatment is appropriate when an authoritative external source should remain responsible for the content and the primary need is discovery and context. Gateway treatment is appropriate when users or applications need controlled, programmatic access to a distributed source. Repository treatment is appropriate when a nationally governed resource requires controlled publication, versioning, review, maintenance, and retirement. A hybrid treatment is used when more than one of these conditions applies.

Table 6. Hybrid CBTL Implementation Model

CBTL Role	Primary Function	Implication for PoC Design
Directory	Discovery and navigation	Index and contextualize externally hosted authoritative resources without duplicating them.

CBTL Role	Primary Function	Implication for PoC Design
Gateway	Controlled integration and access	Provide standardized, API-mediated access to distributed systems when system-to-system interaction is useful.
Repository	National stewardship and lifecycle management	Host and govern selected reusable resources where centralized versioning, review, publication, and maintenance add value.

Each artifact category was evaluated independently against six parameters reflecting how BIM artifacts are created, governed, accessed, and sustained within the transportation ecosystem:

- Authoritative ownership and governance: whether an authoritative source already exists and whether that authority is expected to remain external to the CBTL.
- Lifecycle management responsibility: whether the artifact requires controlled authoring, revision management, approval workflows, and long-term stewardship.
- Access pattern and consumption mode: whether the artifact is primarily accessed through human-oriented discovery, programmatic system-to-system integration, or tool-embedded automated workflows.
- Data scale and operational sensitivity: whether the artifact represents large, frequently updated, or operational datasets for which duplicative storage would introduce risk or inefficiency.
- Need for national harmonization or standardization: whether nationally consistent definitions, schemas, or profiles are needed to support interoperability across agencies and projects.
- Dependency on external systems or standards: whether the artifact depends on external standards, classification systems, or agency platforms that require integration or synchronization.

The role-assignment criteria were formalized as a repeatable, condition-based logic (Step 2 in Table 1) so that decisions are consistent across artifact types and can be reapplied as new content categories are considered. Table 7 summarizes the conditions and the resulting treatment. The conditions represent recurring patterns observed during evaluation, including where authoritative control resides, how artifacts are accessed, and whether national governance or integration is needed.

Table 7. Condition-Based Logic for CBTL Implementation Role Assignment

Condition	Directory	Gateway	Repository	Rationale
Artifact is discoverable content hosted and governed by an external authoritative source, and the CBTL is not expected to manage or transform the data	Always	Not used	Not used	The CBTL acts as a curated national entry point with categorized indexing, metadata navigation, and usage guidance, minimizing duplication of authoritative content.
Artifact is hosted externally but the CBTL should support real-time access, system-to-system integration, or tool embedding	Always	Always	Not used	The CBTL operates as an API-based integration layer enabling real-time access, dynamic querying, and normalized interfaces while content remains in external systems.
Artifact calls for national-level stewardship, authoritative versioning, and lifecycle governance, with no sufficient external host	Always	Optional (external sync or API exposure)	Always	The Repository approach supports central storage, version control, contributor workflows, and quality review for nationally standardized BIM artifacts.
Artifact exists in external systems but also employs a centrally governed, harmonized national version (for example, data dictionary profiles, standard IDMs, MVDs, or IDS)	Always	Always	Always	The CBTL combines discovery (Directory), federated API access (Gateway), and centralized governance (Repository) to maintain authoritative harmonized content.
Artifact consists of large BIM models or operational and transactional data already managed in common data environments (CDEs) or asset management systems, and the CBTL role is mediation and coordination	Always	Always	Not used	The CBTL authenticates users, validates requests, routes API calls, and publishes events without storing heavy model files or operational records.

Condition	Directory	Gateway	Repository	Rationale
Artifact is agency- or project-specific guidance, reference documents, or PDFs not intended as national standards	Always	Not used	Optional (if the CBTL chooses to curate guidance)	The CBTL may index and link to external guidance and optionally host curated guidance documents, without API integration or strict governance.
Artifact should be collaboratively authored, edited, reviewed, approved, and published under CBTL governance (for example, OTL, IDS templates, parametric libraries)	Always	Optional (downstream API consumption)	Always	The Repository layer is necessary to support contributor roles, approval workflows, version control, and authoritative publication.
Artifact is referenced only for semantic alignment, classification, or validation (for example, external code lists or taxonomies) with no need for the CBTL to store it	Always	Used if alignment is API-based	Not used	The CBTL provides discovery and semantic or API-based alignment without cloning or governing the external standard.
Artifact is expected to evolve over time from discovery-only to integrated and ultimately governed (progressive maturity model)	Always	Added as capabilities mature	Added selectively for priority artifacts	The CBTL follows a progressive structure: start as a Directory, add Gateway capabilities, and evolve into Repository stewardship where national standardization is used.

The hybrid model was further evaluated at the artifact level to determine when the CBTL should provide discovery, controlled integration, centralized stewardship, or a combination of these functions. Table 8 summarizes representative implementation assignments derived from the PoC planning analysis.

Table 8. Recommended CBTL Implementation Roles by BIM Artifact Type

BIM artifact	Directory	Gateway	Repository
BIM processes and workflows	✓	—	✓
BIM information needs	✓	—	✓
BIM models	✓	✓	—
Object-type libraries	✓	Conditional	✓
Parametric libraries	✓	Conditional	✓
3D cells	✓	Conditional	✓
Data dictionaries	✓	✓	✓
Information Delivery Manuals	✓	✓	✓
Information Exchange Specifications	✓	✓	✓
Model View Definitions	✓	✓	✓
Information Delivery Specifications	✓	✓	✓
Geospatial data	✓	✓	—

These assignments reinforce the distinction between a unified user experience and centralized data storage. Large operational BIM models and geospatial datasets would generally remain in authoritative agency or external systems, with the CBTL supporting discovery and controlled access. Repository functions would be more appropriate for selected reusable artifacts that warrant national stewardship, controlled publication, and version management. The implementation role for each artifact should be confirmed during subsequent technical definition and pilot planning.

Assignments were made conservatively, favoring retention of artifacts in existing authoritative systems unless there was a demonstrated need for CBTL governance, harmonization, or integration support. Table 9 records the reasoning behind each assignment so that the treatment can be revisited if ownership, source-system capability, or stewardship

responsibilities change.

Table 9. Rationale for CBTL Implementation Role Assignments by BIM Artifact

BIM artifact	Role assignment rationale
1. Processes and workflows	Many workflows exist externally as human-readable documentation (Directory). The CBTL curates national workflow guidance (Repository). Gateway is not used because the content is consumed through the interface, not programmatically.
2. Information needs	Often stored externally as PDF or spreadsheet documents (Directory). The CBTL curates standardized, schema-based information needs (Repository). Gateway is not used because access is primarily interface-based.
3a. BIM models	Models remain in CDEs and asset management systems. The CBTL indexes them (Directory) and integrates through APIs (Gateway). Models are not stored centrally.
3b. Object-type libraries	The CBTL governs a national OTL (Repository) with federated discovery (Directory). Gateway is conditional, used only if authoring tools need programmatic access to OTL definitions.
3c. Parametric library	Centrally hosted and curated (Repository) with federated discovery (Directory). Gateway is conditional, used only if design tools consume parametric objects through an API.
3d. 3D cells	Curated reusable components (Repository) with federated discovery (Directory). Gateway is conditional, used only if modeling tools access 3D cells programmatically.
4. Data dictionary	A complex hybrid: bSDD is authoritative (Directory), accessed through Gateway APIs, while the CBTL harmonizes national dictionaries (Repository).
5. Information Delivery Manuals	Authoritative IDMs exist externally (Directory) and are accessed through Gateway APIs for system integration; the CBTL curates controlled national versions (Repository).
6. Information exchange specifications	Similar to IDM: external discovery (Directory), Gateway API access, and curated national versions stored by the CBTL (Repository).
7. Model View Definitions	MVDs exist externally (Directory), are accessed through Gateway APIs for tool integration, and are curated nationally by the CBTL (Repository).
8. Information Delivery Specifications	Same pattern as MVD: external standards reference (Directory), Gateway API access for tools, and national versions stored by the CBTL (Repository).
9. Geospatial data	National Transportation Atlas Database (NTAD), National Bridge Inventory (NBI), and GIS data live externally (Directory) and are accessed through Gateway APIs. The CBTL does not store geospatial inventories.

The research team proposes this hybrid implementation framework based on the artifact-level analysis and earlier CBTL research. It distinguishes Directory, Gateway, Repository, and hybrid interaction modes according to artifact ownership, lifecycle management, access patterns, data scale, governance needs, and integration requirements.

2.3.1 Technical Capability Baseline for PoC Evaluation

The research team used the artifact and role analysis to define a minimum technical layer for a future PoC. The baseline includes a cloud-hosted user interface; metadata and structured-data services; identity, authentication, and role-aware access; secure API mediation; limited repository and version-control functions for nationally governed content; semantic search and data-dictionary services; selected standards connectors; and basic monitoring and auditability.

The minimum technical layer should reflect the capabilities necessary to evaluate the selected use cases and CBTL interaction roles rather than the complete set of functions that might be appropriate for a future production environment.

The minimum technical layer was derived by filtering the full artifact-by-artifact capability analysis (Step 3 in Table 1; Appendix B) to the components needed to support cross-artifact discovery and navigation, enable federated access and system-to-system integration where used, demonstrate limited centralized governance for nationally curated content, and evaluate user interaction with a unified interface. Capabilities identified as optional, future-phase, or intentionally avoided for certain artifact types are excluded from the baseline to maintain realistic implementation boundaries. Table 10 lists each capability, its PoC treatment, and the rationale.

Table 10. Minimum Technical Layer for the CBTL Proof of Concept

Capability group	Technical capability	PoC	Rationale
Cloud and platform foundation	Cloud-based platform (hosting, scaling, availability)	Core	Hosts the unified interface, APIs, metadata services, and integration logic.
	Database infrastructure (metadata and structured data)	Core	Stores artifact metadata, relationships, user context, and curated repository content.
Identity, access, and security	OAuth / OpenID / SSO	Core	Demonstrates a single entry point and role-aware access across connected systems.
	ABAC / RBAC	Core	Reflects differing user roles (planner, designer, asset manager, administrator).
	Encryption and key management	Core	Baseline expectation for any federal-facing system.
	Audit logging and monitoring	Optional	Included at a basic level to demonstrate traceability, not full compliance tooling.
API gateway and integration	API gateway and management	Core	Demonstrates the Gateway role and system-to-system interaction.
	Middleware validation and governance	Core	Validates schemas and requests and enforces interaction rules.
	Event / message broker	Optional	Not used for baseline gateway mediation. Included only if a selected PoC scenario explicitly needs asynchronous notification, coordination, or deferred processing.
Artifact repository and governance	Artifact storage (files and metadata)	Core	Supports repository-mode artifacts (OTL, data dictionaries, IDMs, MVDs, IDS).
	Version control (identifiers, history)	Core	Demonstrates authoritative stewardship and lifecycle management.
	Data pipelines and orchestration	Optional	Included only if demonstrating synchronization or staged publishing.
	Automated QA / QC	Optional	May be demonstrated through basic rule checks rather than full automation.
Semantics and knowledge services	Data dictionary / ontology service	Core	Supports semantic alignment across artifacts and consistent interpretation.
	Advanced semantic search	Core	Demonstrates the value of unified discovery across heterogeneous artifacts.
	Graph / semantic linking	Optional	Included if demonstrating cross-artifact relationships in the interface.
External integrations	Standards connectors (for example, bSDD, national libraries)	Core	Demonstrates Directory and Gateway connectivity without duplicating content.
	Agency system connectors (common data environments [CDEs], asset management systems [AMS])	Optional	Included selectively for one representative integration scenario.
Geospatial and asset referencing	Geospatial data connectors	Optional	Included only if one PoC scenario involves spatially anchored artifacts.
	Linear referencing and spatial linking	Optional	Included only if directly supporting the selected PoC use cases.
User interface and engagement	Web interface and role-based dashboards	Core	Core PoC deliverable; demonstrates the unified entry point and interaction model.
	NLP / AI-assisted search	Optional	Enhancement that demonstrates advanced discovery but is not needed for the baseline PoC.
	Training, help, and feedback	Core	Demonstrates usability, onboarding, and adoption support.

The distinction between baseline and conditional capabilities is important for controlling PoC scope. Features such as continuous synchronization, large-scale operational hosting, advanced geospatial integration, and production-level compliance implementation are not prerequisites for demonstrating the core CBTL concept. Their inclusion should depend on documented use-case requirements, feasibility, and the objectives established for the selected pilot environment.

Not every capability is required for every artifact. For example, large operational BIM models and geospatial inventories can remain in their authoritative systems while the CBTL indexes metadata and, where justified, provides controlled gateway access. Repository functions are better suited to reusable resources that benefit from national stewardship, such as selected object libraries, data dictionaries, information delivery resources, or nationally governed templates.

Capabilities such as event-driven synchronization, large-scale operational hosting, advanced geospatial services, or broad production compliance are treated as conditional. They would be included only when a selected pilot scenario demonstrates a need. This keeps the PoC focused on validating the concept rather than prematurely building a production environment.

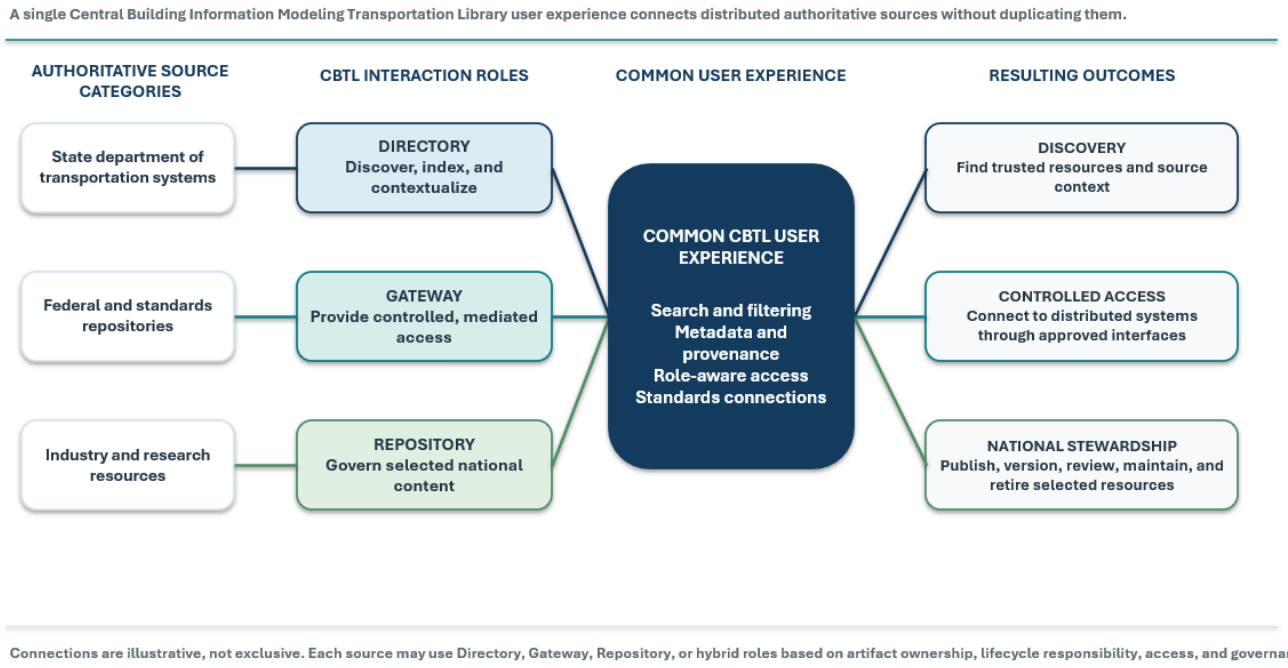


Figure 1. Hybrid Directory–Gateway–Repository Interaction Model.

2.4 Proof of Concept Objectives and Functional Boundaries

The PoC framework is organized around three fundamental validation questions:

Technical Feasibility: Whether a federated CBTL interface can discover, integrate, and govern BIM artifacts across independently maintained repositories without disrupting authoritative source systems.

Functional Utility: Whether the CBTL provides practical value to state DOTs, FHWA, contractors, and industry participants through improved discovery, workflow continuity, and reduced fragmentation.

Operational Readiness: Whether the CBTL concept can operate within representative security, access-control, cloud-hosting, performance, scalability, and resilience conditions.

To address these questions, the PoC provides a structured mechanism to test whether a federated CBTL interface can:

- Discover BIM artifacts across multiple, independently maintained repositories.
- Harmonize metadata across varied schema implementations while preserving source-system integrity.
- Support complex, multidisciplinary search and filtering aligned with real-world design and construction workflows.
- Enable alignment with open standards, including IFC, ISO 19650, bSDD, and other ecosystems central to national interoperability.
- Demonstrate limited model interpretation capabilities, including recognizing, classifying, and validating models

across the formats and schemas commonly used in transportation design and construction, with particular attention to IFC validation workflows.

The PoC is intentionally bounded so it can demonstrate core discovery, metadata harmonization, API-mediated access, search and filtering, governance signaling, and selected standards integration without attempting to operate as a production-scale national platform. Full operational data hosting, replacement of State systems, production-scale compliance implementation, and broad lifecycle governance remain outside the baseline PoC unless a selected scenario provides a clear reason to include them.

Three specifics bound that scope further. The PoC should integrate with at least one external standards source (for example, bSDD or the National Transportation Library), with one representative agency system integration scenario as an optional extension. Repository functions should be scoped to one or two artifact types (for example, an object-type library and a data dictionary) so that governance workflows can be validated without attempting full lifecycle governance for all content. Gateway mediation can be evaluated primarily through synchronous request-response interactions; event-driven or asynchronous patterns are optional extensions included only where a selected scenario requires update notification or deferred processing.

The PoC does not need to be executed for all ten priority use cases at once. Use cases can be selected, tested, and evaluated individually or in groups, in sequence or in parallel, and the framework applies equally to a single use case or to the full set. Section 3.3 describes how this incremental approach is carried into the deployment phases, and Section 6.1 describes how deployment decisions apply to the evaluated scope.

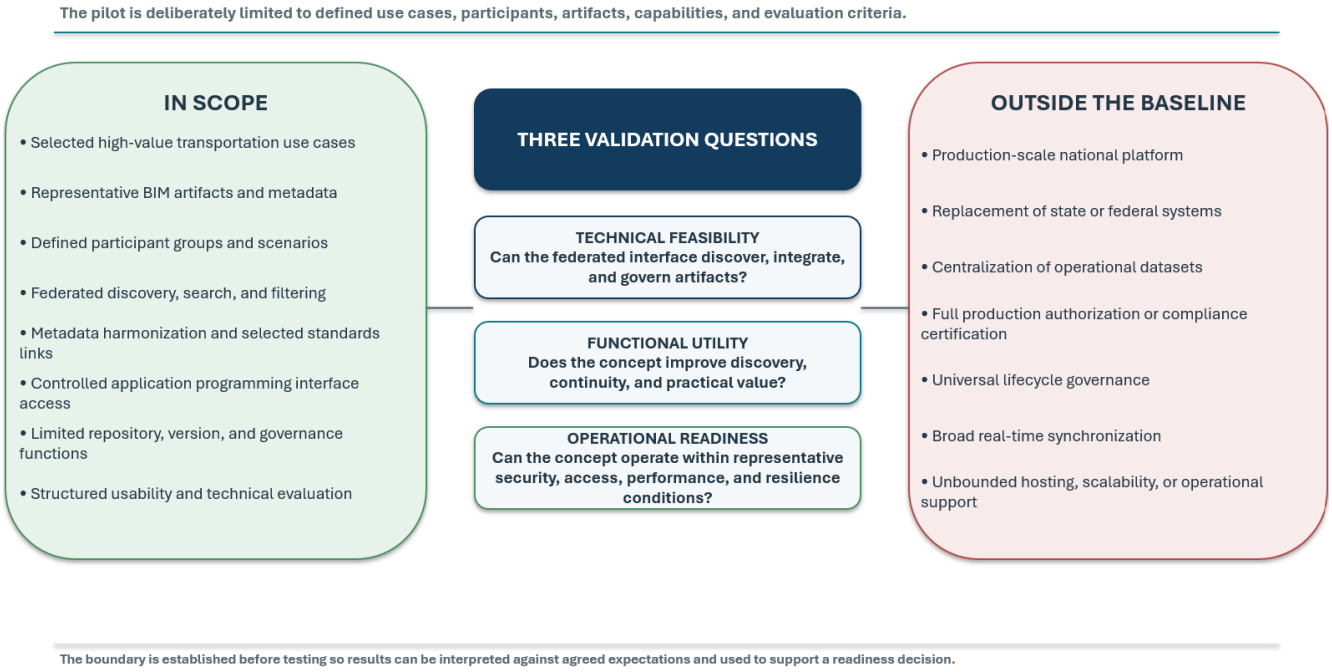


Figure 2. Boundaries of the CBTL Proof of Concept.

The combined findings of the artifact, role, and capability analyses determine what the PoC interface should expose, which backend services it should interact with, and what it intentionally excludes. Table 11 summarizes these architecture implications. Defining both functional responsibilities and intentional exclusions keeps the PoC focused on demonstrating feasibility without overextending technical, organizational, or budgetary constraints.

Table 11. Architecture Implications for the PoC Interface and Services

Architecture dimension	PoC treatment
Functions the user interface exposes	Discovery functions (categorized browsing, metadata-driven navigation, cross-artifact linking); search capabilities (keyword search, semantic search, and advanced filtering by artifact type, discipline, lifecycle phase, and metadata attributes); artifact navigation (role-aware access to artifact details, version history, usage guidance, and external source links); and role-aware dashboards and permissions reflecting Directory, Gateway, or Repository interaction modes.

Architecture dimension	PoC treatment
Backend services the interface interacts with	Authentication services (OAuth/SSO for federated identity management); API gateways providing secure, validated access to external repositories and standards sources; semantic services for data dictionary and ontology alignment and cross-artifact relationship mapping; programmatic integration with external repositories such as bSDD, state DOT systems, and national libraries; and metadata databases for structured storage and querying of artifact metadata, relationships, and governance state.
Intentionally excluded from the baseline PoC	Direct storage or management of operational datasets governed by external systems (heavy BIM models, geospatial inventories); production-grade version control for artifacts managed in authoritative external repositories; full data pipeline orchestration for continuous synchronization (the baseline relies on periodic metadata refresh); and event-driven notification unless explicitly required by a selected use case.

2.5 Evaluation Framework and Participants

The PoC evaluation framework uses representative datasets and structured user interactions to generate comparable evidence across agencies, disciplines, and workflows. The framework pairs selected use cases with representative artifacts and metadata, then uses scenario-based activities to observe how participants discover, filter, interpret, and connect information across lifecycle stages.

Evaluation considerations include:

- Usability and clarity of retrieved content and interface terminology.
- Interoperability across software platforms and standards.
- Time to locate, understand, and assess BIM artifacts, including opportunities to reduce rework and repeated effort.
- Completeness and accuracy of metadata and source information.
- Workflow continuity across planning, design, construction, and asset management.
- Alignment with open standards and nationally relevant data-dictionary approaches.
- Governance, stewardship, security, training, and organizational-readiness considerations identified through user interaction.

To support consistent evaluation across participating agencies and disciplines, the proposed PoC would use structured, scenario-based tasks reflecting actual transportation information needs. Table 12 identifies representative user interactions and the corresponding evidence that could be collected to evaluate discoverability, usability, metadata quality, and workflow continuity.

Table 12. Representative CBTL PoC User Evaluation Tasks

User task	Evaluation focus	Evidence collected
Locate an artifact without knowing its source	Discoverability	Task completion and discovery time
Filter models by discipline and phase	Search usability	Search outcomes and user observations
Confirm artifact source and version	Metadata clarity	Correct identification and missing attributes
Trace design information to as-built records	Workflow continuity	Successful linkages and gaps
Identify restricted content	Access communication	Permission clarity and user understanding
Evaluate artifact suitability for downstream use	Functional utility	Participant feedback and documented limitations

Structured observations would allow the research team to distinguish limitations of the CBTL interface from limitations of the underlying agency data. Results should be documented by use case, artifact type, participant group, and evaluation criterion so that findings can be compared across pilot activities and incorporated into subsequent deployment planning.

Primary pilot participants include design engineers, construction engineering and inspection (CEI) personnel, survey and geospatial teams, and asset-management personnel. Supporting participants may include DOT information technology and security staff, State BIM program managers, FHWA technical specialists, standards organizations, consultants, and industry partners. The project team would facilitate structured sessions, document findings, and synthesize the results for deployment decisions.

The pilot should combine agencies and participants with different levels of digital-delivery maturity. More mature

programs can test integration, interoperability, and governance scenarios, while agencies earlier in adoption can provide important evidence on usability, training burden, organizational readiness, and the clarity of the proposed national resources. A pilot lead agency or small lead group can provide representative datasets and host structured sessions, with supporting agencies providing comparative feedback and FHWA providing technical oversight.

2.5.1 Technical Evaluation Focus

The technical evaluations determine how effectively a CBTL prototype would operate within the heterogeneous digital ecosystems maintained by state DOTs. They assess the performance of metadata translation and alignment mechanisms that reconcile differing naming conventions, attribute structures, and levels of detail across agencies, and they examine the feasibility of API-mediated access to externally hosted artifacts such as object libraries and models, confirming that the CBTL can retrieve, index, and contextualize content from systems that vary in architecture, vendor constraints, and data accessibility.

In parallel, the evaluation examines the federated search and navigation interface, focusing on whether users can efficiently locate artifacts across multiple libraries and portals using discipline-specific, object-specific, or metadata-driven queries, and it examines governance and access-control signaling to confirm that agency security policies, user permissions, and stewardship responsibilities are respected and clearly communicated without undermining interoperability. Finally, the PoC tests limited aspects of model interpretation and validation, including the ability to recognize, classify, and contextualize models across common formats and schemas, with particular attention to IFC given its central role in national and international interoperability standards.

2.5.2 Orientation and User Interaction Protocol

User interaction is a central component of the PoC because it provides direct evidence of how effectively the CBTL supports real workflows. The interactions are structured user testing activities rather than open demonstrations. To establish a consistent baseline and avoid bias related to uneven exposure to BIM workflows, participants should, before completing task-based interactions, receive a brief orientation on the purpose of the PoC and the use cases being evaluated; review sample artifacts, metadata fields, and workflow diagrams relevant to their discipline; and complete a short self-assessment of familiarity with BIM artifacts to contextualize findings.

Table 13 defines the five task groups that make up the protocol, the representative prompts and filters for each, the procedure facilitators follow, and the evidence collected. The task groups expand the summary tasks in Table 12 into repeatable procedures that produce comparable findings across agencies, disciplines, and participant groups.

Table 13. CBTL PoC User Interaction Protocol

Task group	Representative prompts and filters	Procedure	Evidence collected
1. Discoverability and navigation	Locate the model, drawing, or data type needed without prior knowledge of its origin; perform a cross-disciplinary query (for example, design to construction); judge whether naming, metadata, and categorization are intuitive.	Provide each participant with scenario-based prompts (for example, locate a structural model used in hydraulic analysis; check the vertical alignment used in preliminary design; locate the structural analysis model for a bridge span and confirm version date and design stage). Use think-aloud protocols to capture decision pathways and pain points.	Time to discovery, completeness of search results, navigation errors, and terminology confusion.
2. Filter and refine search results	Filter by model type (existing conditions, project information model [PIM], asset information model [AIM], AMG model, analysis model), discipline (roadway, structures, drainage, traffic, geotechnical), metadata tags (LOD, version, schema type, source system), and project phase.	Participants attempt both simple and nested filters. Observers record where users encounter friction, ambiguity, or overly complex terminology. Group debriefs compare filtering approaches across disciplines.	Filter outcomes, friction points, and discipline-specific observations.
3. Artifact quality and readiness assessment	Determine whether retrieved artifacts contain sufficient metadata to understand purpose, source, and limitations; align with expectations for the participant's lifecycle stage; and support intended downstream processes.	Provide a short rubric (clarity, completeness, relevance, cross-discipline usability). Encourage cross-team assessments (for example, design reviewing construction artifacts). The focus is interpretation and classification, not file integrity.	Rubric scores and documented discrepancies between expectations and actual content.

Task group	Representative prompts and filters	Procedure	Evidence collected
4. Workflow continuity	Can a roadway designer find the as-built associated with a design model? Do drainage artifacts connect coherently with geotechnical models? Is the asset information model discoverable without accessing internal DOT systems?	Provide predetermined workflow chains (survey to design to construction to AIM). Pair participants across disciplines to discuss upstream and downstream dependencies.	Points where continuity breaks down because of metadata gaps, multiple versions, missing documentation, or terminology differences.
5. Feedback and reflection	After-action surveys, facilitated focus groups by discipline, open-text reflections, and workflow mapping sessions.	Ask participants to distinguish library limitations from source data limitations and to identify training needs, governance requirements, and barriers to broader adoption.	Structured feedback by discipline and participant group; identified training and governance needs.

Three non-technical dimensions are evaluated alongside the task groups. Usability and accessibility addresses interface clarity, learning curve, terminology alignment with DOT practice, and accessibility considerations under the Web Content Accessibility Guidelines (WCAG) and Section 508 of the Rehabilitation Act. Organizational relevance addresses whether the CBTL reduces redundant searches, improves coordination across divisions, and functions as a reliable single source of discovery. Policy, governance, and stewardship readiness identifies where governance structures need reinforcement, where workflows need clearer documentation, and where knowledge-management integration offers opportunities.

Together, these interactions yield evidence on the usability of the interface in realistic workflows, metadata gaps that impede cross-disciplinary use, organizational readiness for adoption, training and change-management needs, and the clarity and completeness of artifacts relative to intended use. The findings inform the finalization of pilot participants, refinement of metadata schemas, prioritization of early use cases, and the structuring of the governance frameworks described in Chapter 5.

2.5.3 PoC Framework Sequence

The PoC framework follows an applied research structure commonly used in FHWA and TPF pilot programs. The sequence is designed to use representative artifacts aligned to the priority use cases, drive consistent user interactions within the PoC environment, apply agreed evaluation criteria, and produce synthesized findings that inform deployment planning:

- Select high-value use cases for pilot validation.
- Identify a representative dataset package for each use case (minimum package requirements are defined in Chapter 4).
- Identify user interactions within the PoC environment using the protocol in Table 13.
- Establish evaluation criteria aligned with FHWA and NCHRP guidance on pilot assessment.
- Conduct structured observation and feedback collection through facilitated walkthroughs, task-based testing sessions, user surveys, and multidisciplinary focus groups.
- Synthesize findings to inform deployment planning, producing a catalog of gaps and opportunities, insights on readiness levels, recommendations for scaling, and requirements for governance, training, and knowledge management.

2.5.4 Participant Groups

The pilot should involve users who represent the scale and range of DOT workflows and technical competencies, reflecting the life cycle represented in the FHWA BIM workflows. Table 14 identifies the participant groups by tier and the role each plays in the evaluation.

Table 14. PoC Participant Groups and Roles

Participant group	Tier	Role in the PoC
Design engineers (roadway, structures, drainage, traffic)	Primary	Evaluate early- and mid-design artifacts, metadata clarity, and cross-disciplinary retrieval.
Construction and CEI personnel	Primary	Validate AMG models, as-built linkages, and field-ready construction information.
Survey and geospatial teams	Primary	Assess integration of existing conditions models, point clouds, terrain data, and GIS linkages.

Participant group	Tier	Role in the PoC
Asset management personnel	Primary	Evaluate asset information model readiness, long-term maintainability, and metadata interoperability.
DOT IT and security staff	Secondary	Provide guidance on access control, identity management, and hosting constraints.
State BIM program managers	Secondary	Evaluate alignment with existing BIM programs, standards, and digital delivery initiatives.
FHWA technical specialists	Secondary	Support alignment with federal guidance, national harmonization goals, and open standards.
Consultants and industry partners	Optional	Provide insight on multi-state practices and cross-vendor workflows.

2.5.5 Stakeholder Structure and Engagement Cadence

The pilot requires a structured governance arrangement to ensure clarity in responsibilities, communication, and decision-making. Table 15 defines the proposed roles. The lead and supporting agencies should together represent different levels of digital delivery maturity so that integration and governance scenarios and usability and readiness evidence are both captured.

Table 15. Proposed PoC Stakeholder Structure

Role	Participants	Responsibilities
Pilot lead agency	One to two state DOTs	Coordinates test cases, provides datasets, and hosts structured sessions.
Supporting agencies	Two to four state DOTs	Participate in testing and provide comparative feedback across maturity levels.
FHWA oversight	FHWA technical specialists	Ensures alignment with national programs and provides technical review.
Research and facilitation team	Project team	Facilitates sessions, documents findings, and conducts analysis and synthesis.

The engagement cadence proposed for the pilot consists of a kickoff meeting, biweekly pilot sessions, a monthly technical and organizational review, and a final synthesis workshop. This cadence is a planning assumption for resource estimation; the specific agencies, teams, and stakeholders who participate should be confirmed in collaboration with FHWA and state partners following review of the PoC framework. Beyond the agency and FHWA participants in Tables 14 and 15, participation in the PoC and subsequent deployment activities should also include DOT information technology, security, and enterprise architecture staff; software and platform vendors supporting BIM, GIS, and asset management systems; standards development organizations; and knowledge management, training, and change-management leads, so that pilot participation reflects real operational needs, varying levels of digital delivery maturity, and a representative cross-section of the national transportation community.

2.5.6 Expected Outcomes of the PoC

The user and stakeholder structure is designed to produce quantifiable and qualitative evidence that confirms:

- Which CBTL functions are viable for national deployment.
- What metadata structures and workflows are interoperable across DOTs.
- What governance is needed for long-term administration.
- Where gaps persist (for example, training, tools, standards, digital literacy).
- How the CBTL can reduce duplication, improve discoverability, and enable lifecycle continuity.

The results of the pilot, documented after completion, would directly inform the scope and structure of deployment and implementation planning described in Chapters 3 through 6.

2.6 Implications for Deployment Planning

The PoC analysis indicates that future deployment planning should be informed by evidence generated through a bounded pilot rather than by a presumption of immediate national implementation. Principal inputs to subsequent deployment decisions include validated use cases and artifacts, observed user and workflow outcomes, technical findings, governance and stewardship considerations, security and access observations, training and change-management needs, and estimated operating resources. The deployment planning framework uses these inputs to define a phased pathway for pilot execution, governance development, organizational enablement, broader

participation, and potential national scaling.

The resulting PoC framework provides the analytical bridge to deployment planning: future pilot evidence can be used to refine use cases, content priorities, governance, security, training, organizational readiness, and the level of technical capability appropriate for subsequent phases.

3. Deployment Planning Framework

3.1 Strategic Context

The PoC planning work established a framework for evaluating the technical feasibility, functional utility, and operational readiness of the Central BIM Transportation Library (CBTL). The PoC framework defined the proposed PoC objectives, functional boundaries, technical capabilities, participant structure, testing methods, and evaluation criteria. It did not represent execution or validation of the PoC.

Building on that foundation, this deployment planning framework presents a recommended approach for translating future PoC findings into decisions regarding phased implementation and potential national scaling. It identifies the sequencing, governance structures, operational capabilities, organizational conditions, content-stewardship responsibilities, and support mechanisms that would be needed to guide deployment at the national and state levels.

The deployment planning framework is informed by the PoC analysis, stakeholder input, prior CBTL research, and practical implementation considerations developed throughout the project. Because the PoC has not yet been executed, the recommendations in this chapter should be treated as a planning framework rather than confirmation that the CBTL is ready for implementation.

The framework addresses national stewardship, state participation, phased adoption, content governance, organizational readiness, knowledge management, training, communications, performance measurement, and resource planning. It is intentionally technology- and organization-neutral so that AASHTO, participating state departments of transportation, or another designated governing organization can apply the framework based on future PoC evidence and program decisions.

The deployment planning framework addresses two interdependent levels of implementation. At the national level, deployment involves establishing the governance, platform stewardship, standards coordination, content management, and support structures needed to sustain a shared transportation resource. At the state level, deployment involves integrating CBTL resources into agency workflows, systems, policies, training programs, and digital delivery practices. The national and state perspectives cannot be treated independently. A nationally coordinated platform depends on active state participation, while state adoption depends on a stable governance structure, common operating principles, and sustained national support.

The framework is organized around six strategic dimensions identified through the deployment planning process:

1. governance and ownership;
2. content and repository strategy;
3. phased deployment sequencing;
4. organizational enablement;
5. knowledge management and workforce sustainability; and
6. training and communications.

These six strategic dimensions are developed across Chapters 3 and 5. Chapter 3 addresses content and repository strategy (Section 3.2) and phased deployment sequencing (Section 3.3). Chapter 5 addresses governance and ownership (Section 5.2), organizational enablement and workforce readiness (Section 5.3), knowledge management (Section 5.4), and training and communications (Section 5.5). Together, these chapters describe the technical, institutional, and workforce conditions needed to support phased CBTL deployment.

It is important for the framework to be presented in a form that could support future use by AASHTO or another national governing organization, while also providing practical direction for state transportation agencies. The central recommendation of this chapter is a phased deployment pathway that progresses from targeted validation to broader state participation and, ultimately, national harmonization and continuous improvement. The phases represent increasing levels of technical, organizational, and governance maturity rather than fixed calendar periods. This distinction is important because the pace of deployment will depend on the evidence, capabilities, resources, and institutional readiness established during each preceding phase.

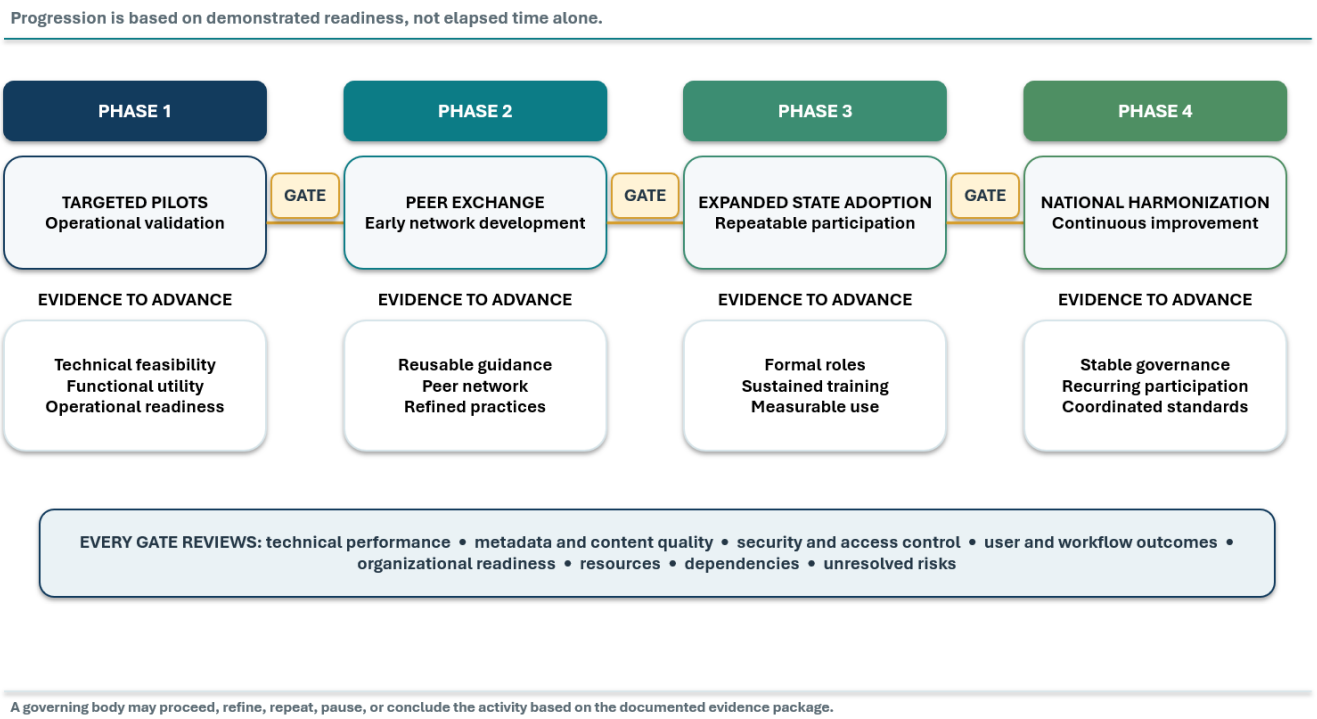


Figure 3. Four-Phase CBTL Deployment Planning Framework.

3.2 Content and Repository Strategy

The long-term value of the CBTL will depend as much on the quality, relevance, and stewardship of its content as on the technical platform itself. The preceding chapter established that BIM artifacts vary substantially in format, scale, ownership, lifecycle, and governance considerations. It also demonstrated that a hybrid Directory–Gateway–Repository model provides a more appropriate foundation than universal centralized storage.

3.2.1 Technical Deployment Architecture Baseline

Future implementation planning should define a baseline technical architecture that is sufficient to support the hybrid Directory–Gateway–Repository model. Recommended baseline elements include the national user interface, federated metadata catalog and search index, metadata registry and controlled vocabulary services, application programming interface gateway, directory connectors, mediated gateway services, repository services for nationally governed content, identity and access management, content submission and review workflows, version and provenance controls, validation services, administrative functions, and operational monitoring.

The architecture should preserve clear system boundaries. Authoritative operational datasets would remain in their source environments unless a specific governance decision authorizes centralized management. Directory services would support discovery and source attribution; gateway services would provide controlled or programmatic access to distributed systems; and repository services would manage content for which the CBTL has an approved national stewardship role. Synchronous request-response access should serve as the default integration pattern, while event-driven or asynchronous capabilities should be introduced only when supported by a validated workflow. Geospatial, linear-referencing, and other specialized services should likewise be treated as use-case-dependent capabilities rather than universal platform capabilities.

A future package of system architecture and design documents, developed and approved for pilot implementation, should include logical, component, data-flow, deployment, and security views; an interface and connector inventory; a source-of-truth matrix; nonfunctional criteria; and documented procedures for interface versioning, backward compatibility, deprecation, and replacement. These materials would provide a common technical baseline for pilot configuration, procurement, security review, and future scaling.

3.2.2 Content Prioritization and Initial Population

The recommended deployment strategy applies the same principle to content population. Rather than attempting to aggregate all available BIM-related resources at launch, initial deployment would focus on a limited set of high-value, well-governed content categories. Selection would be informed by national relevance, readiness, quality, interoperability, practical value, and the ability to support representative workflows.

Priority content may include nationally applicable processes and workflows, information needs, object-type libraries, data dictionaries, information delivery resources, exchange specifications, Model View Definitions, Information Delivery Specifications, selected parametric resources, training materials, and documented lessons learned. Large operational models and agency-managed geospatial datasets would generally remain in authoritative source environments, with the CBTL providing discovery, contextual information, and, where appropriate, mediated access.

3.2.3 Repository Roles and Content Access

The hybrid Directory–Gateway–Repository model avoids unnecessary duplication while preserving a unified user experience. Some artifacts are most appropriately managed as centrally governed national resources. Others are better indexed and linked to authoritative external sources. Still others may be better supported by gateway services that enable users or applications to access distributed systems through consistent interfaces.

The resulting strategy aligns content treatment with artifact ownership, lifecycle, and use. It also allows CBTL to expand incrementally as governance, technical capability, and participation mature.

3.2.4 Content-Treatment Decision Framework

Each candidate resource should be assigned to a Directory, Gateway, or Repository role through a documented governance and technical review. The review should consider the location of the authoritative source, ownership and licensing, update frequency, access restrictions, expected use, artifact size, source-system capabilities, national relevance, stewardship capacity, and the consequences of duplicating the resource. The condition-based logic in Table 7 and the artifact-level role-assignment matrix in Table 8, supported by the rationale in Table 9, provide the baseline developed through PoC planning. Pilot validation should assess these proposed assignments for the selected use cases and artifacts. The resulting findings and any documented revisions would then inform use of the matrix during deployment, subject to resource-specific governance and technical review.

1. Directory treatment is generally appropriate when an authoritative external source can remain responsible for the resource and the CBTL can provide reliable discovery, context, and source verification.
2. Gateway treatment is appropriate when users or applications benefit from controlled, mediated, or standardized access to a distributed source.
3. Repository treatment is appropriate for stable, reusable, nationally governed resources for which the CBTL or its governing organization has accepted responsibility for publication, version control, maintenance, and retirement.

Large operational models, frequently changing project datasets, and agency-managed geospatial information would generally remain in authoritative source systems unless a specific operational need and governance approval justify a different approach. The selected treatment, authoritative source, responsible steward, access conditions, synchronization method, and review interval should be recorded for each content category. Treatment decisions should be reassessed when ownership, source-system capability, access conditions, or stewardship responsibilities change.

3.2.5 Content Lifecycle and Stewardship

National deployment involves more than initial artifact collection. It also depends on defined processes for submission, review, approval, metadata assignment, versioning, publication, maintenance, archival, and retirement. The level of control will vary by artifact type.

A nationally governed object library or data dictionary, for example, benefits from a formal review and release process. Agency guidance retained in a state repository may involve only metadata validation and confirmation that the source remains active. This differentiated approach supports consistent stewardship without imposing the same level of control across all content.

3.2.6 Recommended Metadata and Provenance Profile

A common baseline metadata profile can support consistent national participation while allowing artifact-specific extensions. Recommended metadata fields include a persistent artifact identifier; title and artifact type; discipline and lifecycle phase; applicable use case or workflow; file format, schema, and applicable standard; artifact version and publication date; authoritative source system; content owner and steward; access classification; rights or distribution restrictions; validation or approval status; related artifacts; and the date on which the source and metadata were last verified.

The governance framework should distinguish among the version of the artifact, the version of its metadata record, the version of the applicable standard or national profile, and the version of any connector or source-system interface. Provenance records should identify who submitted, reviewed, approved, modified, published, archived, or retired a resource and should preserve the relationship between superseded and current versions.

Metadata validation should combine automated checks with steward review. Automated checks can identify missing

expected fields, invalid identifiers, unsupported values, broken links, and inconsistent version information, while stewards confirm subject-matter accuracy, ownership, authority, and fitness for publication. Exceptions should be documented, time-limited where appropriate, and subject to periodic review.

3.2.7 Alignment with Existing Standards and Repositories

The CBTL is expected to complement rather than duplicate existing standards initiatives and authoritative resources. Coordination with buildingSMART International (bSI) standards and technologies, including the buildingSMART Data Dictionary (bSDD), Information Delivery Manuals (IDM), Model View Definition (MVD), and Information Delivery Specification (IDS), national transportation libraries, open standards initiatives, and related federal or state systems will be important to maintaining consistency and reducing competing sources of truth.

In this context, the CBTL functions as a national integration and knowledge layer that connects resources across the transportation ecosystem while preserving the authority of existing systems.

3.3 Phased Deployment Sequencing

Based on the technical, organizational, and governance conditions identified in the preceding chapter, the recommended deployment pathway is structured as a four-phase progression. The sequence begins with targeted validation, expands through peer-based learning and early network development, advances toward repeatable state-level adoption, and culminates in national harmonization and continuous improvement.

Testing may be undertaken for selected use cases and associated artifact types at different times; it does not require simultaneous evaluation of the full set of use cases or CBTL capabilities. Different use cases may progress through the phases at different rates, and phase activities may proceed sequentially or in parallel where dependencies and readiness permit.

The phases are cumulative. Each phase develops evidence, capabilities, institutional relationships, and operating practices that support the next level of deployment. Progression for each selected use case or defined implementation scope is therefore based on demonstrated readiness rather than elapsed time. This allows the framework to accommodate changes in platform development, governance, available resources, agency participation, and national priorities.

1. **Phase 1: Targeted Pilots and Operational Validation:** Evaluation of selected high-value use cases and associated artifact types suitable for early testing environments.
2. **Phase 2:** Peer Exchange and Early Network Development: Coordination with leading DOTs to encourage harmonization of standards and shared practices.
3. **Phase 3:** Expanded State-Level Adoption: Identification of strategies for broader agency participation, standards alignment, and training expansion.
4. **Phase 4:** National Harmonization and Continuous Improvement: Potential governance coordination and structured update cycles across agencies.

These phases are presented as a planning framework rather than an implementation roadmap, illustrating how adoption could progress over time.

Table 16. Deployment Planning Phases and Readiness Evidence

Phase	Primary Purpose	Evidence Needed to Advance
1. Targeted pilots and operational validation	Test selected use cases, artifacts, and core technical capabilities	Technical feasibility, functional utility, operational readiness, documented risks
2. Peer exchange and early network development	Translate pilot findings into reusable guidance and shared practice	Reusable resources, functioning peer network, refined governance/content practices
3. Expanded state-level adoption	Demonstrate repeatable adoption across agencies and workflows	Formal roles, recurring participation, sustained training, measurable use
4. National harmonization and continuous improvement	Sustain national coordination, standards alignment, and improvement	Stable governance, recurring state participation, coordinated standards and performance cycles

3.3.1 Phase 1: Targeted Pilots and Operational Validation

Phase 1 applies the bounded PoC framework to selected use cases and representative artifacts to evaluate technical feasibility, functional utility, and operational readiness. Sections 4.1 and 4.2 describe the pilot activities and testing framework.

Before pilot activities begin, the sponsoring organization and participating agencies would identify interim governance responsibilities, consistent with Section 4.1. The sponsoring or interim governing organization would coordinate pilot

participation, establish provisional operating practices, and support evaluation. Potential long-term CBTL owners and operators should be engaged during the pilot to inform governance and operational planning. These arrangements would be refined through the pilot and Phase 2 peer exchanges, with national governance authority and operating responsibilities confirmed before progression to expanded state-level adoption.

3.3.2 Phase 2: Peer Exchange and Early Network Development

The second phase expands the focus from isolated validation to shared learning and network formation. Transportation agencies have historically advanced digital delivery through peer exchange, pooled-fund research, stakeholder groups, working sessions, and the adaptation of practices developed by early adopters. The CBTL deployment pathway can build on the same model.

During this phase, findings from the targeted pilots are translated into reusable implementation resources. These may include use-case documentation, governance templates, content criteria, readiness tools, training materials, technical guidance, and lessons learned. The intent is to reduce the burden on each new agency and to prevent repetitive development of similar policies and practices.

Peer exchanges also create an environment for identifying areas where national harmonization is both feasible and valuable. Agencies may use different terminology, metadata structures, approval practices, and technical platforms, yet still share common information needs and workflow objectives. Structured comparison allows the governing organization to distinguish between differences that warrant accommodation and differences that can be reduced through national guidance or shared standards.

The early network formed during this phase provides an important governance function. Participants become a practical advisory community capable of testing policies, reviewing content, identifying emerging needs, and supporting agencies entering later phases. This network also creates the foundation for communities of practice and change-champion structures that continue throughout deployment.

Engagement with potential long-term CBTL owners and operators initiated during Phase 1 should continue through Phase 2. Pilot findings and peer-exchange activities should inform the evaluation of prospective governance and operating arrangements, including organizational responsibilities, resource requirements, and long-term sustainability. These activities would support confirmation of governance authority and operating responsibilities before expanded state-level adoption.

Phase 2 represents the transition from a project-based pilot environment to an emerging national program. The CBTL begins to develop an identity, user community, and repeatable participation model. Governance and content processes are refined through use, while training and communications become more systematic.

3.3.3 Phase 3: Expanded State-Level Adoption

The third phase focuses on repeatable adoption across a broader group of state transportation agencies. By this stage, the CBTL has moved beyond initial proof and early peer learning. The principal objective becomes the integration of CBTL resources into state business practices, digital delivery programs, and organizational structures.

State adoption is expected to occur at different levels of depth. Some agencies may initially use the CBTL as a discovery resource. Others may contribute content, connect agency systems, incorporate national artifacts into standards, or rely on CBTL resources in project delivery. The framework does not assume uniform adoption. It provides a progression through which agencies can move from limited participation toward institutionalized use.

A practical state progression can be described as pilot, expand, standardize, and institutionalize. The pilot stage applies the CBTL to a specific workflow or user group. Expansion introduces additional disciplines, projects, or content categories. Standardization incorporates CBTL resources into formal agency procedures, guidance, or digital delivery criteria. Institutionalization integrates the CBTL into ongoing governance, training, workforce development, and performance management.

Building on the governance arrangements developed during Phases 1 and 2, the designated national governing organization would assume broader responsibilities for supporting state adoption. These responsibilities would include oversight of platform operations, implementation guidance, technical support, content administration, training, and adoption monitoring, with delivery supported by designated operating and implementation partners as appropriate. Any transition from interim governance to the designated national governing organization would include an explicit transfer of authority and responsibilities. The objective is to create a consistent national support environment that reduces the cost and complexity of participation.

State agencies, in turn, establish internal ownership, assess readiness, identify affected workflows, align policies, prepare content, train users, and monitor outcomes. Successful implementation depends on responsibility extending beyond a single BIM specialist or technology unit. Cross-functional participation from engineering, construction, asset management, information technology, data governance, training, standards, and leadership is important because CBTL adoption affects both technical and business processes.

Phase 3 is complete when adoption becomes repeatable rather than dependent on isolated champions or individual projects. Evidence of maturity includes formal agency participation, established internal roles, recurring content contribution, integration into business processes, sustained training, and measurable use across multiple organizational areas.

3.3.4 Phase 4: National Harmonization and Continuous Improvement

The fourth phase represents a mature national operating environment. The CBTL functions as a sustained digital infrastructure and knowledge resource supported by established governance, broad state participation, recurring content updates, and continuous performance improvement.

National harmonization does not depend on every agency using identical systems or internal procedures. The objective is to improve compatibility, interoperability, consistency, and shared understanding where national alignment produces practical value. This may include common metadata profiles, nationally governed artifact categories, standardized exchange criteria, consistent terminology, and coordinated update cycles.

At this stage, the governing organization maintains a recurring process for evaluating performance, prioritizing enhancements, updating standards, expanding partnerships, and responding to emerging technologies. The CBTL becomes a living ecosystem rather than a static repository. New use cases, standards, software capabilities, and agency needs are incorporated through established governance and release processes.

State agencies continue to maintain local implementation, contribute lessons learned, update internal practices, and participate in national decision-making. More mature agencies may provide peer support, lead working groups, contribute advanced resources, or test emerging capabilities before broader release.

Continuous improvement is organized around a recurring cycle of feedback collection, performance assessment, prioritization, implementation, communication, and measurement. This cycle allows the CBTL to remain aligned with changing transportation practices while preserving stability and trust.

4. Pilot Testing and Validation

This chapter expands the pilot testing discussion so that the research basis, test purpose, representative activities, and readiness criteria are clear to a reader without relying on internal contract task references. The testing approach draws from the CBTL technical requirements and testing work developed earlier in this project and adapts that material to the bounded PoC described in Chapter 2.

4.1 Targeted Pilots and Operational Validation

This section describes Phase 1, Targeted Pilots and Operational Validation, of the four-phase CBTL deployment framework introduced in Section 3.3. During this phase, the proof of concept framework described in Chapter 2 would be applied under controlled but representative conditions. Selected use cases, representative BIM artifacts, defined workflows, and participation from state DOT and FHWA stakeholders would be used to evaluate the CBTL's technical feasibility, functional utility, and operational readiness. These targeted pilot activities would generate evidence to inform decisions about progression to subsequent deployment phases.

The purpose of this pilot phase is to determine how effectively the CBTL can support selected transportation workflows while operating within representative governance, security, metadata, technical, and organizational conditions. Pilot activities should align with the participant groups, stakeholder structure, evaluation criteria, observation methods, and functional boundaries established in Chapter 2.

Pilot selection is most useful when it includes a limited number of high-value use cases and participants representing different levels of digital delivery maturity. Agencies with established BIM programs can help evaluate more advanced integration, interoperability, and content-governance considerations. Agencies at earlier stages of adoption can provide important evidence regarding usability, training, resource constraints, organizational readiness, and accessibility for users with varying levels of BIM experience.

The pilot phase also provides an initial environment for evaluating national and state roles. At the national level, the sponsoring or interim governing organization would coordinate participation, establish provisional operating practices, define content criteria, and support technical evaluation. At the state level, participating agencies would identify relevant workflows, provide or reference representative artifacts, assign participants, and document implementation barriers, user observations, and outcomes.

The evaluation approach builds on earlier CBTL technical research and is further refined through the PoC framework in Chapter 2. Together, these efforts provide a structured basis for evaluating functionality, performance, security, usability, integration, regression, data integrity, user interaction, and operational readiness during pilot activities. This approach supports consistent documentation of findings across agencies, artifacts, workflows, and participant groups and provides an evidence base for decisions regarding refinement, additional testing, or broader deployment.

4.2 CBTL Testing Framework for Pilot Validation

Section 2.4 establishes the PoC's three validation questions—technical feasibility, functional utility, and operational readiness—and identifies the capabilities to be evaluated. Building on that scope and the evaluation considerations described in Section 2.5, pilot testing during Phase 1 of the deployment framework is organized around seven complementary testing areas: functional, performance, security, usability, integration and interoperability, regression, and data integrity and recovery. These seven testing areas and their application during Phase 1 are summarized in Table 18.

The testing areas provide a structure for generating evidence to address the validation questions and assess the capabilities identified in Section 2.4. A capability may be assessed through several testing areas; for example, artifact discovery may involve functional, usability, and performance testing. Together, these areas support evaluation of CBTL performance and its ability to serve the users, workflows, artifacts, and system interactions included in the approved pilot scope.

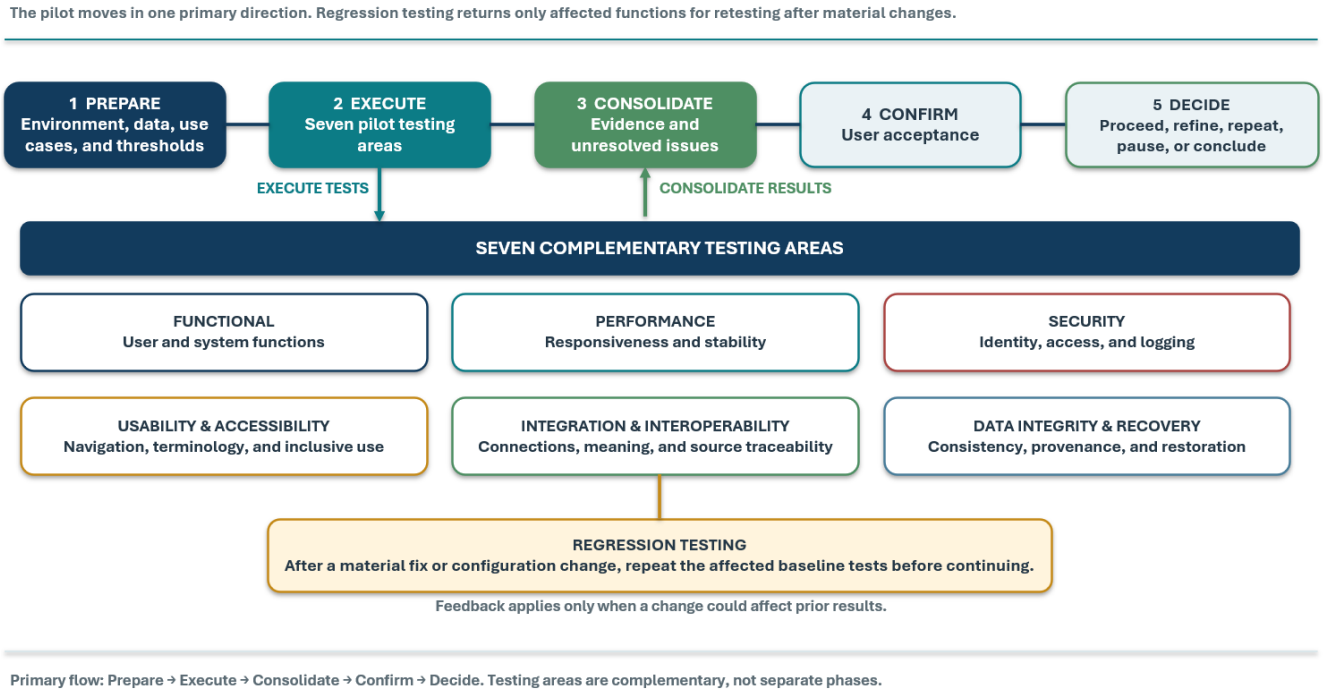


Figure 4. CBTL Pilot Testing and Readiness Sequence.

The testing framework is intended to support a bounded pilot rather than a production-scale certification or acceptance process. Testing activities should therefore be aligned with the selected use cases, representative BIM artifacts, participant groups, technical capabilities, and evaluation criteria established for the pilot. The depth of testing may vary by use case and by the capabilities included in the pilot environment.

The pilot testing framework builds on the CBTL technical requirements and testing approach developed during earlier project research. The testing areas are carried forward here and tailored to the selected proof of concept use cases, participant groups, technical capabilities, and pilot evaluation objectives. Detailed test procedures and acceptance thresholds would be finalized for the approved pilot environment before execution. The testing areas were defined before the pilot use cases were selected. Once use cases, representative artifacts, and technical capabilities are confirmed for the approved pilot scope, additional test areas or scenarios specific to those selections may be identified and incorporated; such use-case-specific tests are not enumerated here.

Each testing area addresses a different aspect of CBTL performance and is described in more detail below. Functional testing verifies selected user and system functions; usability testing examines navigation, terminology, accessibility, and workflow fit; integration and interoperability testing evaluate system connections and information consistency across platforms and standards; security testing examines representative identity, access, logging, and data-protection controls; performance testing observes responsiveness and stability; regression testing confirms that changes do not disrupt previously demonstrated functions; and data integrity and recovery testing evaluates traceability, version behavior, consistency, and recovery following errors or failures.

The framework is designed to generate comparable findings across pilot activities. Results can be documented by use case, artifact type, participant group, and testing area so that technical and user observations can be evaluated together. This structure also supports identification of limitations, dependencies, and areas that may warrant additional testing or refinement before broader deployment.

Completion of pilot testing does not automatically mean the CBTL is ready for broader deployment. The output is an evidence package that identifies demonstrated capabilities, unresolved defects and dependencies, user outcomes, security and governance considerations, training needs, resource implications, and recommended next actions. That package becomes the basis for the readiness decision described in Section 4.3.

4.2.1 Test Environment and Data Preparation

Before formal testing begins, the pilot team should establish a controlled environment, identify the specific use cases to be tested, and prepare representative datasets and metadata. The environment should include the minimum services needed for the selected Directory, Gateway, and Repository interactions and should be separated from production systems unless an approved interface is required for a test scenario.

Dataset preparation should document the authoritative source, artifact type, discipline, lifecycle phase, version or date, format or schema, access classification, and known limitations. Where an agency cannot provide a full artifact,

metadata-only records or controlled session-based access may be used. Baseline test cases, expected outcomes, acceptance thresholds, and defect-severity definitions should be agreed upon before execution.

To ensure that pilot findings are repeatable, comparable across agencies, and traceable to the priority use cases, each selected use case should be paired with a representative dataset package. Packages should reflect real DOT conditions, including multi-platform environments, varying levels of artifact maturity, and typical metadata inconsistency, and should include artifacts sufficient to support discovery, filtering, contextual interpretation, and, where applicable, limited validation workflows. Table 17 defines the minimum content of each package.

Table 17. Minimum Dataset Package Requirements per Use Case

Package element	Minimum content
Representative artifacts	Existing BIM artifacts sufficient to represent the use case at a demonstrable level (for example, an existing conditions model, one discipline model, and one downstream-use model such as an analysis, AMG, or as-built model where applicable).
Metadata samples	As-is identifiers and fields available from the authoritative source environment (file names or identifiers, discipline, phase, version or date, and format or schema indicator where available).
Reference documentation	Only what is necessary to interpret the artifact's purpose and lifecycle role (a workflow excerpt, deliverable description, or transmittal or context note).
Artifact inventory list	Artifact name or identifier, source system or repository, and access classification (shareable or restricted) for every artifact in the package.
Core metadata fields (per artifact)	Artifact type, discipline, lifecycle phase, version or date marker, and format or schema indicator where available.
Source and stewardship fields (per artifact)	Authoritative host and owner or steward, if known.
Handling constraints	Where full artifacts cannot be shared, the package may be metadata-only with controlled, session-based access to the authoritative system through the PoC gateway. The baseline PoC does not require full geospatial datasets or event-driven synchronization; spatially anchored datasets are included only when a selected scenario needs them.

4.2.2 Functional Testing

Functional testing verifies that selected CBTL capabilities work as intended for representative user tasks. Test cases should cover the functions included in the approved pilot scope, such as user authentication, artifact discovery, search and filtering, navigation to authoritative sources, metadata display, controlled access, and, where repository functions are included, submission, review, versioning, and publication workflows.

Representative test cases can include locating an artifact without knowing its source repository, retrieving the correct metadata and source link, confirming that access restrictions are enforced, and validating that a governed artifact can move through an approved review and publication sequence. Critical functional defects should be corrected, and the affected baseline tests repeated before the pilot proceeds to dependent activities.

4.2.3 Usability and Accessibility Testing

Usability testing evaluates whether participants can understand the interface, terminology, and workflow without excessive assistance. Participants should perform scenario-based tasks such as locating a structural model, filtering by discipline or lifecycle phase, confirming version information, and identifying the authoritative source. Facilitators can record task completion, time to discovery, navigation errors, terminology confusion, and participant feedback.

The pilot should also consider accessibility and differences in digital-delivery maturity. Feedback from users who are less familiar with BIM can identify whether the interface and training materials are understandable outside a specialist audience. Findings should be documented separately from source-data limitations so the team can distinguish interface issues from gaps in the underlying agency content. Accessibility evaluation should include applicable Section 508 and Web Content Accessibility Guidelines (WCAG) criteria for the user interface and supporting digital content included within the approved pilot scope.

4.2.4 Integration and Interoperability Testing

Integration testing focuses on whether CBTL components and approved external sources communicate reliably. Testing should validate API calls, authentication, metadata exchange, error handling, and traceability back to the authoritative system. Failure scenarios, such as unavailable services, malformed requests, or incomplete responses, should be included so that the pilot demonstrates controlled behavior when an integration does not operate as expected.

Interoperability testing evaluates whether information remains understandable and usable across software, schemas, standards, and organizational boundaries. The emphasis is not only on successful connectivity but also on whether identifiers, metadata, formats, and mappings preserve meaning. Where open standards such as IFC, IDS, or buildingSMART resources are included in a scenario, the pilot should document the extent to which the information can be interpreted consistently across platforms.

4.2.5 Security and Access-Control Testing

Security testing should be proportionate to the pilot environment and should verify the controls actually included in the PoC. Representative activities include authentication and authorization checks, role- or attribute-based access validation, logging, controlled API credentials, encryption expectations, and confirmation that restricted content is not exposed to unauthorized users.

The PoC is not intended to substitute for production authorization or compliance assessment. The purpose of this testing is to determine whether the concept can operate within representative agency security and access constraints and to identify controls, approvals, or responsibilities that would need to be strengthened before implementation expands.

4.2.6 Performance, Regression, and Data Integrity Testing

Performance testing should observe responsiveness and stability at a scale appropriate to the pilot rather than attempting to certify production-scale capacity. Measures may include search response, API success and failure rates, connector health, authentication outcomes, and the ability to handle the expected pilot dataset and user load.

Regression testing should be repeated after material configuration changes, defect corrections, or interface updates to confirm that previously demonstrated functions still work. Data-integrity and recovery testing should confirm that metadata, identifiers, version relationships, source attribution, and governed repository content remain consistent and traceable following errors or restoration activities.

4.2.7 User Acceptance and Pilot Validation

User acceptance combines technical evidence with structured participant feedback. The research team should compare observed outcomes against the evaluation criteria established before the pilot and document where the CBTL improves discoverability, workflow continuity, interoperability, or reuse—as well as where limitations remain.

User acceptance activities should involve representative participants from the selected DOT and FHWA user groups and focus on whether the CBTL supports the intended workflows under realistic pilot conditions. Findings should document task outcomes, participant observations, usability concerns, training needs, and unresolved functional limitations. These findings would contribute to the overall PoC evidence package and inform subsequent readiness decisions rather than constitute authorization for broader deployment.

Table 18 summarizes the relationship between each testing area and its application during Phase 1. The detailed discussion above should be used with the table: the table provides the quick reference, while the narrative describes the purpose, representative test activities, and type of evidence expected from each area.

Table 18. CBTL Pilot Testing Areas and Application During Phase 1

Testing Area	Evaluation Focus	Application During Phase 1
Functional	Selected user and system functions relevant to the pilot's use cases and CBTL components, such as discovery, navigation, access to artifacts, and applicable content-management workflows.	Evaluate selected CBTL functions against representative user tasks, use cases, artifact workflows, and the Directory–Gateway–Repository interactions included in the approved pilot scope.
Performance	Responsiveness, stability, load behavior, capacity, and scalability.	Observe system response, stability, and performance at a scale appropriate to the pilot environment.
Security	Access control, authentication, data protection, vulnerability exposure, and auditability.	Evaluate representative identity, authorization, logging, and security controls within the bounded pilot environment.
Usability	Ease of use, navigation, terminology, workflow clarity, training, and adoption considerations.	Use scenario-based tasks, structured observation, and participant feedback to assess ease of use and workflow fit.
Integration / Interoperability	Interaction among CBTL components, external repositories, standards sources, and agency systems.	Evaluate selected Directory and Gateway connections and confirm that information remains traceable to authoritative sources.

Testing Area	Evaluation Focus	Application During Phase 1
Regression	Whether configuration changes or enhancements adversely affect previously demonstrated functions.	Repeat selected baseline tasks after refinements or configuration changes to identify unintended impacts.
Data Integrity and Recovery	Consistency, traceability, preservation, and recovery of data following errors or failures.	Confirm metadata integrity, version and provenance behavior, and recovery expectations appropriate to the pilot scope.

The testing areas identified in Table 18 can be translated into representative scenarios for the bounded pilot environment. The activities summarized in Table 19 illustrate how technical and user-facing capabilities could be evaluated using selected BIM artifacts, participating agencies, and approved interfaces. The specific procedures, expected results, and acceptance thresholds would be finalized before pilot execution.

Table 19. Representative CBTL Pilot Test Scenarios and Expected Evidence

Testing area	Representative scenario	Expected evidence
Functional	Discover and retrieve artifact metadata	Task outcomes and defects
Performance	Observe search and API response under pilot conditions	Response times and stability
Security	Test access restrictions for selected users	Authorization results and exceptions
Usability	Complete representative DOT user tasks	Task success and participant feedback
Integration	Exchange metadata through approved interfaces	API results and error handling
Interoperability	Assess consistency of cross-platform data	Mapping accuracy and semantic consistency
Regression	Retest affected functions after changes	Confirmation of retained behavior
Data Integrity and Recovery	Introduce or simulate a representative data error or recovery event and verify preservation of metadata, version, and provenance relationships.	Documented integrity, traceability, and recovery results.

These scenarios are illustrative and should be refined according to the technical capabilities and artifacts included in the approved pilot scope. Testing would generate documented evidence of demonstrated functionality, limitations, defects, and operational dependencies. The findings would inform readiness assessments and future technical requirements rather than establish production-scale certification or authorization.

The principal outcome of Phase 1 is an evidence base for deployment decisions. This includes findings related to technical performance, metadata quality, content readiness, governance considerations, user acceptance, training needs, and resource demands. Completion of the phase does not imply that all issues have been resolved; rather, it indicates that key risks, limitations, and conditions have been documented sufficiently to support refinement, additional testing, or broader engagement.

4.3 Cross-Phase Gate and Readiness Criteria

Progression between deployment phases should be governed by formal decision gates rather than by schedule alone. Before a phase begins, the responsible governing body should approve its scope, participating organizations, accountable owner, identified capabilities, expected outputs, evaluation method, resource commitment, and decision criteria. For the PoC, acceptance thresholds should be established for the approved pilot scope before pilot activities begin so that evidence is assessed against agreed expectations rather than interpreted after completion. Acceptance criteria for later implementation or operational activities should be defined separately if those activities are authorized.

Each gate review should consider technical performance; metadata and content quality; security and access-control performance; usability and workflow outcomes; organizational readiness; staffing and financial capacity; stakeholder commitments; unresolved dependencies; and the status of significant risks. The decision package should document evidence, exceptions, corrective actions, and residual risks.

4.4 PoC Validation Criteria

Progression beyond the PoC pilot phase should be based on documented evidence addressing the three fundamental validation questions defined in the PoC framework:

1. **Technical Feasibility:** Whether a federated CBTL interface can effectively discover, integrate, and govern BIM artifacts across independently maintained repositories without duplicating or disrupting authoritative source systems.
2. **Functional Utility:** Whether the CBTL provides sufficient practical value to state departments of transportation, FHWA, contractors, and industry stakeholders to support adoption, as demonstrated through user acceptance, workflow integration, improved discoverability, and reduced data fragmentation.
3. **Operational Readiness:** Whether the CBTL can operate within applicable agency security, access-control, cloud-hosting, governance, and resource constraints while demonstrating the performance, scalability, resilience, and support capabilities needed for broader deployment.

Table 20. CBTL PoC Evidence and Readiness Decision Framework

Validation question	Evidence	Potential decision
Technical feasibility	Discovery, metadata, integration, interoperability, and security results	Proceed, refine, or repeat technical testing
Functional utility	User task outcomes, artifact usefulness, workflow continuity	Refine use cases or proceed with further validation
Operational readiness	Security, governance, staffing, support, and resource findings	Define outstanding operational requirements
Potential progression	Integrated findings, risks, dependencies, and readiness	Proceed, refine, repeat, pause, or conclude

Readiness determinations should be based on documented findings evaluated against criteria established before testing. Unresolved issues, risks, dependencies, and capabilities outside the approved pilot scope should be identified separately. A determination to proceed would support further planning and authorization of subsequent activities; it would not independently establish that the CBTL is ready for national implementation.

The findings generated through the PoC evaluation framework should serve as the primary evidence for these determinations. Relevant measures include usability and accessibility; successful completion of representative user tasks; search and filtering effectiveness; time needed to locate and assess artifacts; metadata completeness and accuracy; interoperability across platforms and standards; workflow continuity across lifecycle stages; security and access-control performance; governance and stewardship readiness; training and change-management needs; and the resources needed to operate and sustain the CBTL.

A positive determination does not depend on every capability being production-ready. However, unresolved limitations, risks, dependencies, and exclusions should be documented and evaluated before deployment expands. Each gate decision should identify whether the applicable capability will proceed, be refined, be retested, remain limited to the pilot environment, or be deferred to a future phase.

The designated decision authority should issue a documented determination to proceed, refine, repeat, pause, or conclude the relevant activity. Completion of Phase 1 should be based on sufficient evidence generated through execution of the PoC framework to assess technical feasibility, functional utility, and operational readiness. The governing or sponsoring organization should document which capabilities were successfully demonstrated, which warrant refinement or additional testing, and which remain outside the recommended deployment scope.

Advancement to Phase 2 should also be supported by documented findings concerning representative use cases, user acceptance, metadata quality, interoperability, governance, security, organizational readiness, and operating-resource needs. Where the evidence is inconclusive, the appropriate decision may be to refine or repeat selected pilot activities rather than proceed directly to broader adoption. Phase 2 should demonstrate that pilot findings have been converted into reusable participation, governance, training, and technical resources and that an effective peer network is functioning. Phase 3 should demonstrate repeatable adoption across agencies and workflows without dependence on isolated champions. Phase 4 should demonstrate sustained national operations, recurring state participation, coordinated standards management, and an effective continuous-improvement cycle.

4.5 Performance Measurement and Benefits Realization

A common performance framework should be used across all phases to determine whether the CBTL is technically reliable, operationally useful, organizationally sustainable, and producing measurable value. Baselines, targets, data sources, reporting intervals, and responsible owners should be defined before each pilot or expansion activity. Measures may be refined as the platform matures, but changes should be documented so that results remain interpretable over time.

Technical measures should address availability, response performance, application programming interface success and failure rates, connector health, authentication and authorization outcomes, recovery performance, and security findings. Content measures should address metadata completeness, verified authoritative sources, stale or broken references, review backlogs, provenance completeness, and resources that have exceeded their approved review period.

User and workflow measures should address task completion, search and discovery success, time needed to locate and assess an artifact, usefulness of retrieved content, reuse across agencies or workflows, and reductions in repeated development or rework where those outcomes can be measured. Adoption measures should address participating agencies, active and repeat users, contributors, reviewers, connected systems, supported workflows, training completion, and progression among participation levels.

Performance reporting should distinguish activity counts from realized benefits. For example, the number of records or users indicates scale, while reduced search time, improved reuse, better metadata quality, fewer disconnected sources, or more consistent exchanges indicates operational value. Gate decisions and improvement priorities should be supported by an integrated performance report rather than by platform-usage statistics alone.

5. Governance, Organizational Readiness, and Sustainability

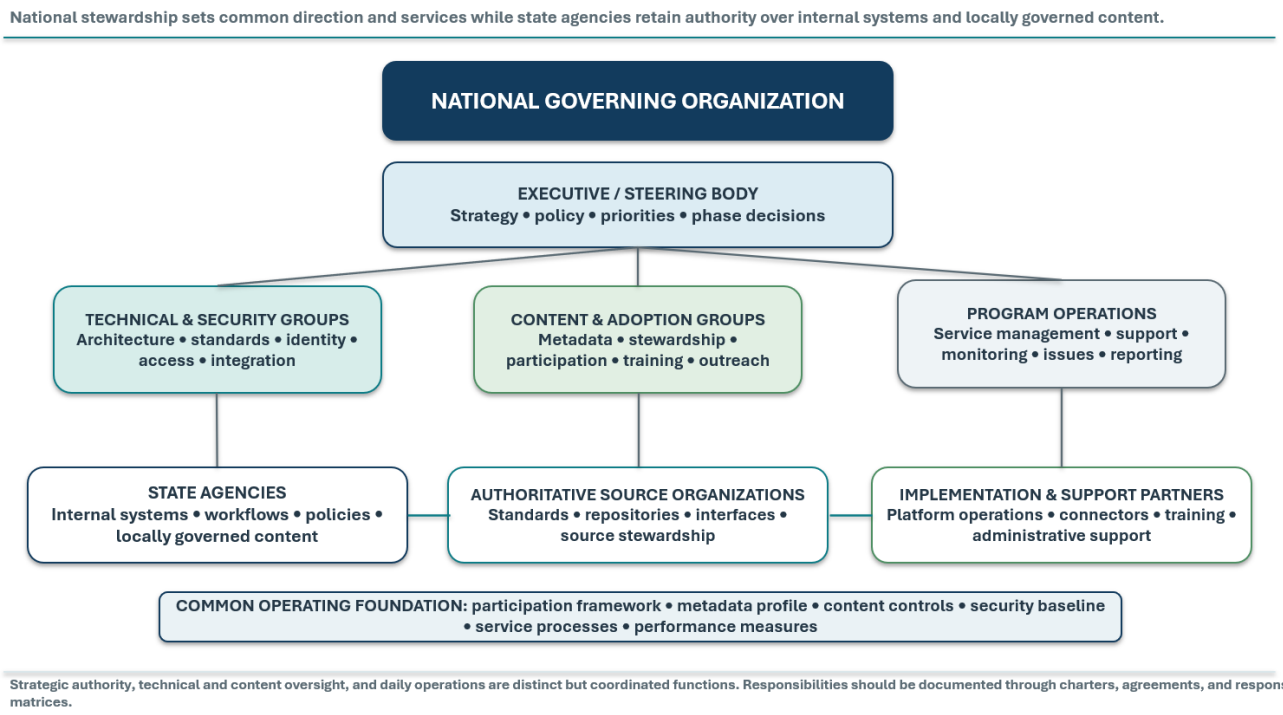


Figure 5. Illustrative CBTL Governance and Operating Relationship.

5.1 National Stewardship and State Participation

The CBTL is intended to function within a distributed national transportation environment in which agencies maintain different standards, systems, software platforms, governance models, and levels of digital delivery maturity. As discussed in Chapters 2 and 3, this heterogeneity supports a federated implementation model rather than the replacement of existing agency repositories or operational systems. The deployment pathway therefore depends on a coordinated relationship between national stewardship and state participation that leads to a shared operating model.

5.1.1 National Stewardship Responsibilities

At the national level, the governing organization would provide the institutional structure needed to maintain the CBTL as a durable and trusted resource. This role includes strategic direction, platform stewardship, policy development, standards coordination, content oversight, stakeholder engagement, and long-term resource planning. It also includes maintaining the common elements that allow agencies to participate without independently recreating governance, metadata, training, and support structures.

National stewardship provides the consistency needed to support interoperability and shared practice across a diverse agency environment. The governing organization would establish the participation framework, define common operating principles, coordinate nationally relevant standards, and oversee the processes through which content is reviewed, maintained, updated, and retired. It would also provide the continuity needed to sustain the CBTL beyond individual projects, funding cycles, or pilot efforts.

The national role does not depend on the governing organization independently performing every technical, operational, or implementation function. Strategic authority can remain with the governing organization while defined responsibilities are supported by qualified technical, administrative, training, and organizational partners. This approach allows national oversight and accountability to be preserved while reducing the institutional burden associated with developing, operating, and scaling the platform.

5.1.2 State Participation and Adoption

At the state level, agencies would determine how CBTL resources align with existing digital delivery programs and how participation can be incorporated into current practices. State implementation is expected to vary based on agency

maturity, available staff, technical infrastructure, procurement conditions, and internal priorities. Some agencies may begin by using the CBTL as a discovery and reference environment, while others may contribute artifacts, integrate platform services into agency systems, or incorporate CBTL resources into formal standards and project delivery criteria.

State participation may therefore occur at different levels of depth. An agency in an early stage of digital delivery maturity may initially use the CBTL to locate guidance, examples, standards, and training resources. A more advanced agency may contribute curated artifacts, participate in governance or technical working groups, or connect agency systems to CBTL services. This variability reinforces the need for a deployment model that establishes common national structures while allowing implementation to vary across agencies.

State agencies would retain authority over their internal systems, workflows, project-specific criteria, and locally governed content. The purpose of the national framework is not to replace that authority, but to provide a common environment that improves discovery, interoperability, coordination, and reuse across jurisdictions.

5.1.3 Shared Operating Model

The relationship between national stewardship and state participation establishes a shared operating model. The national governing organization defines the framework for participation, while each state determines the pace and depth of adoption. National consistency is most valuable where it enables interoperability, common discovery, shared standards, coordinated stewardship, and reusable implementation resources. State flexibility remains important where agencies retain responsibility for internal business processes, technical systems, procurement decisions, staffing, and project delivery practices.

This shared model also distributes responsibility in a practical manner. The national organization maintains the common infrastructure and governance needed to sustain the CBTL, while state agencies provide the operational context, content, feedback, and use cases that make the platform relevant. Neither level can achieve the intended outcomes independently. National stewardship without state participation would limit practical value, while state participation without a stable national framework would risk fragmented implementation and duplication of effort.

5.1.4 Potential Role of AASHTO

The American Association of State Highway and Transportation Officials (AASHTO) has been identified through stakeholder discussions as a potential organization capable of supporting national governance and coordination. Its existing committee structure, state-based membership, standards-development role, and ability to convene agencies align with several CBTL stewardship functions. These characteristics may position AASHTO to provide strategic oversight, facilitate state participation, coordinate national standards, and support long-term adoption.

The framework is designed to remain applicable across association-led, federal-led, consortium, and hybrid governance models. Regardless of the structure selected, successful deployment depends on clearly defined ownership, accountability, partnership arrangements, and operational responsibility.

5.2 Governance and Ownership

Clearly defined governance is a foundational condition for broader CBTL deployment. Without assigned authority, the initiative is vulnerable to fragmented decision-making, inconsistent content quality, unclear accountability, and limited long-term sustainability. Governance therefore serves as an operational foundation that enables the CBTL to operate as a trusted national resource, rather than as an administrative structure added after technical development.

Although the final CBTL governance model has not been selected, several core functions would need to be assigned before broader implementation. These functions include national oversight, standards coordination, content stewardship, platform operations, security, and state participation. Table 21 provides an illustrative allocation of responsibilities that could be adapted to a federal-led, association-led, consortium, or hybrid governance arrangement.

Table 21. Illustrative CBTL Governance and Stewardship Responsibilities

Governance function	Potential responsible party
National oversight and policy	Designated governing organization
Standards coordination	Governing organization and standards partners
State-owned content	Participating state DOTs
Nationally curated artifacts	Designated content stewards
Technical platform operations	Designated platform operator
Security and access control	Applicable security authorities and system owners

Governance function	Potential responsible party
Training and adoption	National coordination and participating agencies

These responsibilities are presented as functional requirements for future governance planning rather than assignments to specific organizations. The final structure would need to establish authority, accountability, decision rights, participation agreements, and appropriate oversight mechanisms before sustained national operations could be authorized.

5.2.1 Governance Functions and Potential Models

Although the specific governance model may vary, the underlying functions remain consistent. National deployment benefits from an entity with authority to establish participation policies, define content and metadata criteria, coordinate standards, oversee platform operations, manage updates, resolve competing priorities, and plan for long-term sustainability. These responsibilities extend beyond the operation of a website or repository; they establish the institutional framework through which the CBTL earns and maintains trust.

Several governance arrangements remain feasible. A federal-led model could provide direct alignment with national programs and funding priorities. An association-led model could strengthen state ownership and connect the CBTL to existing standards and committee structures. A consortium model could distribute responsibility among agencies, standards organizations, academic partners, and industry participants. A hybrid model could combine federal sponsorship, association-based governance, and specialized technical or operational support.

The appropriate governance model may vary, but strategic authority, technical oversight, and daily program operations remain distinct and coordinated functions under any model.

5.2.2 Tiered Governance Structure

A tiered governance structure provides a practical mechanism for separating these responsibilities while maintaining clear accountability. An executive or steering body could establish strategic direction, approve major policies, and resolve high-level priorities. Supporting committees or working groups could address technical architecture, content standards, state participation, knowledge management, and training. A program management function could coordinate daily operations, stakeholder communications, performance monitoring, and issue resolution.

This structure also creates a formal mechanism for incorporating state and user perspectives into national decision-making. State transportation agencies are not solely end users of the CBTL; they are potential contributors, standards owners, pilot participants, and co-developers of national practice. Structured representation from agencies at different levels of BIM and digital delivery maturity would help ensure that governance reflects both advanced implementation needs and the practical constraints of agencies earlier in adoption.

Under any governance model, the designated governing organization would not need to perform every technical, administrative, or implementation function independently. Strategic authority may remain with the governing organization while qualified partners support defined activities such as platform operations, content administration, stakeholder engagement, training, and program delivery. This arrangement can preserve national oversight while reducing the operational burden associated with deployment.

5.2.3 Decision Rights and Responsibility Assignment

The selected governance model should be implemented through a charter and responsibility matrix that distinguish strategic authority, technical authority, content authority, security authority, and operational responsibility. The matrix should identify which body recommends, reviews, approves, implements, operates, monitors, and resolves disputes for each major decision area.

Decision rights should be defined for participation policies; metadata and content criteria; national profiles and standards mappings; content publication, revision, archival, and retirement; application programming interfaces and connector changes; security controls and risk exceptions; platform releases; performance targets; funding priorities; and progression between deployment phases. State representation should include agencies at different levels of digital delivery maturity so that national decisions account for both advanced integration needs and practical adoption constraints.

The operating framework should also identify the agreements that support coordination among participating organizations, including participation agreements, content authorizations or licenses, data-access agreements, security responsibilities, service-level expectations, intellectual-property provisions, and procedures for transition, withdrawal, or removal of content. These agreements would convert general governance principles into enforceable responsibilities and reduce uncertainty during deployment.

5.2.4 Ownership, Authority, and Stewardship

Governance and ownership are closely related but distinct. Platform ownership, content ownership, intellectual property, standards authority, and operational responsibility may reside with different entities. Future implementation agreements will therefore need to define these roles explicitly.

For example, a state agency may retain ownership of an artifact while authorizing the CBTL to index, reference, or distribute it. A standards organization may remain the authoritative source for a classification system while the CBTL provides a harmonized national profile or access mechanism. Similarly, the governing organization may retain policy and decision-making authority while delegating selected technical or operational functions to supporting partners.

Clarifying these distinctions early in deployment would reduce ambiguity, protect authoritative sources, and support consistent content stewardship across the CBTL ecosystem.

5.2.5 Program Operations and Service Management

National deployment should establish a production operating model that separates policy and oversight from daily service delivery. The model should identify a service owner, platform operator, content-administration function, security and access-management function, connector owners, training and support leads, and escalation paths to the appropriate governance bodies.

Documented operating processes should address release and change management; incident, problem, and security-event response; source-link and connector health; identity administration; onboarding and offboarding; content-review queues; user support and escalation; planned maintenance; performance and availability monitoring; backup and restoration; continuity of operations; disaster recovery; and service reporting. Connector ownership should be explicit because the reliability of federated access depends on coordinated maintenance between the CBTL operator and authoritative source organizations.

Service objectives and support expectations should be established at a level appropriate to each deployment phase and content type. The operating model should also define how services, content, credentials, documentation, and operational knowledge would be transferred if a vendor, contractor, source organization, or governing arrangement changes.

5.3 Organizational Enablement

The organizational conditions supporting CBTL adoption also support digital delivery more broadly. DOTs with established leadership, governance, workforce development, and technology-support arrangements may be able to incorporate CBTL participation into their existing programs with limited adjustments. Agencies should assess these arrangements against their intended level of CBTL participation and identify any additional responsibilities, capabilities, or resources needed. The following considerations outline how agencies can build on existing programs and address gaps relevant to CBTL adoption.

Section 5.5 describes the training and communications approaches that would support agency participation as deployment progresses.

5.3.1 Adoption Challenges and Readiness Considerations

Readiness assessment should consider how CBTL participation aligns with agency priorities, established workflows, staff capacity, and digital delivery maturity. Existing digital delivery assessments and improvement plans can provide a starting point. Particular attention should be given to the barriers summarized in Table 5, including workforce capacity constraints and limited visibility into existing model content. Participation should be connected to clear business needs, defined responsibilities, and practical benefits.

5.3.2 Leadership Alignment

Existing executive sponsors and digital delivery program leaders can provide oversight for CBTL participation. Their role would include confirming its operational value, assigning accountability, and allocating appropriate staff time and resources. Additional leadership arrangements may be needed where participation extends beyond the scope or authority of an existing program.

5.3.3 Internal Governance

Agencies can use existing governance bodies to assign CBTL responsibilities for content, standards, systems, training, and coordination with the national governing organization. These responsibilities should be integrated across the relevant business and technical functions. Agencies should confirm where existing policies and decision processes are sufficient and where CBTL participation calls for additional agreements or coordination.

5.3.4 Workforce Readiness

Existing training and knowledge-transfer programs can be adapted to prepare staff for their CBTL roles. Depending on the level of participation, these roles may involve discovering and interpreting BIM artifacts, managing metadata, reviewing content, supporting integrations, or training users. Planning should account for staff capacity, turnover, retirements, and differences in digital competency.

CBTL resources should be incorporated into relevant business processes, such as standards development, project scoping, design coordination, construction information exchange, and asset handover. Existing technology and support services should be assessed against these workflows, with targeted adjustments where needed.

5.3.5 Security, Identity, and Access-Control Baseline

A security baseline can be established before pilot configuration and carried forward as a governed national baseline. The baseline should support trusted agency identity integration where feasible, least-privilege access, role-based and attribute-based authorization, separation of administrative and content-approval duties, controlled application programming interface credentials, documented onboarding and offboarding, and periodic review of user and system access.

Content and services should be assigned an access classification that distinguishes resources that are publicly discoverable and downloadable; publicly discoverable with controlled artifact access; restricted to approved participants; limited to metadata or source references; or ineligible for CBTL indexing or access. The classification should inform authentication, authorization, logging, distribution, retention, and review controls.

The technical baseline should also address encryption in transit and at rest; audit logging and traceability; vulnerability, patch, and dependency management; security monitoring; incident reporting and response; backup and recovery; third-party and vendor access; connector security; and periodic security assessment. Responsibility for approving controls, accepting exceptions, and responding to incidents should be assigned through the governance framework.

5.4 Knowledge Management

Knowledge management is integral to the long-term purpose of the CBTL. Transportation agencies continue to face institutional knowledge loss associated with retirement, staff turnover, fragmented systems, project-based documentation, and the rapid evolution of digital delivery practices. The CBTL offers a mechanism for preserving and transferring knowledge that might otherwise remain inaccessible within individual projects, local repositories, or personal experience.

The recommended framework extends beyond the storage of technical artifacts. It positions the CBTL as a knowledge environment in which artifacts are connected to their purpose, lifecycle context, ownership, use cases, standards, and implementation experience. This context increases the value of the underlying content because users can understand not only what an artifact is, but also how and why it is used.

A conceptual CBTL Knowledge Hub may include standards, workflows, implementation guidance, case studies, lessons learned, training materials, frequently asked questions, user videos and resources, and links to subject-matter expertise. Metadata and semantic relationships provide the structure that allows these resources to be discovered and connected across disciplines and lifecycle stages.

The preservation of lessons learned is particularly important. Agencies frequently document successful pilots or implementation challenges without creating a durable mechanism for national reuse. The CBTL can support structured documentation of the conditions under which a practice was applied, the barriers encountered, the outcomes achieved, and the considerations relevant to other agencies.

Knowledge resources benefit from stewardship in the same manner as technical artifacts. Documentation becomes outdated as standards, systems, and practices change. Governance therefore includes responsibility for review cycles, ownership, revision, and retirement. This prevents the CBTL from becoming a collection of unmaintained resources and supports continued trust in the information presented.

5.5 Training and Communications

Building on the organizational readiness considerations in Section 5.3, this section describes how CBTL training and communications would be delivered and sustained across the deployment phases. Their scope evolves as deployment progresses. During targeted pilots, training focuses on orientation, use-case participation, platform interaction, and feedback collection. In the peer exchange phase, it expands to include reusable implementation guidance, shared lessons learned, and the development of agency champions. During broader adoption, the training architecture becomes role-based and scalable. In the mature phase, it supports ongoing updates, advanced practice, new users, and continuous professional development.

A layered training model aligns content with the needs of different user groups. Foundational training introduces the purpose, structure, governance, and value of the CBTL. Role-based training focuses on the functions performed by specific users, while discipline-specific training addresses the artifacts and workflows associated with design, construction, geospatial practice, asset management, standards, and information technology. Advanced training supports contributors, reviewers, administrators, integrators, trainers, and governance participants.

5.5.1 Train-the-Trainer and Agency Champions

A train-the-trainer model provides a practical mechanism for national scaling. The governing organization can prepare agency trainers, program leads, super users, or change champions who adapt national resources to local policies and workflows. These individuals can provide peer support, reinforce new practices, capture lessons learned, and help transfer institutional knowledge across the organization. This approach builds internal agency capacity and reduces long-term dependence on centralized training delivery.

Centralized and reusable training resources further support this model. On-demand tutorials, videos, how-to guides, manuals, onboarding materials, and workflow demonstrations can provide consistent baseline instruction while allowing agencies to tailor content to different offices, disciplines, and levels of digital delivery maturity.

5.5.2 Communications and Program Engagement

Communications perform a related but distinct function. They establish program awareness, explain participation opportunities, communicate platform changes, reinforce value, and provide channels for feedback. Effective communications distinguish among executive, technical, practitioner, and external stakeholder audiences rather than relying on a single national message.

The recommended communications approach combines an initial program launch with recurring updates and knowledge-sharing opportunities. Launch communications can introduce the CBTL, explain its benefits, direct users to available resources, and identify how agencies or individuals can participate. Ongoing communications can share deployment progress, use cases, success stories, training opportunities, platform updates, and calls to action. Regular “office hours,” quarterly knowledge-sharing sessions, and structured feedback mechanisms can help maintain engagement and address questions as adoption expands.

5.5.3 Leadership Communication and Advocacy

Agency leaders can reinforce participation through existing digital delivery communications, explaining how CBTL resources support agency priorities and relevant workflows. Messages should clarify participation expectations, direct staff to training and support, and share examples of practical value. This communication role complements the sponsorship, accountability, and resource considerations addressed in Section 5.3.2.

5.5.4 Consistent Messaging and Program Identity

Consistent terminology and program identity also contribute to adoption. The CBTL spans several technical and organizational domains, and stakeholders may interpret its purpose differently. Centralized messaging, adaptable communication templates, repeatability, and a recognizable program brand identity can reduce confusion and help agencies communicate consistently across offices and projects.

Clear messaging positions the CBTL as a coordinated national infrastructure for discovery, access, standards alignment, and knowledge sharing rather than as a replacement for agency systems or a conventional file repository. Together, the training, program marketing, outreach, and communications architecture supports awareness, onboarding, continued learning, workforce upskilling, and sustained participation throughout the deployment lifecycle.

5.6 Resource Considerations

Future national and state deployment involves coordinated planning across a range of programmatic, technical, operational, and workforce resources. The categories identified in this section provide a foundation for subsequent implementation planning, budgeting, procurement, and funding analysis.

5.6.1 National-Level Resourcing

At the national level, resource considerations include program leadership, governance administration, stakeholder coordination, legal and policy support, technical operations, cloud hosting, cybersecurity, identity and access management, platform development, system integration, content review, metadata management, standards coordination, training, communications, user support, and performance monitoring.

5.6.2 State-Level Resourcing

At the state level, resource considerations include executive sponsorship, program management, internal governance, subject-matter expertise, information technology support, cybersecurity review, standards and content management,

workflow analysis, training participation, change management, pilot support, system integration, and performance measurement.

5.6.3 Cost, Funding, and Procurement Framework

Implementation planning should distinguish one-time development and transition costs from recurring operating and lifecycle costs. One-time costs may include architecture and platform development, pilot configuration, interface and connector development, security assessment, identity integration, metadata preparation, content migration, testing, training development, and initial organizational change activities. Recurring costs may include hosting, storage, network transfer, software and service licensing, platform operations, connector maintenance, content review, standards coordination, cybersecurity, monitoring, backup and recovery, user support, training delivery, communications, governance administration, and continuous improvement.

A responsibility matrix should identify which costs are funded nationally, which are borne by participating states, which are shared, and which remain the responsibility of authoritative source organizations or implementation partners. The analysis should also identify the staffing assumptions and in-kind contributions associated with governance, technical operations, content stewardship, agency integration, training, and performance reporting.

Procurement planning should evaluate the appropriate balance among internal delivery, contracted program support, commercial cloud or software services, open-source components, and specialized implementation partners. Procurement planning should address data portability, documented interfaces, standards-based integration, access to configuration and operational documentation, transition assistance, and the ability to replace a vendor or component without loss of authoritative content or governance control. Selection of a long-term funding mechanism should follow a separate business and funding analysis informed by pilot evidence and validated operating costs.

5.6.4 Software and Hardware Needs

Hardware and software needs will vary by agency and by the depth of participation. Agencies using the CBTL primarily for discovery may need little beyond secure web access and user administration. Agencies contributing content, integrating systems, or embedding CBTL services into operational workflows may use development environments, API support, software configuration, additional security review, and dedicated technical staff.

The phased framework allows resource commitments to grow with demonstrated value and maturity. Targeted pilots benefit from a focused set of participants and technical capabilities. Peer exchange adds coordination, communications, and reusable support resources. Expanded adoption increases training, content, integration, and help-desk demands. National harmonization is supported by sustained governance, standards management, platform maintenance, and continuous improvement.

5.6.5 Dependencies and Deployment Risk Management

Each phase should maintain a dependency register identifying the approvals, organizations, technical capabilities, content, agreements, resources, and external systems supporting successful execution. Key dependencies may include completion of PoC evaluation activities, availability of representative agency artifacts, participation by agencies at different maturity levels, interim governance authority, data and content agreements, security approval, platform availability, procurement and funding authority, qualified content stewards, and access to authoritative standards and repositories.

A corresponding risk register should address insufficient state participation; unresolved ownership, licensing, or intellectual-property conditions; incomplete or inconsistent metadata; unavailable or unstable source-system interfaces; connector or source-link failure; security approval delays; vendor or platform lock-in; excessive content-curation demands; unsustainable operating costs; incompatible standards or version changes; dependence on individual champions; workforce turnover; outdated content; and delayed governance decisions. The trends and barriers in Table 5 provide an evidence-based starting point for populating the register.

Each significant risk should have an assigned owner, likelihood and impact assessment, mitigation action, trigger or early-warning indicator, contingency approach, target resolution date, and current status. Critical dependencies and risks should be reviewed at each phase gate, and unresolved items should be formally accepted, mitigated, or closed before deployment expands. This approach would connect strategic deployment decisions to documented operational conditions and reduce the likelihood that unresolved pilot issues are transferred into national-scale implementation.

6. Implementation Pathway and Next Steps

6.1 Transition from Proof of Concept to Deployment

The PoC framework establishes an approach for conducting and evaluating a CBTL PoC. This chapter identifies how future PoC findings can be translated into a phased, evidence-based deployment pathway. Together, the PoC and deployment planning frameworks provide continuity between technical and user validation, organizational readiness, governance, and potential national implementation.

Capabilities identified as optional, conditional, or outside the baseline PoC scope should not automatically become baseline implementation elements. Their inclusion should depend on validated use cases, documented benefits, technical feasibility, governance approval, and available resources.

Consistent with the phased approach described in Section 3.3, the PoC may evaluate the full scope defined by the framework or a selected subset of use cases, workflows, artifact types, and supporting capabilities. Evaluation and subsequent deployment may therefore proceed incrementally. A defined set of use cases or workflows may advance to implementation when the applicable readiness criteria are satisfied and relevant dependencies, governance approvals, and resource needs have been addressed, while other elements remain under evaluation or are deferred. Completion of the entire PoC scope is not a prerequisite for deployment of an adequately validated subset.

Each deployment decision should be supported by documented evidence of technical feasibility, functional utility, and operational readiness for the scope proposed for implementation. As applicable to that scope, evidence should address federated discovery, metadata harmonization, standards alignment, application programming interface-mediated access, usability, workflow continuity, governance signaling, security and access control, organizational readiness, training needs, scalability, and operating-resource needs. Findings and deployment decisions should clearly identify the evaluated scope, its limitations, and any dependencies on capabilities that have not yet been validated.

The PoC should remain within the boundaries established by the framework. It is not intended to constitute a production platform, replace existing state systems, centralize operational datasets already governed by authoritative sources, or demonstrate full production-scale security and lifecycle governance. Any expansion beyond these boundaries should be supported by a documented use case, governing-body approval, available resources, and an evaluation method appropriate to the additional capability.

6.2 Transition Decision

Following execution and evaluation of the PoC framework, the sponsoring or designated governing organization should conduct a formal readiness review. Conducting this review does not presume that the CBTL will advance; its purpose is to determine whether the available evidence supports continued development, additional testing, modification of the concept, or conclusion of the initiative. The review should determine:

- Which CBTL functions demonstrated sufficient value and feasibility for continued development;
- Which technical components warrant refinement, additional testing, or limited deployment;
- Which content categories and use cases are appropriate for initial implementation;
- Whether the proposed governance, ownership, and stewardship arrangements are sufficiently defined;
- Whether applicable security, access-control, privacy, licensing, and intellectual-property considerations can be addressed;
- Whether participating organizations possess the necessary staffing, funding, technical capabilities, and leadership support;
- Which risks and dependencies warrant resolution before deployment expands; and
- Whether the appropriate decision is to proceed, refine, repeat, pause, or conclude the initiative.

A decision to proceed should result in an approved implementation scope, documented governance authority, designated pilot or early-adopter participants, prioritized use cases and content categories, baseline technical and security criteria, defined performance measures, a resource and funding strategy, and an updated risk and dependency register.

6.3 Initial Implementation and Operational Readiness

If the readiness review supports continued development, subsequent development may include a limited implementation environment based on the capabilities and use cases validated through the PoC. Initial implementation should emphasize high-value, achievable functions while preserving the hybrid Directory–Gateway–Repository model described in the PoC framework.

The initial environment may include a national user interface, federated metadata catalog, search and filtering capabilities, controlled access to authoritative external resources, semantic or data-dictionary services, and limited repository functions for content assigned to national stewardship. The specific platform, hosting environment, integration method, and supporting technologies should be determined through subsequent technical definition, security review, alternatives analysis, and applicable procurement processes.

Operational-readiness activities should define governance procedures, content-stewardship responsibilities, review and approval workflows, security and identity-management controls, platform-support processes, service objectives, training resources, communication mechanisms, user-support procedures, and performance-reporting needs. These capabilities should be tested at a scale appropriate to the participating organizations before broader adoption.

6.4 Broader Adoption and National Scaling

Incremental expansion beyond the initial implementation is recommended, informed by the governing organization's assessment of prior-phase performance and readiness. Broader adoption may include additional state participants, content categories, use cases, integrations, training resources, and governance functions.

National scaling does not depend on participating agencies replacing their internal systems or adopting identical implementation methods. Instead, the CBTL should promote interoperability, common discovery, coordinated stewardship, standards alignment, knowledge sharing, and reusable implementation resources while preserving state authority over locally governed systems, content, policies, and workflows.

As participation expands, the governing organization should maintain formal processes for performance monitoring, stakeholder feedback, standards coordination, content lifecycle management, security oversight, risk management, workforce development, and continuous improvement. The scope and pace of expansion should remain proportional to demonstrated value, institutional readiness, and available resources.

6.5 Organization and Technology Neutrality

This deployment planning framework does not select a governing organization, implementation partner, software provider, hosting environment, or procurement approach. AASHTO has been identified as one potential national coordinating organization because of its state-based membership and existing committee and standards-development structures; however, final governance and ownership decisions remain with FHWA and other authorized stakeholders.

Similarly, the identification of a technical concept, platform example, or potential implementation resource during research does not constitute endorsement or preselection. Future platform and partner decisions should follow approved criteria, alternatives analysis, security and interoperability considerations, applicable procurement procedures, and the findings generated through the PoC.

The framework presented in this report identifies the technical, organizational, and governance considerations that would inform a future CBTL proof of concept and potential deployment. Before pilot execution, the sponsoring organization and participating agencies would need to confirm the evaluation scope, available resources, stakeholder responsibilities, and conditions necessary to support a structured assessment. Table 22 summarizes recommended preparatory actions and the corresponding planning outputs.

Table 22. Recommended Preparatory Actions for Future CBTL Pilot Evaluation

Proposed action	Expected output
Confirm priority use cases	Defined pilot scope
Identify participating agencies	Stakeholder participation plan
Confirm representative artifacts	Dataset and metadata inventory
Define technical capabilities	Pilot configuration baseline
Establish evaluation criteria	Proposed test and evaluation protocol
Identify interim governance responsibilities	Responsibility and decision framework
Assess staffing, resources, and dependencies	Readiness and resource assessment
Conduct pre-pilot readiness review	Decision on whether to authorize pilot activities

The sequence and timing of these actions would depend on future program decisions, available resources, and participating agency commitments. The recommendations do not represent an approved pilot schedule or authorization

to implement the CBTL. Rather, they identify the preparatory conditions necessary to translate the completed research and planning framework into a controlled future evaluation.

6.6 Conclusion

The proof of concept and deployment planning work collectively provide an evidence-based pathway for advancing the CBTL concept. The PoC framework defines what can be evaluated, who can participate, and how findings can be collected. The deployment planning framework identifies how future evidence can inform governance, content stewardship, organizational enablement, resource planning, phased adoption, and potential national scaling.

The recommended approach does not assume that the CBTL has already been validated or that national deployment is predetermined. Instead, it provides FHWA, AASHTO, participating state departments of transportation, and other authorized stakeholders with a structured decision framework for determining whether, how, and at what pace the CBTL could advance. Future implementation decisions can therefore be based on documented evidence, operational realities, cross-agency collaboration, and demonstrated value.

7. References

Bhargava, A., Parve, L., Chipman, T., Bouknight, S., & Mallela, J. (2024). BIM Workflows and Centralized BIM Transportation Library for Bridges and Roadways (FHWA-HIF-24-004). Federal Highway Administration, Office of Bridges and Structures. https://www.fhwa.dot.gov/bridge/pubs/hif24004.pdf

Costin, A., Ketterl, M., & Grant, R. (2025). Towards a Centralized BIM Transportation Library. National Institute of Building Sciences. https://rosap.ntl.bts.gov/view/dot/86424

Note: Sources for the Transportation Pooled Fund studies TPF-5(372), TPF-5(523), and TPF-5(480), the FHWA Digital As-Builts initiative, and the FHWA and NCHRP pilot assessment guidance cited in Chapter 2 are documented in the references of Costin, Ketterl, & Grant (2025).

Appendix A. Use Case and BIM Artifact Evaluation Detail

This appendix presents the detailed use-case evaluation that underlies Section 2.2. Each priority use case was reviewed to understand its objectives, decision points, and information dependencies, emphasizing what information is needed to perform the task, how that information is represented, and how it is exchanged across stakeholders and systems. Artifact identification was driven by workflow intent and information needs rather than by assumptions about specific software platforms, data formats, or repositories. Table A-1 summarizes which artifact types each use case explicitly uses and which it could use; the narratives that follow explain the role each artifact plays.

Table A-1. BIM Artifact Usage per Priority Use Case

Use case	1. Proc.	2. Info. needs	3a. Models	3b. OTL	3c. Param.	3d. Cells	4. Dict.	5. IDM	6. Exch.	7. MVD	8. IDS	9. Geo.
1. PSD.1: Planning scoping documents	✓	✓	✓	◐	◐	◐	◐	◐	◐	◐	◐	✓
2. PSD.3: Visualization for alternatives	✓	✓	✓	◐	◐	◐	◐	◐	◐	◐	◐	✓
3. DA.9: Coordination and clash detection	✓	◐	✓	◐	◐	◐	◐	◐	✓	✓	◐	✓
4. DA.11: Structural analysis model	✓	✓	✓	◐	◐	◐	◐	◐	◐	◐	◐	—
5. DA.12: Final plans and model (PS&E)	✓	✓	✓	◐	◐	◐	◐	◐	◐	◐	◐	—
6. DC.2: Quantity take-off (QTO)	✓	✓	✓	◐	◐	◐	◐	◐	◐	◐	◐	✓
7. DC.3: AMG design information	✓	✓	✓	◐	◐	◐	◐	◐	◐	◐	◐	✓
8. DC.6: Shop drawings / LOD 400	✓	✓	✓	◐	◐	◐	◐	◐	◐	◐	◐	—
9. DC.7: As-built verification	✓	✓	✓	◐	◐	◐	◐	◐	◐	◐	◐	✓
10. DCA.3: Bridge inspection for AIM	✓	✓	✓	◐	◐	◐	✓	◐	◐	◐	◐	✓

Notation: ✓ = used (explicitly called for by the use case); ◐ = could be used (not explicitly called for, but functionally applicable or beneficial); — = not applicable. Column headings abbreviate the artifact categories defined in Table 3. Use case identifiers and names follow Table 2-2 of Bhargava et al. (2024).

Use Case 1 (PSD.1): Create Project Scoping Documents from Planning Data

This use case involves developing project scoping documents by assembling a planning data model that organizes key information for early decision-making. The planning model consolidates project location, roadway characteristics, asset conditions, anticipated work needs, traffic information, and high-level cost considerations. These data elements are structured into property sets, enabling consistent communication of scope and context among multidisciplinary teams during the transition from planning to design.

The planning model is implemented as an object-based or entity-based dataset within a geodatabase, providing integrated spatial and tabular information that supports conceptual design, existing conditions modeling, survey planning, environmental evaluation, and preliminary engineering tasks. While the dataset includes structured attributes organized in a BIM-like manner, there is no indication that it is produced using an object-type library, parametric object library, or 3D cell library. The structured nature of the data may resemble standardized object definitions, but their use is not demonstrated.

Geospatial data plays a central role, as the geodatabase manages project extents, roadway alignments, terrain information, asset locations, and other spatial attributes for downstream modeling and analysis. The combination of spatial context and structured property sets describes the essential information needs for project scoping activities.

Used

- BIM models: planning model containing structured property sets.
- BIM information needs: property sets and fields defining scoping information.
- BIM processes and workflows: planning and project scoping sequence.
- Geospatial data: spatial assets, routes, terrain, and project extents stored in a geodatabase.

Can be used

- Data dictionary: standardize attribute definitions for planning models.
- Object-type library (OTL): a statewide or national OTL could specify standard classes for planning-level roadway segments, assets, and project extents.
- Parametric object library: parametric components for corridors, alignments, or asset assemblies could enable automated scoping model generation.
- 3D cells: simple 3D asset representations (for example, signs, barriers) could improve visualization and consistency in planning models.
- Information Delivery Manuals (IDM): formalize the planning-to-design handoff.
- Information Delivery Specifications (IDS): validate attribute completeness for planning data submissions.
- Model View Definitions (MVD): describe planning-specific IFC subsets for data exchange.
- Information exchange specifications: enable structured transfer of planning model data into early design tools.

Use Case 2 (PSD.3): Create Visualizations for Alternatives Evaluation and Public Outreach

This use case involves producing conceptual and preliminary visualization models that support the evaluation of design alternatives, environmental considerations, and public communication. Visualization modeling draws on multiple information sources, including the planning model created during PSD.1, survey datasets, right-of-way information, environmental constraints, and conceptual or preliminary design inputs from various disciplines. The resulting models incorporate terrain surfaces, roadway geometry, structural elements, utilities, grading features, and other components needed to represent proposed alternatives in a clear, spatially accurate manner.

Visualization workflows rely on both existing conditions models and conceptual or preliminary design representations. Existing conditions are established through survey-derived reality capture data such as photogrammetry, lidar, uncrewed aircraft system (UAS), imagery, and global navigation satellite system (GNSS) measurements. These datasets provide spatial control and terrain context, allowing proposed alternatives to be placed accurately within the modeled environment.

The presence of structured elements within the visualization models does not demonstrate the use of object-type libraries, parametric libraries, or 3D component libraries. Although such resources are common in visualization practice, this workflow does not provide evidence that they were employed. The data categories for visualization, such as roadway geometry, environmental features, and utility information, represent clear and explicit information needs for this use case.

Used

- BIM models: existing conditions models and conceptual or preliminary visualization models used to develop alternative design representations.
- BIM information needs: data categories for visualization, including roadway geometry, structures, drainage, utilities, traffic features, and environmental constraints.
- BIM processes and workflows: steps involved in generating, refining, and evaluating visualization alternatives.
- Geospatial data: terrain models, imagery, lidar, photogrammetry, and GNSS datasets providing spatial accuracy and geographic context.

Can be used

- Object-type library (OTL): standardized classes for reusable visualization components such as roadway furniture, structural features, or vegetation.
- Parametric object library: parametric roadway and structural assemblies enabling automated updates during alternatives refinement.
- 3D cells: reusable 3D visualization assets that improve modeling consistency and efficiency.
- Data dictionary: standardized attribute definitions for alternative scenarios and mitigation elements to support consistent comparison.
- Model View Definitions (MVD): subsets of IFC entities and properties tailored to visualization workflows.
- Information Delivery Specifications (IDS): automated validation of geometry, metadata, and environmental attributes.
- Information Delivery Manuals (IDM): structured guidance for producing and exchanging visualization models at key planning and environmental milestones.
- Information exchange specifications: standardized formats supporting transfer of visualization data into rendering platforms or analysis tools.

Use Case 3 (DA.9): Interdisciplinary Coordination and Clash Detection

This use case involves coordinating multiple discipline-specific design models within a shared environment to identify geometric conflicts and ensure design consistency. Each discipline, such as roadway, structures, drainage, utilities, geotechnical, and traffic and safety, produces its own BIM model. These individual models are then combined into a federated coordination model that supports structured review processes. The workflow emphasizes model-based integration rather than manual comparison of 2D documents, enabling more systematic evaluation of spatial and functional interactions between discipline elements.

Coordination depends on data exchanges and quality control checks that ensure each discipline model is correctly aligned and complete for integration. Model View Definitions (MVDs) are explicitly used to transfer subsets of data between modeling environments, making this one of the cases where the exchange mechanism is clearly identified. Although the models contain structured elements typical of standardized component definitions, there is no indication that an object-type library, parametric object library, or 3D cell library was used to generate them.

Accurate spatial alignment is essential for interdisciplinary coordination, and this is achieved through an existing conditions survey model created from photogrammetry, lidar, imagery, and GNSS data. This geospatial foundation provides the reference frame in which all discipline models should be correctly positioned to support clash detection and integrated design review.

Used

- BIM models: discipline models, federated coordination model, and survey-based existing conditions model used for spatial alignment and clash evaluation.
- BIM processes and workflows: interdisciplinary coordination and clash detection procedures.
- Model View Definitions (MVD): explicit mechanism for transferring discipline-specific model subsets into coordination workflows.
- Information exchange specifications: specified rules guiding discipline-to-coordination data transfer and QA/QC checks.
- Geospatial data: reality capture datasets providing spatial reference for accurate model integration.

Can be used

- BIM information needs: formalized attributes for discipline models entering coordination cycles.
- Object-type library (OTL): standardized definitions for roadway, structural, utility, and drainage components to enhance semantic consistency.
- Parametric object library: parametric assemblies for common discipline elements to improve uniformity across models.
- 3D cells: reusable components to streamline model development and ensure consistent representations.
- Information Delivery Specifications (IDS): automated validation of discipline models for completeness prior to federation.
- Information Delivery Manuals (IDM): structured coordination workflows defining responsibilities, frequency, and model content.
- Data dictionary: unified terminology and attribute definitions to reduce semantic inconsistencies across disciplines.
- Additional MVDs: specialized view definitions tailored to specific coordination or clash detection scenarios.

Use Case 4 (DA.11): Develop Final Structural Analysis Model

This use case involves producing a structural analysis model, typically at a level of development consistent with LOD 300, to evaluate structural performance and confirm compliance with design standards. Structural analysis is often performed using spreadsheets or stand-alone finite element analysis (FEA) tools, which historically operate separately from BIM environments. A BIM-enabled workflow improves this process by deriving the analytical model directly from the structural design model, ensuring that geometry, material definitions, section properties, and connectivity relationships are consistently represented.

The analytical model produced in this workflow is explicitly identified as a BIM output derived from the design model. It includes the structural attributes for load calculations and compliance checks, such as member types, section dimensions, material characteristics, and force paths. These attributes constitute clear examples of information needs for structural analysis. The workflow also reflects the presence of BIM processes and workflows governing the transition from geometric design to analytical representation.

There is no direct mention that MVDs, IDS, IDMs, or information exchange specifications are used to export or validate the analytical model. Although beams, girders, piers, and deck elements may resemble components commonly found in object-type or parametric libraries, the use case narrative does not indicate that such resources were used. Geospatial data is not required for this analytical task and is not included under the artifacts explicitly used.

Used

- BIM models: structural design model and derived analytical model used for structural evaluation.
- BIM information needs: structural attributes such as geometry, materials, section properties, and connectivity.
- BIM processes and workflows: procedures for developing an analytical model from the structural design model.

Can be used

- Object-type library (OTL): a structural OTL defining standardized beam, girder, pier, and deck element types could ensure consistent analytical representation.
- Parametric object library: parametric structural components could automate analytical model generation and reduce manual re-input into FEA tools.
- 3D cells: 3D analytical elements could enable more rapid modeling for repetitive components.
- Information exchange specifications: standard BIM-to-FEA exchange formats (for example, the IFC Structural Analysis View or specialized analysis schemas) could improve interoperability.
- Model View Definitions (MVD): a structural analysis MVD could identify the IFC entities and properties needed for analysis-ready models.
- Information Delivery Specification (IDS): IDS could validate whether structural models contain the materials, section properties, and analytical attributes prior to FEA export.
- Information Delivery Manuals (IDM): an IDM could formalize when structural analysis models are created, updated, and validated during design development.
- Data dictionary: a unified dictionary of structural attributes could harmonize terminology across BIM authoring tools, FEA platforms, and DOTs.

Use Case 5 (DA.12): Produce Final Plans and Model

This use case involves developing the final design model and the associated plan sheets that form the plans, specifications, and estimates (PS&E) package. The final design model is produced after discipline-specific BIM models have been coordinated, validated, and checked for conflicts earlier in the workflow. It should contain geometry, attributes, and configuration information consistent with the level of development needed to support downstream construction, fabrication, estimation, and stakeholder interpretation. This model becomes the authoritative digital representation on which contractors and other parties rely during bidding and project execution.

Model development progresses through stages, such as the preliminary design model, advanced design model, and final design model, each refined to reflect increasing detail and accuracy. These models are explicitly identified as BIM artifacts within the workflow and serve as the foundation for generating contract plan sheets. The final design model incorporates structured attributes associated with discipline elements, which qualify as information needs that should be satisfied before the model is used for PS&E production.

Although the model contains structured information that could be associated with object-type definitions or parametric assemblies, there is no direct mention that object-type libraries, parametric libraries, or 3D cells are used to build the final design model. Geospatial data is not specifically mentioned, but it would be helpful for topographical details, earthwork quantities, and survey alignment.

Used

- BIM models: preliminary, advanced, and final design models serving as the structured basis for PS&E deliverables.
- BIM information needs: attributes, geometry, and configuration necessary for contract-ready model content.
- BIM processes and workflows: steps for preparing, validating, and finalizing design models and plan sheets.

Can be used

- Object-type library (OTL): a design-stage OTL could specify standardized roadway, structural, drainage, and utility components used in final design modeling.
- Parametric object library: parametric assemblies (for example, guardrails, decks, retaining walls) could streamline updates across the design model.
- 3D cells: predetermined 3D components could improve consistency in final deliverables.
- Information exchange specifications: standardized formats for delivering the final design model to contractors

and CDEs.

- Model View Definitions (MVD): a final design MVD could describe which IFC entities and properties constitute the contract-ready digital deliverable.
- Information Delivery Specification (IDS): automated validation of the final design model to ensure that attributes and geometry meet contract specifications.
- Information Delivery Manuals (IDM): an IDM could formalize the preparation, QA/QC, review, and approval process for final design models and plans.
- Data dictionary: a standardized dictionary of design attributes could enhance consistency across DOTs and software platforms.
- Geospatial data: final model geospatial checks could ensure proper alignment with survey control when preparing for construction.

Use Case 6 (DC.2): Detailed Quantity Take-Off and Estimate

This use case involves performing detailed quantity take-off (QTO) and cost estimation using BIM models. Quantity derivation depends on design information such as geometry, material attributes, section configurations, and component assemblies. Multiple design models, including the conceptual, preliminary, advanced, and final design models, may contribute to QTO depending on their respective levels of development and completeness.

QTO processes should have well-described dimensions, units, material classifications, pay-item relationships, and other structured attributes that enable quantities to be calculated accurately. These represent explicit information needs associated with model elements that drive estimating activities. The workflow for extracting and validating quantities, comparing results, and preparing estimates demonstrates the presence of BIM processes and workflows that govern how design data is translated into measurable quantities.

Although QTO-ready objects often benefit from object-type libraries, standardized component definitions, or parametric assemblies, there is no indication that such resources are used in this workflow. Geospatial data is explicitly incorporated when QTO involves earthwork, as terrain surfaces and grading models are used to determine cut-and-fill volumes and related quantities.

Used

- BIM models: conceptual, preliminary, advanced, and final design models used to extract quantities.
- BIM information needs: geometric, material, and attribute information for deriving quantities and assigning pay items.
- BIM processes and workflows: procedures for extracting quantities, validating calculations, and preparing estimates.
- Geospatial data: terrain and grading surfaces used to compute earthwork quantities.

Can be used

- Object-type library (OTL): standardized object definitions for structural, roadway, and drainage components could ensure consistent quantification across models.
- Parametric object library: parametric objects tied to design standards could automate quantity updates as design changes occur.
- 3D cells: 3D components (inlets, barriers, pipes, beams) could support consistent measurement rules for quantities.
- Information exchange specifications: standard schemas for exporting model-based quantities into estimating software.
- Information Delivery Specification (IDS): automated checking ensuring that quantity-driving elements contain necessary properties.
- Model View Definitions (MVD): a QTO-oriented MVD could restrict exchanges to quantity-bearing entities and attributes.
- Information Delivery Manuals (IDM): formal workflows defining when QTO-ready models are delivered and reviewed.
- Data dictionary: a standardized dictionary for materials, units, pay items, and measurement rules could harmonize QTO practices across agencies.

Use Case 7 (DC.3): Provide Design Information for Automated

Machine Guidance

This use case involves generating design information suitable for automated machine guidance (AMG), which supports machine-controlled construction equipment such as dozers, graders, excavators, and paving machines. AMG workflows depend on a collection of BIM-based design models that provide the geometric, spatial, and material information for automated construction. Models explicitly referenced for this workflow include the survey model, roadway geometry model, pavement section model, roadway corridor model, drainage model, and grading model.

AMG relies on precise alignments, profiles, cross-sections, pavement layers, design surfaces, and other geometry necessary for equipment guidance. These represent explicit information needs because they identify the attributes and level of detail needed to translate design intent into machine-executable instructions. The presence of a survey model constructed from aerial photogrammetry, lidar, GNSS observations, and other forms of reality capture establishes a definitive role for geospatial data.

The AMG preparation narrative includes the steps necessary to generate design surfaces, extract alignment information, convert geometric data into machine-readable files, and verify model accuracy before field deployment. Although AMG workflows often rely on standardized roadway templates, parametric assemblies, or object libraries in industry practice, the use case does not identify any object-type library, parametric library, or 3D cell resource.

Used

- BIM models: survey, roadway geometry, pavement section, roadway corridor, drainage, and grading models used to produce AMG-ready deliverables.
- BIM information needs: geometric and material attributes such as alignments, profiles, cross-sections, pavement layers, and design surfaces.
- BIM processes and workflows: steps for preparing AMG data, validating model content, and generating machine-readable files.
- Geospatial data: reality capture datasets (photogrammetry, lidar, GNSS) providing spatial control for AMG surfaces and alignments.

Can be used

- Object-type library (OTL): standardized definitions for surfaces, breaklines, control features, and corridor components could ensure consistency across AMG data outputs.
- Parametric object library: parametric roadway assemblies and templates could automate the generation of AMG surfaces as design updates occur.
- 3D cells: reusable components (for example, drainage structures, roadway assets) could improve consistency in AMG model exports.
- Model View Definitions (MVD): an AMG-oriented IFC 4.3 MVD could specify entities for alignment-based and surface-based construction automation.
- Information Delivery Specification (IDS): IDS could validate that AMG models meet tolerances, coordinate systems, and attribute standards before field deployment.
- Information Delivery Manuals (IDM): IDMs could formalize responsibilities, schedules, and deliverables for preparing AMG-ready models.
- Information exchange specifications: standardized formats for transferring alignment and surface models to machine control systems (proprietary and open data schemas).
- Data dictionary: a unified dictionary defining terms such as finished grade, subgrade, alignment, and breakline would improve consistency across DOTs and contractors.

Use Case 8 (DC.6): Develop and Review Shop Drawings and Models

This use case involves generating and reviewing fabrication-level models and shop drawings, typically developed at a level of development consistent with LOD 400. These models contain the detailed information fabricators need to manufacture structural components such as girders, precast elements, rebar cages, steel assemblies, and connection hardware. The final detailing model, identified explicitly as an input to this workflow, serves as the authoritative BIM model used to support fabrication preparation.

Fabrication models should contain precise geometric definitions, material specifications, tolerances, camber information, fastener types, splice details, and other constructible attributes. These represent clear information needs because they identify the data necessary for accurate fabrication and contractor coordination. The narrative describing shop drawing preparation and review outlines steps for verifying completeness, checking constructability, coordinating with engineering review teams, and revising detailing content, demonstrating the presence of BIM processes and workflows.

Although fabrication modeling frequently uses parametric objects, standardized detailing components, or object-type libraries in industry practice, none of these are explicitly referenced in the workflow. Because the focus of the use case is on component fabrication rather than spatial validation or site integration, geospatial data is not explicitly part of this workflow.

Used

- BIM models: final detailing model (LOD 400) used as the basis for producing fabrication-ready content and shop drawings.
- BIM information needs: detailed geometric, material, connection, and tolerance attributes for fabrication preparation.
- BIM processes and workflows: steps for developing, reviewing, and revising shop drawings and detailed fabrication models.

Can be used

- Object-type library (OTL): a fabrication OTL for girders, rebar elements, precast components, and steel assemblies could improve standardization and reduce modeling inconsistencies.
- Parametric object library: parametric detailing components could automate updates to fabrication models and shop drawings when design changes occur.
- 3D cells: predetermined fabrication subcomponents (for example, bolts, plates, connections, embedments) could streamline detailing workflows.
- Information exchange specifications: standard schemas for exporting fabrication-ready BIM data to shop drawing or manufacturing software (for example, IFC4Precast, IFC4Steel subsets).
- Model View Definitions (MVD): fabrication-specific MVDs could standardize exchanges for structural steel, precast concrete, or bridge component fabrication.
- Information Delivery Specification (IDS): IDS could validate that fabrication models meet tolerances, materials, and completeness needed prior to review.
- Information Delivery Manuals (IDM): IDMs could formalize the workflow for exchanging models and shop drawings between designers, fabricators, and contractors.
- Data dictionary: standardized definitions for fabrication-related attributes such as material grades, connection types, and tolerance classifications.

Use Case 9 (DC.7): Verify Construction Results and Record As-Built Data

This use case involves verifying constructed work and developing an as-built model that reflects actual field conditions, typically ranging from LOD 300 to LOD 500 depending on the level of detail. Two BIM models are explicitly part of this workflow: the existing conditions model and the as-built model. Construction verification relies extensively on reality-capture technologies such as lidar, photogrammetry, UAS imagery, GNSS observations, and terrestrial scanning. These datasets provide accurate spatial information used to assess deviations between the constructed work and the design intent, which constitutes explicit use of geospatial data.

As-built modeling identifies structured attributes that describe installed components, their physical characteristics, their condition, and installation-specific metadata. These represent clear information needs because they identify the properties necessary to document and validate constructed features. The presence of consistent attribute definitions, such as component type, installation date, and measured dimensions, indicates reliance on a data dictionary, as these attributes should be standardized to ensure meaningful comparison and data continuity across construction and asset management workflows.

The workflow includes steps for comparing field measurements to design geometry, identifying discrepancies, updating the as-built model to reflect true conditions, and preparing the resulting model for downstream asset management integration. These activities demonstrate the use of BIM processes and workflows.

Used

- BIM models: existing conditions model (LOD 300/500) and as-built model (LOD 300/500) used to document and compare field conditions.
- BIM information needs: attributes describing installed components, dimensions, conditions, and metadata needed for construction documentation.
- BIM processes and workflows: procedures for verifying construction results, updating model geometry, and preparing as-built deliverables.
- Geospatial data: reality-capture datasets (lidar, photogrammetry, UAS, GNSS, terrestrial scanning) used for

construction verification.

Can be used

- Object-type library (OTL): an OTL containing standardized as-built element classes (for example, installed materials, structural elements, utilities) could support more uniform field capture and modeling.
- Parametric object library: parametric components could allow rapid updating of as-built models as measured dimensions change.
- 3D cells: reusable 3D components could streamline representation of field-installed elements.
- Information exchange specifications: standardized schemas could support as-built data exchange between contractors, DOTs, and asset management systems.
- Model View Definitions (MVD): an as-built MVD could identify which IFC entities and attributes need to be included to support downstream workflows (for example, asset management, inspections).
- Information Delivery Specification (IDS): IDS could automate quality checks to ensure as-built models contain fields such as installation dates, material records, and location accuracy.
- Information Delivery Manuals (IDM): an IDM could formalize the construction verification process, including roles, responsibilities, and data needed at each project milestone.
- Data dictionary: standardized definitions for as-built attributes enabling consistent data capture and comparison.

Use Case 10 (DCA.3): Provide Routine Bridge Inspection Data for Asset Management

This use case addresses the integration of routine bridge inspection data into an asset information model (AIM) to support asset management activities. The workflow uses a GIS-based AIM, identified at LOD 300/500, which serves as the central BIM model for organizing bridge geometry, materials, condition states, element-level assessments, and defect information.

Bridge inspection activities depend on structured information established by inspection standards such as the National Bridge Inventory (NBI), the AASHTO Bridge Management Elements (BME), and state-level inspection standards. These standards determine the attributes, condition ratings, and defect classifications that inspectors need to document, making them clear examples of BIM information needs. Because these standards provide authoritative definitions for bridge elements, conditions, and terminology, they also function as a data dictionary within the workflow.

The AIM is geospatially anchored, incorporating spatial locations for bridge elements, inspection observations, and defect locations, which establishes explicit use of geospatial data to support mapping, visualization of deterioration patterns, and maintenance planning. The workflow narrative describes procedures for collecting inspection data, assessing condition, recording defects, and updating the AIM. Although the AIM includes recurring bridge elements such as decks, girders, piers, bearings, and joints, the use case does not indicate that object-type libraries, parametric object libraries, or 3D cells are used in constructing or updating the AIM.

Used

- BIM models: GIS-based asset information model (LOD 300/500) containing structural elements, attributes, and inspection data.
- BIM information needs: inspection attributes defined by NBI, BME, and state-level standards.
- Data dictionary: standardized element definitions, condition states, and defect classifications derived from inspection standards.
- BIM processes and workflows: inspection procedures for collecting data, assessing conditions, documenting defects, and updating the AIM.
- Geospatial data: spatial referencing of bridge elements, inspection observations, and deterioration locations within a GIS environment.

Can be used

- Object-type library (OTL): a bridge-specific OTL could identify standardized classes for elements (for example, girders, decks, piers, abutments, joints), improving consistency in inspection data capture.
- Parametric object library: parametric bridge elements could enable semi-automated updating of inspection models as condition or geometry changes.
- 3D cells: 3D bridge components could support richer AIM visualizations for inspection, deterioration mapping, or maintenance planning.
- Information exchange specifications: standardized formats for transferring inspection data to asset management systems could improve interoperability.

- Model View Definitions (MVD): an inspection-focused MVD could identify the IFC entities and attributes needed to support NBI and BME reporting and AIM integration.
- Information Delivery Specification (IDS): IDS could machine-check that inspection datasets include required fields before being accepted into the AIM.
- Information Delivery Manuals (IDM): IDMs could formalize inspection data collection, digital form design, handoff procedures, and AIM update responsibilities.

Appendix B. Technical Capability Analysis by BIM Artifact

This appendix presents the artifact-by-artifact technical capability analysis that underlies the hybrid implementation model in Section 2.3 and the minimum technical layer in Table 10. The analysis has three parts: a capability baseline for each artifact type (Table B-1), assignment of a CBTL interaction role to each artifact type (Step 2 in Table 1, Tables 7 through 9), and refinement of the baseline to match the assigned role (Step 3 in Table 1, Table B-2, summarized in Table 10). Each component was evaluated at the capability level (for example, "API gateway and management" rather than a specific product) so that the analysis remains technology-agnostic. Abbreviations used in the matrices: OTL = object-type library; IDM = Information Delivery Manual; MVD = Model View Definition; IDS = Information Delivery Specification; bSDD = buildingSMART Data Dictionary; NTL = National Transportation Library; SDC = U.S. Department of Transportation (USDOT) Secure Data Commons; AMS = asset management system; CDE = common data environment; NTAD = National Transportation Atlas Database; NBI = National Bridge Inventory.

Indicator Definitions

Each technical component was assigned one of four indicators for each BIM artifact type:

- ✓ Used: the component is necessary to support the artifact's function, access, governance, or lifecycle management.
- ◐ Conditional or optional: the component may be used depending on implementation choices, maturity level, or whether the CBTL acts as a directory, gateway, or repository for that artifact.
- X Intentionally avoided: the component should not be implemented for that artifact, typically to avoid duplication, overreach, or inappropriate centralization (for example, storing heavy operational data already managed in agency systems).
- — Not applicable: the component has no meaningful role for the artifact type.

Assignments were made conservatively, favoring minimal capability and explicitly identifying cases where platform features should not be applied. Common triggers that elevate a conditional component to required status include: database infrastructure when artifacts need full structured storage rather than metadata indexing; API gateway and middleware when artifacts must be accessed programmatically by external tools rather than through the interface alone; event or message brokers when real-time event propagation, publish-subscribe patterns, or asynchronous notifications are needed; artifact storage and version control for repository-mode artifacts requiring centralized governance; standards connectors when semantic alignment or terminology synchronization with authoritative sources such as bSDD is necessary; and agency system connectors only when direct operational integration with CDEs or asset management systems is explicitly needed.

Capability Baseline by BIM Artifact (before role alignment)

The technical components were grouped into eight categories reflecting modern digital platform architecture. The assignment rationale by category was as follows:

- Cloud and data platform: a cloud-based platform is used across all artifact types to support scalability, availability, and access. Database infrastructure is used where artifacts need full structured storage or metadata indexing (for example, geospatial metadata) and conditional where only minimal linkage or referencing is needed.
- Identity, access, and security: authentication, authorization, encryption, and audit capabilities are used across all artifacts, reflecting the need for secure, role-aware access regardless of artifact type or hosting model.
- API gateway, middleware, and data exchange: API and middleware capabilities are used for artifacts supporting automated workflows, tool integration, or real-time exchange (BIM models, IDMs, MVDs, IDS, geospatial data). Event and message brokers are conditional across all artifacts because their necessity depends on whether asynchronous event propagation, real-time synchronization, or publish-subscribe patterns are used.
- Artifact repository and version control: centralized storage, version control, and quality checks are used for artifacts that are nationally governed, curated, or standardized (object libraries, data dictionaries, IDMs, MVDs, IDS) and intentionally avoided for heavy operational datasets such as geospatial or agency-managed inspection data.
- Semantics, query, and knowledge services: semantic services and advanced search are used or conditional for most artifacts, particularly those relying on structured definitions, relationships, or cross-artifact alignment.
- External integrations: standards connectors are used or conditional where alignment with external authoritative

sources is necessary. Direct agency system connectors are limited to artifacts that explicitly interact with operational systems and intentionally avoided elsewhere.

- Geospatial and asset referencing: geospatial services apply only where artifacts are spatially anchored. The CBTL intentionally avoids storing full geospatial datasets, which remain in authoritative systems such as NTAD and NBI, while indexing geospatial metadata to enable discovery, spatial querying, and linking.
- User interface and engagement: user-facing capabilities, including dashboards, search interfaces, and training resources, are used to support usability, adoption, and effective interaction with all artifact types.

Table B-1 records the capability baseline before role alignment. Cloud hosting, identity and security controls, semantic search, and user interface functions apply across all artifact types. API and middleware capabilities apply to artifacts that support automated workflows, tool integration, or real-time exchange. Centralized storage, version control, and quality checks apply to artifacts that are nationally governed, curated, or standardized and are intentionally avoided for heavy operational datasets such as geospatial inventories. Geospatial services apply only where artifacts are spatially anchored; the CBTL indexes geospatial metadata to enable discovery and linking but does not store full geospatial datasets, which remain in authoritative systems such as NTAD and NBI.

Table B-1. BIM Artifact and CBTL Technical Capability Matrix (before role alignment)

Capability group	Technical component	1. Proc.	2. Info. needs	3a. Models	3b. OTL	3c. Param.	3d. Cells	4. Dict.	5. IDM	6. Exch.	7. MVD	8. IDS	9. Geo.
Cloud and data platform	Cloud-based platform (AWS/Azure/SDC)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Database infrastructure (multi-format)	◐	◐	◐	✓	✓	◐	✓	✓	✓	✓	✓	✓
Identity, access, and security	OAuth / OpenID / SSO	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	ABAC / RBAC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Zero-trust controls (MFA, least privilege)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Encryption and key management	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Audit logging and monitoring	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
API gateway, middleware, and data exchange	API gateway and management	◐	◐	✓	◐	◐	✓	✓	✓	✓	✓	✓	✓
	Middleware validation and governance	◐	◐	✓	◐	◐	✓	✓	✓	✓	✓	✓	◐
	Event / message broker	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
Artifact repository and version control	Artifact storage (files and metadata)	◐	◐	◐	✓	✓	◐	✓	✓	✓	✓	✓	X
	Version control (identifiers, history)	◐	◐	◐	✓	✓	◐	✓	✓	✓	✓	✓	X
	Data pipelines and orchestration	—	—	✓	◐	◐	✓	✓	◐	✓	✓	✓	✓
	Automated intake conformance checks (type, format, schema, metadata)	—	—	✓	✓	◐	✓	✓	✓	✓	✓	✓	X
Semantics, query, and knowledge services	Data dictionary / ontology service	◐	◐	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Advanced semantic search	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Graph / semantic linking	◐	◐	✓	✓	✓	◐	✓	✓	✓	✓	✓	✓
External integrations	Standards connectors (bSDD, NTL, SDC)	◐	◐	✓	◐	◐	◐	✓	✓	✓	✓	✓	✓
	Agency system connectors (AMS, CDEs)	X	X	✓	X	X	✓	X	X	X	X	X	✓
Geospatial and asset referencing	Geospatial data connectors	—	—	◐	—	—	◐	—	—	—	—	—	✓
	Linear referencing and spatial linking	—	—	◐	—	—	◐	—	—	—	—	—	✓
User interface and engagement	Web interface and role-based dashboards	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NLP / AI search interface	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Training, help, feedback	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Role-Aligned Technical Component Needs (after role alignment)

The refinement reassessed each component against the assigned interaction role using consistent refinement rules. For Directory-supported artifacts, discovery, indexing and metadata, identity and access controls, audit logging, the user interface, and semantic search are confirmed as needed; database infrastructure beyond metadata indexing, standards connectors, and limited validation are conditional; and centralized artifact storage, heavy data pipelines, and repository-

grade version control are intentionally avoided where the CBTL is not the authoritative host. For Gateway-supported artifacts, API gateway and management, authentication and authorization enforcement, middleware validation and governance, and integration security controls are confirmed as needed; event brokers, semantic mediation services, and limited caching are conditional; and authoritative long-term hosting and deep repository lifecycle management are avoided unless the artifact is also assigned repository responsibilities. For Repository-supported artifacts, artifact storage, authoritative versioning, lifecycle workflows (review, approval, publication), quality assurance, governance controls, and semantic services are confirmed as needed; gateway exposure, external connectors for standards synchronization, and change notifications are conditional; and minimization that would undermine authoritative stewardship is avoided. For hybrid artifacts, the union of the relevant rules applies, with duplication avoidance treated as a constraint so that the CBTL can govern a harmonized national profile while still referencing external authoritative sources without cloning operational datasets.

Table B-2. Role-Aligned Technical Component Needs by BIM Artifact (after role alignment)

Capability group	Technical component	1. Proc.	2. Info. needs	3a. Models	3b. OTL	3c. Param.	3d. Cells	4. Dict.	5. IDM	6. Exch.	7. MVD	8. IDS	9. Geo.
Cloud and data platform	Cloud-based platform (AWS/Azure/SDC)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Database infrastructure (multi-format)	◐	◐	◐	✓	✓	◐	✓	✓	✓	✓	✓	✓
Identity, access, and security	OAuth / OpenID / SSO	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	ABAC / RBAC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Zero-trust controls (MFA, least privilege)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Encryption and key management	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Audit logging and monitoring	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
API gateway, middleware, and data exchange	API gateway and management	—	—	✓	◐	◐	◐	✓	✓	✓	✓	✓	✓
	Middleware validation and governance	—	—	✓	◐	◐	◐	✓	✓	✓	✓	✓	◐
	Event / message broker	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
Artifact repository and version control	Artifact storage (files and metadata)	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	X
	Version control (identifiers, history)	✓	✓	X	✓	✓	✓	✓	✓	✓	✓	✓	X
	Data pipelines and orchestration	—	—	◐	◐	◐	◐	✓	◐	◐	◐	◐	◐
	Automated intake conformance checks	◐	◐	◐	✓	✓	✓	✓	✓	✓	✓	✓	◐
Semantics, query, and knowledge services	Data dictionary / ontology service	◐	◐	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Advanced semantic search	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Graph / semantic linking	◐	◐	✓	✓	✓	◐	✓	✓	✓	✓	✓	✓
External integrations	Standards connectors (bSDD, NTL, SDC)	◐	◐	✓	◐	◐	◐	✓	✓	✓	✓	✓	✓
	Agency system connectors (AMS, CDEs)	X	X	✓	X	X	X	X	X	X	X	X	✓
Geospatial and asset referencing	Geospatial data connectors	—	—	◐	—	—	◐	—	—	—	—	—	✓
	Linear referencing and spatial linking	—	—	◐	—	—	◐	—	—	—	—	—	✓
User interface and engagement	Web interface and role-based dashboards	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	NLP / AI search interface	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Training, help, feedback	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Legend: ✓ = used; ◐ = conditional or optional; X = intentionally avoided; — = not applicable. Column headings abbreviate the artifact categories defined in Table 3. Compared with Table B-1, role alignment removes API and middleware needs for processes, workflows, and information needs (consumed through the interface rather than programmatically); confirms artifact storage and version control for repository-governed artifacts, including processes and information needs, while marking them intentionally avoided for BIM models and geospatial data that remain in authoritative systems; relaxes data pipelines and orchestration to conditional for all artifacts other than the data dictionary; and makes automated intake conformance checks conditional for processes and workflows, information needs, BIM models, and geospatial data while keeping them in use for the repository-governed artifact types. The consolidated output distinguishes capabilities that belong in the CBTL core (shared services) from those activated only for artifacts with Gateway or Repository responsibilities, and it provides the technical basis for the minimum technical layer in Table 10.